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PROCEEDINGS

Croatian Association for Construction Management
University of Zagreb, Faculty of Civil Engineering
Croatian Association for Project Management

THE 16TH ORGANIZATION, TECHNOLOGY AND MANAGEMENT INTERNATIONAL CONFERENCE

AND

2ND IPMA GLOBAL PROJECT PROFESSION FORUM

CONFERENCE PROCEEDINGS

Šibenik, September 25-28, 2024 Croatia

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Foreword

Dear Colleagues and Friends,

On behalf of the Organizing Committee, it was our great pleasure to host 16th International Conference on Organization, Technology, and Management in Construction, as well as the 2nd IPMA Global Project Profession Forum. We are excited to come together once again to exchange knowledge in the fields of organization, technology, and management in construction, as well as to explore current trends in project management.

Our conference featured seven keynote lectures by distinguished practitioners, offering insights into the latest developments in the field. Additionally, during the parallel sessions, we had the opportunity to engage with 40 peer-reviewed presentations by 90 researchers and professionals from 17 countries.

Beyond the academic and scientific program, the conference also hosted discussion panels and workshops on pressing topics such as ESG and public-private initiatives, agile project management, European and Chinese project opportunities, as well as special interest groups in project management, led by eminent professionals.

We would like to extend our sincere gratitude to our conference patrons, sponsors, and partners for their generous support in making this event a success.

Yours Sincerely,

Ivica Završki, Chair, 16th International Conference on Organization, Technology, and Management in Construction

Vladimir Obradović, Co-chair, 2nd IPMA Global Project Profession Forum

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Sustainability in Construction: Process or Profit?

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Abstract:

This paper examines whether the construction industry is truly committed to sustainability or if short-term profit motives overshadow these efforts. With growing global environmental concerns, the construction sector faces increasing pressure to adopt sustainable practices. However, skepticism persists regarding the sincerity and effectiveness of these initiatives. The paper assesses whether the industry's focus is on genuinely integrating sustainable processes or merely highlighting innovation without significant impact. Despite public commitments to sustainability, major challenges hinder effective implementation, including high initial costs, regulatory complexities, and resistance to change. Additionally, the paper explores whether the industry's emphasis on innovation is genuinely aimed at long-term sustainability or serves as a marketing tool to enhance reputation and secure funding. The balance between promoting innovative solutions and embedding them into standard practices is crucial for meaningful progress. Economic pressures, such as the need for quick returns on investment, often lead to prioritizing short-term gains over long-term environmental benefits. Furthermore, financial cycles can dictate decision-making, potentially undermining sustained sustainability efforts. The paper concludes that, while there are commendable initiatives within the construction industry, a fundamental shift in mindset and policy is necessary to fully integrate sustainable practices into the construction process. This shift requires not only fostering innovation but also ensuring that sustainability is embedded in every stage of construction. Without addressing these challenges, the industry's contribution to mitigating climate change remains questionable, as short-term profit motives may continue to outweigh long-term environmental goals.

Keywords: *Sustainability in construction; sustainability commitment; sustainable practices; long-term approach*

Introduction

In the realm of construction, the pursuit of sustainability often presents a complex interplay between process and profit. While profit is an economic measure easily quantified in financial terms, the process of achieving sustainability involves a more intricate, long-term approach that may not yield immediate financial returns. This process is inherently multifaceted, encompassing environmental, social, and economic dimensions that extend beyond the straightforward calculus of profit.

Unlike profit, which is typically evaluated on a short-term basis and driven by market forces, the process of sustainability requires a commitment to ongoing improvement, adaptation, and innovation. It is about embedding sustainable practices into every stage of a project. Construction industry faces the tension between these two objectives, so the right question could be whether the drive for profit can coexist with the rigorous demands of sustainable practices. Sustainability as a process may sometimes conflict with the immediate pursuit of profit, but also, with the right strategies and frameworks, these two goals can align to support both the long-term health of the industry and the planet.

Sustainability is urgently needed in the construction industry: In the EU, it is responsible for almost 40% of emissions and nearly a third of all waste. (Policy Learning Platform, 2024). It is well recognized that construction industry has a negative effect on nature (Liew, et al., 2017); (Lam, et al., 2010); (Polat, et al., 2017); (Habert, et al., 2020).

Environmental responsibility is increasingly recognized as a crucial aspect of modern construction practices. While it is widely accepted that addressing environmental issues is a collective responsibility, the dispersed nature of this responsibility can sometimes hinder the effective implementation of sustainable practices. When everyone is responsible, it can lead to a lack of accountability and diffuse commitment, which may undermine efforts to make meaningful progress. It is essential to move beyond the generalized sense of shared responsibility and foster a more focused approach that emphasizes clear roles and actionable strategies within the construction industry.

An overview of current global environmental concerns underscores the urgency of addressing these issues. The construction sector plays a significant role in the global environmental crisis. It is a major contributor to carbon emissions, resource depletion, and waste generation. For instance, the construction industry was in charge for 39% of the world's total annual carbon emissions in 2022 (World Economic Forum, 2022), and without effective carbon reduction measures, it is projected to account for 52% of global emissions by 2050 (Houghton, et al., 2001). Furthermore, the construction industry has an impact beyond carbon emissions. The sector also contributes to environmental degradation by consuming nonrenewable resources and creating building and demolition trash. As urbanization accelerates and infrastructural demands rise, the burden on natural resources grows, emphasizing the need for more sustainable methods.

Addressing these environmental challenges requires a shift from a diffuse sense of responsibility to a more structured and strategic approach. By focusing on specific, actionable steps and clearly defined roles within the construction industry, it is possible to drive significant improvements in sustainability. This shift is not only crucial for mitigating environmental impacts but also for ensuring that the construction industry contributes positively to global sustainability goals. During the construction process, huge quantities of energy and raw materials are used. It consumes roughly 70 percent of the energy generated and 17% of the water resources, exploits natural resources, generates approximately 50% of what is disposed of in landfills, and produces around 35% of CO_2 emissions (Naik & Moriconi, 2005); (Liu, et al., 2012); (Sabnis, 2015); (Polat, et al., 2017).

But not only the new buildings and infrastructures are a problem to consider: Built environment is also one of the most resource intensive sectors of the economy. It accounts for around 50% of all extracted materials, 33% of water usage, and more than 35% of the EU's total waste generation (Policy Learning Platform, 2024). Moreover, the construction industry in the EU employs 25 million people, contributing 10% to the total value added to the EU economy, and being responsible for 9.4% of the total domestic carbon footprint (European Commision, 2022). According to the Ellen MacArthur Foundation (2024), the system-wide benefits of a circular and nature-positive built environment by 2035 include (Ellen MacArthur Foundation, 2024): (1) 575 billion euros of potential annual revenue distributed across the built environment value chain, and (2) 158 billion euros for wider economic benefits realised annually for businesses and municipalities.

In comparison, the total value of all manufactured goods and services (gross domestic product or GDP) in the EU in 2021 was 14.5 trillion euros. The annual planned budget of the European Union for 2025 is 199.7 billion euros. These funds will be supplemented in 2025 by payments from the "NextGenerationEU" instrument, estimated at 72 billion euros. In this context the EU is recognized the construction industry as one area to focus for further sustainability development: European

Green Deal, EU Taxonomy regulation and the Circular Economy Action Plan are the current directives and regulations to include more sustainable process and work in the construction industry.

At this time there are additional directives and regulatory frameworks like Thematic Strategy on the Sustainable Use of Natural Resources COM/2005/670, Roadmap to a Resource Efficient Europe COM/2011/571, Proposal for a new Ecodesign for Sustainable Products Regulation COM/2022/142, Revision of monitoring framework for the circular economy COM/2018/29 and Strategy for a Sustainable Built Environment to ensure and specify more detailed measures in appliances of sustainability in the construction industry.

These recommendations are the extrudates of UN global goals applied all over the world (see Figure 1).

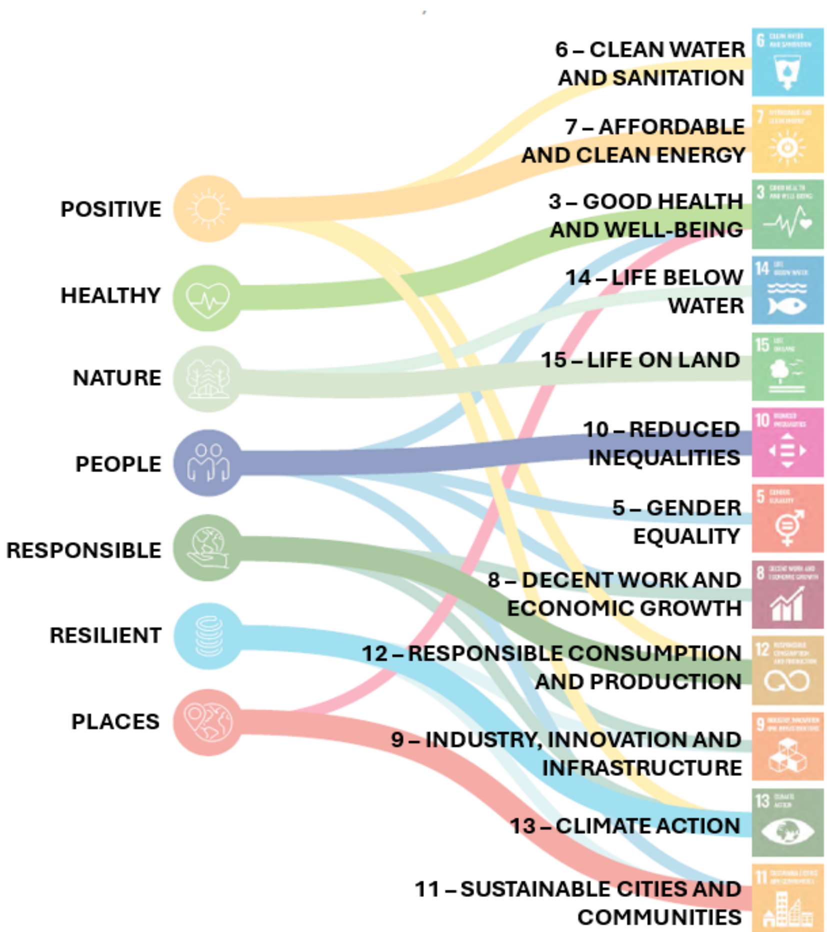

Figure 1 Sustainable recommendations (source: Green Building Council Australia, 2021)

Sustainable construction materials and methods play a crucial role in tackling the environmental issues associated with conventional construction practices. Using recycled materials and locally sourced resources helps create a more sustainable material palette, decreasing the industry's dependence on new raw materials and cutting down on emissions related to transportation. Additionally, modern construction techniques such as modular construction and prefabrication improve process efficiency, boost resource utilization, and highlight the industry's dedication to environmentally friendly practices. As the construction industry advances, adopting these sustainable materials and methods is essential for building a resilient and eco-conscious built environment (Umoh, et al., 2024).

The objective of this paper is to contribute to the research discussion about current processes and efforts in the construction industry which attend to raise the awareness of sustainability and to implement them in real life project.

Current State of Sustainability in Construction

As global awareness of environmental issues and the impact of human activities on climate change grows, the demand for sustainable construction practices has never been more urgent. However, achieving widespread sustainability in construction remains fraught with challenges. The industry continues to face issues such as the high costs of green technologies, the slow integration of new materials and methods, and the need for more rigorous standards and certifications. Furthermore, there is a persistent gap between the ambitious goals set by various stakeholders and the actual outcomes achieved on the ground.

Currently, proof of sustainability in construction products is often demonstrated through product-based certifications. However, these certifications do not always guarantee that the overall implementation is genuinely sustainable. Over 60 international and local building certification systems are in use globally. However, the limited accessibility and transparency of data publicly released by these certification bodies continue to pose a significant challenge (UNEP and GlobalABC, 2024). Certifications from independent organizations, such as BREEAM, LEED, and DGNB, can validate the sustainability of construction projects (see Table 1). Nonetheless, these certifications alone may not fully capture the real-world effectiveness of sustainability practices across all phases of construction.

Table 1 Selected recognized sustainable certification systems (PWC, 2023)

Certifier	BREEAM	LEED	DGNB
Area of application	Global	Global	Global
Scope of application	New buildings, existing properties (commercial and residential), renovation and fitting out, infrastructure	Design and construction, land use planning and construction, building operation and maintenance, neighbourhood development, residential buildings, cities	New buildings, existing buildings, renovation, buildings in use, city districts, interiors, dismantling
Coverage of core issues	- Governance and ethics - Climate change and CO_2 - Water - Resources - Ecosystems and Biodiversity - Social concerns	- Governance and ethics - Climate change and CO_2 - Water - Resources - Ecosystems and biodiversity - Social concerns	- Governance and ethics - Climate change and CO_2 - Water - Resources - Ecosystems and biodiversity - Social concerns

These certifications are not mandatory and are often used primarily for marketing purposes. Given that substantial investments in the construction industry often come from governments and local authorities, it is notable that such certifications are rarely utilized since they are not required by EU regulations.

At present, establishing a unified certification standard is challenging. For example, the HafenCity project—a major transformation of a former industrial port area in Hamburg—serves as a pioneering model of circular and nature-positive urban development. Covering 157 hectares, HafenCity has expanded Hamburg's city area by 40% while avoiding greenfield development (Policy Learning Platform, 2024). Despite its achievements, HafenCity is awarded Version 3.0 of the Ecolabel, highlighting that a standardized approach to sustainability certification has yet to be universally established.

In practice, there are several building certifications that primarily assess the sustainability of new and refurbished buildings. Infrastructure projects, however, are not required to obtain certifications beyond local ecological regulations.

Currently, sustainability assessments are typically a one-time evaluation: once a building or infrastructure project is completed, there are no obligations for the end-user to measure and review its ongoing impact on the ecological, economic, and social environment. Essentially, there is no systematic oversight of the long-term outcomes of construction industry products, including those related to the mining sector, which supports infrastructure development and refurbishment. To ensure true sustainability in construction, both input and output must be subject to ongoing monitoring and evaluation.

Previous literature reviews on sustainability performance measurement in manufacturing industries have led to several key observations (Mengistu & Panizzolo, 2021), that is very applicable for the construction industry. The analysis indicated that most of the sustainability indicators cited in the literature were applied only a single time, reflecting a significant lack of consistency and agreement regarding which indicators are best suited for assessing sustainability across various industrial contexts. In contrast, only a small number of indicators were found to be both consistently used and widely accepted for evaluating sustainability performance. These reliable indicators typically focus on several critical areas: enhancing financial performance, reducing costs, and boosting market competitiveness; improving resource utilization through greater efficiency, recycling, and substitution; reducing emissions; managing waste effectively; and advancing the well-being of employees, customers, and the broader community (Mengistu & Panizzolo, 2021). The same authors published cause-and effect diagram of the sustainability indicators, that are very applicable to the construction industry (see Figure 2).

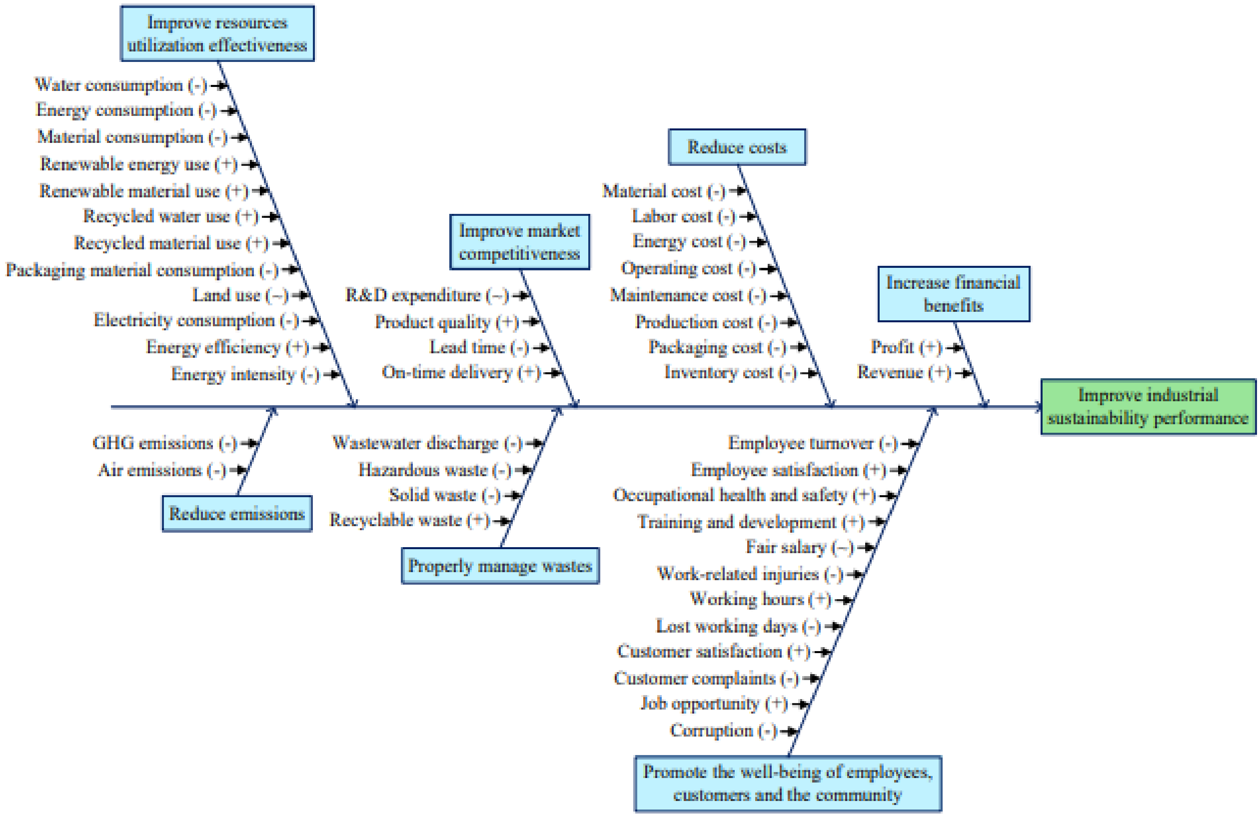

Figure 2 Cause-effect diagram of the sustainable indicators (Mengistu & Panizzolo, 2021)

In the pursuit of sustainable construction practices, decarbonization plays a critical role as a measurable outcome of these efforts. The concept of sustainability in construction is inherently linked to reducing carbon emissions, as lowering the industry's carbon footprint is essential for achieving long-term environmental goals.

For a quick assessment of the state of sustainability, the global Buildings Climate Tracker (GBCT) method indicator was selected - The tracker is a composite statistic composed of seven measures, characterized as a 'decarbonization index' for buildings (UNEP and GlobalABC, 2024). The index measures progress toward the aim of decarbonizing the building sector by 2050 (see Table 2).

Table 2 GBCT's indicators observations summary, 2015-2022 (UNEP and GlobalABC, 2024)

Indicator	Starting value in 2015	Observed value in 2022	Observed change from 2015 to 2022	Necessary change from 2015 to 2022
Emissions				
Building sector energy related emissions	9,3 [$GtCO_2$/year]	9,8 [$GtCO_2$/year]	+5,4 [%]	-24,6 [%]
Impact				
Building sector energy intensity	153,1 [kWh/m^2]	145,3 [kWh/m^2]	-5,1 [%]	-17,3 [%]
Renewable share in final energy demand in buildings	5 [%]	5,9 [%]	+0,9 percentage points	+6,1 percentage points
Action				

Cumulative energy efficiency investment in buildings	176 [billion €]	1.794 [billion €]	+1.618 [billion €]	+2.765 [billion €]
Green building certification (cumulative growth)	1.0 points	9,1 points	+8,1 points	+15,3 points
NDC considering buildings extensively (aggregated)	0,7 [%]	5,7 [%]	+5,0 percentage points	+34,7 percentage points
Building codes ZEB-aligned (aggregated)	0 [%]	3,3 [%]	+3,3 percentage points	+35,0 percentage points

The reference path for decarbonization of the building stock is outlined from 2015 to 2050 (see Figure 3). This path is the outcome of integrating the reference paths for seven critical indicators. Each indicator is projected to follow a linear trajectory from 2015 to a milestone in 2030 and then to the objective in 2050. The reference paths of these indicators are then combined using a weighted total, as previously described, and multiplied by the CO_2 emissions indicator. Observations show that the building sector's decarbonization is severely lagging. By 2022, the difference between actual progress and the reference path is 39.8 decarbonization points. Following a significant surge in 2020—likely due to COVID-19 pandemic restrictions—and a comeback in 2021, the decarbonization index increased by 0.8 points in 2022, reaching -0.2 points. The first seven years of the Paris Agreement's implementation reveal that global attempts to decarbonize the building stock have made little progress. By 2022, the decarbonization index has remained close to its 2015 beginning point, showing that worldwide efforts to minimize the climatic effect of buildings and construction have essentially stalled.

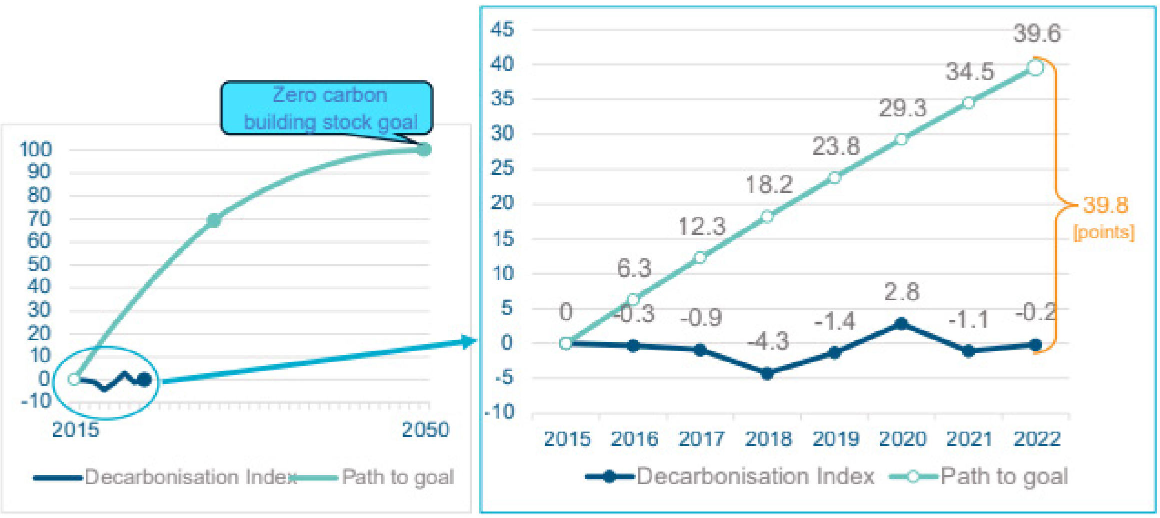

Figure 3 GBCT decarbonization index. Left: reference path until 2050. Right: zoom in for the 2015-2022 period (source: UNEP and GlobalABC, 2024); Buildings Performance Institute Europe (BPIE)

A similar situation exists with CO_2 emissions. Despite ambitious goals, the construction sector is currently falling behind in achieving its global targets. The fact that productivity improvements in this sector are relatively slow is not sufficient to ensure further success.

Challenges to Sustainable Implementation

Despite the clear goals of green buildings to conserve natural resources, protect the environment, decrease waste, promote eco-friendly materials, and cut life cycle costs, sustainable construction approaches confront significant hurdles. Significant gaps exist in the specifications, standards, and laws required to enhance the uptake of green buildings and support sustainability (Cole, 2005); (Suhendro, 2014); (Maraveas, 2020);. Government intervention through new standards and policies is crucial to making sustainability a primary focus (Opoku, et al., 2019), especially given that green standards remain voluntary rather than legally mandated (Naik, 2008).

In various regions, the implementation of green construction is hindered by specific challenges. For example, Egypt's 'Green Pyramids Evaluation Method' faces regulatory and assessment barriers (Al Attar, et al., 2018). In Turkey, green construction projects are challenged by factors such as the absence of green design, slow adaptation to changes, misunderstanding of green requirements, substandard quality of materials, and lengthy quotation processes (Polat, et al., 2017). In Singapore, major obstacles include the need for greater investment, poor investment recovery, lack of incentives, insufficient sustainability knowledge, resistance to changing current practices, and low customer interest (Hwang, et al., 2018). In Sweden, the challenges include technological limitations, lack of expertise, and financial constraints (Apine & Valdes, 2017); (Schulte, 2019); (Baghdady, et al., 2021). Previous research highlights that the most significant barriers to implementing sustainability include outdated educational curricula, inadequate building codes and regulations, and a lack of awareness and training (Baghdady, et al., 2021); (Polat, et al., 2017). Additionally, higher costs, insufficient government incentives, and limited funding schemes are common obstacles (Chan, et al., 2018).

Research has identified five significant issues in sustainable building: lack of client finances, inadequate or erroneous sustainable design data, frequent design revisions, unduly short schedules, and poor scope description (El-Sayegh, et al., 2018). These problems highlight the need of risk evaluation in project management, which allows for proper risk response planning and monitoring. Previous research has categorized risks, further emphasizing the complexity of sustainable construction implementation (see Table 3).

Table 3 Risk identification by categories: challenges for sustainability (Baghdady et al., 2021, adjusted)

1. Regarding to stakeholders and management - Assume green construction is not important. - Resistance to change in current practices. - No previous green construction culture. - Lack of experience with waste management systems or specifications. - Project size and maturity of consulting. - Lack of familiarity with new green items or technologies. - Clients' resistance to adopting new green concepts. - Limited understanding of green and sustainability concepts. - Fear about upcoming changes. - Difficulty in finding experienced or expert labour for green projects. - Concerns about the high cost of investing in green construction. - Lack of knowledge and training.	**2. Regarding to regulations and standards** - Lack of educational programs to promote sustainability and green thinking among graduates. - Lack of promotion for sustainable projects. - Lack of initiative from government and private bodies. - Local green certifications are unavailable or difficult to get. - The government has not prioritized green construction. - Inadequate or incomplete criteria for green and sustainability. - Lack of local documentation and information on green technologies. - Building laws and regulations must reflect advances in green building and sustainability. - Inadequate initiatives to promote sustainable construction.
3. Regarding the technical issues. - Fear of failing to meet green code or certification standards. - Lack of government approval - Failure to seek out locally sourced green materials or goods that promote sustainability. - Limited local model options for consideration. - Limited local database and knowledge - Lack of local carbon footprint measurements for green products. - There is a lack of local evaluation for green suppliers. - Concerns about increased documentation and extensive pre-contract planning for sustainable projects.	**4. Relating to materials and supply** - Low demand for green construction products. - Limited availability of local manufacture and eco-friendly products. - Green materials require storage conditions. - Limited green sources. - Need to import green resources or products from international markets. - Local green materials and products may be of poor quality. - Need to collaborate with new vendors. - Limited trust in suppliers of green materials and products. - Local green materials are scarce and take a long time to replenish.
5. Relating to design issues. - Limited creativity and innovation in green and sustainable design. - Designers lack experience with green projects. - Long approval process for implementing new green designs and goods. - Uncertainty about the long-term performance of green materials or goods.	**6. Regarding financial and external difficulties.** - Assume higher costs for green building. - High prices for green materials and products. - Concerned about increased costs associated with utilizing green materials or goods. - The political and economic crises have impacted the import of green materials and their prices. - The local building market's lack of demand has led to little investment in green projects.

To overcome these challenges, organizations must prioritize sustainability over short-term profits by integrating long-term goals for both environmental and economic stability. Policymakers can create supportive frameworks, align economic incentives with nature-positive outcomes, and foster collaboration for a circular economy by reforming subsidies, adapting intellectual property rights, and implementing effective monitoring systems.

Public funds should support research in sustainable materials, building techniques, material recovery, and nature-based solutions. Encouraging interdisciplinary research is crucial for addressing systemic challenges in construction. Key EU policies should embed circular economy principles into the built environment, with input from government and industry to ensure alignment with diverse needs.

Businesses and asset owners should integrate circular principles by reviewing property and land holdings, setting standards for longevity and resource efficiency, and collaborating with local stakeholders for responsible urban development. Industry supply chains, designers, and contractors must collaborate, using digital tools to deliver circular economy solutions. Establishing industry-wide standards for circular procurement and production can guide sustainable decision-making. Financial institutions and investors are critical in directing capital towards nature-positive, circular solutions by valuing natural assets and promoting regenerative use and conservation.

The role of innovation

Innovation plays a pivotal role in advancing sustainability within the construction industry, offering both promising opportunities and inherent risks. As the sector strives to reduce its environmental impact, numerous projects are emerging that aim to develop more sustainable construction products and methods.

Implementing innovative activities within projects leads to a significant boost in competitiveness. Research results has demonstrated a positive correlation between innovation and competitiveness at the project level (Küçükoğlu & Pinar, 2015) (Garcia-Morales, et al., 2007); (Gunday, et al., 2011); (Zhang, et al., 2024).

A prime example is the KOdeCO net zero project, funded by the European Union's Innovation Fund. This initiative seeks to decarbonize the Koromačno cement plant, with the ambitious goal of achieving total carbon capture and storage by 2028. While the project is driven by a noble objective, it also comes with substantial costs—approximately €237 million, partially funded by public sources such as the Just Transition Fund and the Innovation Fund of the EU, alongside private investments.

Innovations like KOdeCO highlight the potential for transformative change in the construction sector. By utilizing public funding to establish proof-of-concept for nature-positive innovations, these projects can serve as a catalyst for attracting private investment. Financial strategies such as grants, risk underwriting, match funding, and blended finance solutions play a crucial role in bridging the financing gaps for high-risk projects, making them viable and scalable.

However, the reliance on innovation also carries risks. The significant financial outlay required for pioneering projects may not always yield the expected results, potentially leading to wasted resources if the technologies do not perform as anticipated. Moreover, the pace of innovation can sometimes outstrip the development of regulatory frameworks and industry standards, creating uncertainties and potentially hindering widespread adoption.

Investing in innovation and upskilling within the construction industry is essential to ensuring that new technologies deliver nature-positive outcomes. This includes supporting research in advanced areas and fostering a critical mass of providers who are committed to regenerative practices. Collaboration and incentives are key to creating an environment where these innovations can thrive. Strategic investments in public-private partnerships, combined with efforts to stimulate demand across the built environment value chain, can unlock impactful circular economy projects on a large scale.

Aligning funding with circular principles helps to establish a circular economy while also capitalizing on upcoming opportunities. This method establishes new standards for value creation, incorporating both environmental and socioeconomic benefits. However, for innovation to truly drive sustainability in construction, it must be supported by a thorough risk assessment and a commitment to long-term, systemic change.

The best outcomes will come from focusing on advances in the manufacture and usage of the most used construction materials. Cement, concrete, iron, and steel are the most used materials in building. Aside from their considerable environmental implications, several of these commonly used building materials are non-renewable, which means that their raw material supplies are limited and cannot be renewed. Traditional non-renewable materials including cement, concrete, steel, aluminium, petroleum-based polymers, and glass will be the principal building materials for decades, and renewable alternatives are not always feasible solutions (UNEP, 2023). Below is a summary of the basic guidelines for sustainability for selected materials (only for cement, concrete and masonry, for the purpose of this paper). All above mentioned materials must be in concern when achieving impactful sustainability.

Cement and concrete

Global cement production reached 4,300 million tons in 2020 (IEA, 2022).

Cement is made by grinding raw materials into a fine powder and heating it to make clinker, which is then combined with gypsum to form cement (IEA, 2018). Cement, a crucial component of concrete (making about 10-15%), is extremely carbon-intensive, accounting for around 7% of world CO_2 emissions (Hasanbeigi 2021).

The decarbonization of cement manufacturing is difficult, with most emissions (55-70%) resulting from the chemical conversion of limestone to calcium oxide and the remainder (30-45%) from fuel burning (IEA, 2018; Cao et al. 2020). Producing one ton of clinker produces around 600 kg of CO_2 (Fennell et al., 2021), thus switching to renewable energy in this process might drastically cut emissions.

In new construction, the main source of embodied emissions in concrete buildings is cement production, namely clinker formation. This needs innovation in cementitious binders, as regular Portland cement, which is widely used, is the largest contributor to CO_2 emissions.

Since the early 2000s, China and other Asian countries have dominated global cement consumption, accounting for 80% of output in 2014 (Rissman et al., 2020). This increase is being driven by infrastructure needs due to a growing middle class, following a trend in which per capita cement consumption is connected to economic prosperity (Cao et al. 2017). Countries often proceed through stages of cement use, beginning with minimal to rapid expansion, then slowing and eventually declining.

To reverse the trend of increased global cement consumption while raising living standards and urbanization in low-income countries, material efficiency measures and low-carbon cement production must be implemented. It will be critical to reduce the clinker-to-cement ratio by incorporating novel compounds derived from forestry and agricultural byproducts.

Despite potential transitions to bio-based materials, rising urbanization in developing countries indicates that demand for high-carbon cement and concrete will persist. The main techniques with innovative parts for decarbonization of cement and concrete are listed in the Figure 4.

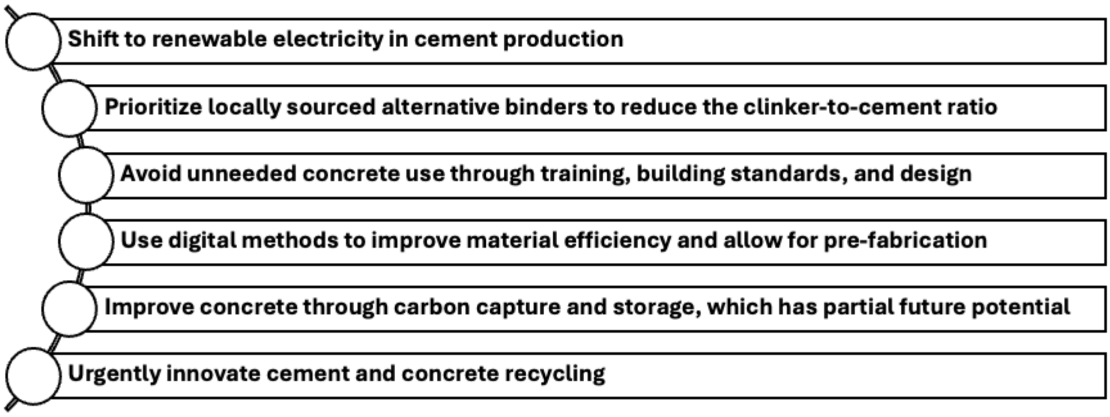

Figure 4 Decarbonizing cement and concrete options (UNEP, 2023)

Masonry and Earth-Based Materials

Earth brick production has the potential to be low carbon, however it faces concerns associated with bad labour and environmental circumstances. At the end of the twentieth century, over one-third of the global population lived in earth-based structures, but this figure has subsequently plummeted to 8-10%, especially in developing nations such as Bangladesh, India, and Nigeria (Houben and Guillaud 1994; Marsh and Kulshreshtha 2022). As incomes have grown and availability to concrete has improved, the usage of earth as a building material has decreased. In many developing countries, earth masonry is seen as substandard due to factors such as poor durability, moisture problems, and excessive maintenance requirements, all of which lead to a bad view of the material. However, there is an increasing interest in updating earth-based building processes with modern techniques and standards, particularly in high-end architectural design.

Regardless of the environmental benefits, the manufacture of earth-based minerals can have substantial societal consequences. Brick manufacture is linked to forced labour in over 20 countries, where workers, including minors, frequently face debt bondage and hazardous working circumstances (Grace Farms Foundation, 2022). Non-fired adobe earth bricks that dry in the sun have a minimal carbon footprint, with 1.2 to 5.4 kilos of CO_2 per kilogram of block (Illampas, Ioannou, and Charmpis 2014; Christoforou et al. 2016). However, burnt clay bricks have a significantly higher carbon footprint, particularly when employing natural gas or oil-fuelled kilns, with emissions reaching up to 340 kilos of CO_2 per kilogram of block (Kulkarni and Rao 2016; Venta and Eng 1998).

Rammed earth buildings, which are constructed by compacting processed earth dirt into solid walls, have larger carbon footprints when Portland cement stabilizers and electric or pneumatic ramming are utilized. These stabilizers, while necessary to prevent mechanical and moisture damage, can lead to higher CO_2 emissions compared to traditional concrete masonry (Reddy and Kumar 2010; Scrivener, John, and Gartner 2018).

Despite the challenges, the high quality and appeal of modern earthen buildings have led to a resurgence in their use, particularly as a niche, reliable, and attractive building option (Swan, Rteil, and Lovegrove 2011; Niroumand et al. 2017). This has spurred the development of innovative earth-based products and increased the global stock of modern earthen buildings (Leylavergne

2012; Marsh and Kulshreshtha 2022; Correia, Dipasquale, and Mecca 2011). However, the high costs of experimentation and early adoption continue to be a significant barrier for clients. The most recognizable decarbonizing strategy for masonry is seen at Figure 5.

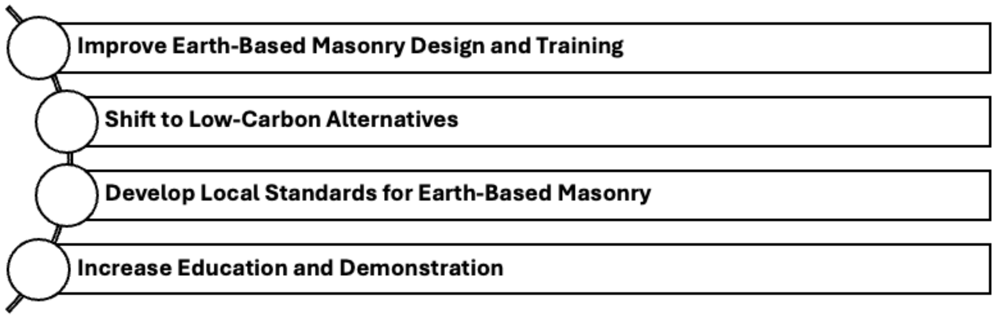

Figure 5 Decarbonizing of masonry material (UNEP, 2023)

Economic Pressures and Financial Cycles

In the context of sustainability in construction, economic pressures and financial cycles play a significant role in shaping both short-term and long-term strategies. The construction industry, characterized by its long project timelines and substantial upfront investments, often finds itself at odds with the shorter financial and political cycles that dominate national and regional planning. It is well recognized that life cycle assessment is commonly used in the construction industry to analyze environmental effect, with carbon emissions as the major evaluation indicator, and it is scientifically validated (Chen, et al., 2023).

One of the most prominent financial cycles affecting sustainability projects is the four-year national electoral cycle. As elections approach, governments often prioritize projects that yield immediate, visible results, aiming to showcase achievements to the electorate. This can create a challenge for sustainability initiatives in construction, which typically require longer timeframes to demonstrate tangible benefits. Projects with outcomes that extend beyond the four-year cycle may be deprioritized or underfunded, as decision-makers focus on initiatives that can be completed within their term.

Similarly, the seven-year European Union budget cycle further complicates the landscape for sustainability in construction. While the EU budget planning process allows for more extended project horizons, the inherent delay between planning and execution can lead to disruptions in funding for ongoing projects. As new budgets are negotiated, previously allocated funds may be reallocated or reduced, creating uncertainty for long-term sustainability projects. Additionally, the pressure to align with EU funding priorities can lead to shifts in project focus, potentially diverting resources away from sustainability efforts that require consistent, multi-year support.

The misalignment between these financial cycles and the long-term nature of sustainable construction projects presents a critical challenge. Sustainable construction initiatives, such as those focused on energy efficiency, green building materials, and circular economy principles, often require significant upfront investments and can take decades to fully realize their benefits. These projects are essential for reducing environmental impact and achieving long-term economic stability, yet they may struggle to secure the necessary funding and political support in a landscape dominated by shorter financial cycles.

To address these challenges, construction firms and policymakers must develop strategies that align with both short-term and long-term objectives. In the short term, it is possible to implement strategies that deliver measurable results within a four-year cycle, such as:

1. Energy Efficiency Upgrades: Implementing energy-efficient retrofitting in existing buildings can lead to immediate reductions in energy consumption and costs, making it a visible achievement within a short political cycle.

2. Pilot Projects for Green Technologies: Launching pilot projects that demonstrate the viability of new green technologies can generate quick wins and build momentum for broader adoption in future budget cycles.

3. Incentivizing Sustainable Practices: Offering tax incentives or grants for sustainable construction practices can drive industry adoption and showcase government commitment to sustainability, with results evident within a few years.

However, sustainable construction also requires long-term strategies that extend beyond the confines of electoral and budgetary cycles. These include:

1. Long-Term Infrastructure Planning: Developing and committing to infrastructure projects with sustainability at their core, such as green building districts or renewable energy integration, requires a vision that spans multiple financial cycles.

2. Sustainable Materials Research and Development: Investing in the research and development of new, sustainable building materials is a long-term endeavor that will yield benefits over decades, necessitating consistent funding and support.

3. Circular Economy Integration: Fully integrating circular economy principles into the construction industry, including recycling materials and designing buildings for adaptability, requires a sustained effort over many years.

4. Educational Programs and Workforce Development: Creating and maintaining educational programs that train the workforce in sustainable construction techniques ensures that the industry evolves to meet future demands. This long-term investment will pay off by building a knowledgeable and skilled workforce capable of implementing sustainable practices across projects.

The innovative sustainability strategies for concrete, cement, and masonry, shown in the chapter 4, require long-term planning and investment, contrasting with typical short-term budget cycles. For concrete and cement, transitioning to renewable electricity, using alternative binders, and improving material efficiency are crucial long-term investments. Similarly, innovations in carbon capture and recycling need sustained financial support beyond immediate budgets. In masonry, advancing design, adopting low-carbon alternatives, and developing local standards demand ongoing education and industry changes. Aligning financial cycles with these long-term sustainability goals is essential to fully realize their impact.

Conclusion

The paper highlights the urgent need for Circular Sustainability in construction. Despite increasing awareness, the EU lacks a comprehensive legal framework for this sector. Future frameworks must include clear guidelines, ongoing education, and robust transparency systems. The industry must shift from profit-driven to sustainability-focused practices, evaluating new developments based on long-term impacts and aligning with cradle-to-cradle principles.

Significant progress will require EU regulations and local laws that prioritize sustainability, particularly in public procurement. Addressing current barriers, such as outdated education and inadequate regulations, demands a long-term commitment and evolution of economic and social strategies. Without this, sustainability efforts will remain fragmented and ineffective, falling short of the industry's potential for meaningful progress.

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CONSTRUCTION MONITORING USING 4D AND 5D BUILDING INFORMATION MODELS

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Abstract:

In the modern construction industry, the use of Building Information Modeling (BIM) has become crucial for the effective planning, implementation, and management of construction projects. BIM is a digital approach that enables the creation of a comprehensive and interactive BIM model of the facility, in which all information and data about the construction project are combined in one place. This enables a comprehensive view of the project, increases cooperation between stakeholders, and optimizes processes in the construction industry. In the conducted research, 4D and 5D BIM models of the building project Center Rotovž Library complex were first created, which represent the planned implementation, allowing a better understanding and management of the project. The 4D BIM integrates geometric and scheduling data, while the 5D BIM incorporates geometric and cost estimate data. The aim of the research was to evaluate the advantages of using the BIM approach for the management of construction projects, with a focus on the construction implementation phase, including one month of construction monitoring. Monitoring was carried out weekly by recording actual time and cost data to track progress on-site. The direct comparison between planned and actual construction execution facilitated the identification of discrepancies in both BIM dimensions, leading to updates of the plans for the continuation of construction on a weekly basis. Through the monitoring of the practical case and the performed analysis, the research identifies key factors illustrating how the BIM approach enhances the accuracy and efficiency of construction project management.

Keywords: construction; BIM approach; construction monitoring; digitalization

Introduction

Problem definition

In the last few decades, the construction industry has changed a lot, as trends towards a digital and green transition require changes in the process of considering construction projects. The rapid development of advanced solutions, new technologies and methods dictates the implementation of these and the transformation of construction project management into a modern approach. Thus, the use of Building Information Modeling (BIM) has become key to the effective planning, execution and management of construction projects (Hasan & Sacks 2021; Sacks, Eastman, Lee & Teicholz 2018). BIM represents a digital approach that enables the creation of a comprehensive and interactive BIM model of a building, where all data and information about the construction project are consolidated in one place (Šuman & Pučko 2021). This integration allows for a comprehensive insight into the project, promotes collaboration, and optimizes processes in the construction industry. Monitoring construction through 4D and 5D information models represents a shift from traditional approaches to advanced and efficient project management methods (Pučko & Šuman 2024). These models enable better visualization, coordination, and control over construction processes, contributing to improved efficiency, risk reduction, and optimization of time and cost planning. The stated findings come from scientific and professional literature, where this is well confirmed in the design phase, less so in the implementation phase and the discrepancies between theory and practice are significant, as it is widely known that the use of modern approaches in construction practice requires time (Xavier & Jacob 2018). The reasons for this are that construction is one of the most traditional industries (Klinc & Turk 2019), in terms of digitization it is in last place compared to other industries, where construction is additionally faced with a lack of qualified personnel, low added value per employee and many other reasons. One of the main problems is also that most construction projects are not completed within the agreed time and budget. By addressing these problems, the research emphasizes the importance and role of 4D and 5D information models, especially in the construction phase, i.e. for construction monitoring purposes (Pučko, Šuman & Rebolj 2018). The analysis of the research covers their practical use and the study of their effects on the quality, efficiency and economy of construction projects. The research also identifies the challenges and obstacles faced by the construction industry in the implementation of these technologies and provides guidelines for improving processes and increasing the adoption of these innovations in the construction industry.

Purpose and aim

The aim is to explore and assess the impact of using 4D and 5D information models for construction monitoring purposes and to analyse their implementation in practice. It is analysed in more detail how information models contribute to the improvement of construction project quality, including error reduction, better understanding of complex spatial relationships, and enhanced communication (Lu, Liang, Fung & Rowlinson 2014). Specific objectives include the analysis of the impact of the use of 4D and 5D information models on the effectiveness of the implementation of construction projects. With the help of 4D BIM, especially in terms of time tracking, work coordination and timely completion. With the use of 5D BIM, the cost monitoring of construction projects and the impact on reporting processes on planned and realized implementation costs. Based on the results, guidelines and recommendations will be formulated to improve the implementation procedures of 4D and 5D information models in the construction industry.

Assumptions and limitations

Conducting research on the use of the BIM approach for monitoring construction projects involves acknowledging certain key assumptions and limitations that may affect the results and interpretation of the data. Assumptions include access to a high-quality 3D BIM model of the construction project, credible time and cost data for creating 4D and 5D BIM models, and uninterrupted access to the construction site for observation and measurement. However, limitations such as the restricted scope of research due to limited resources, potentially limited access to complete project data due to privacy protection, and the uniqueness of each construction project may affect the transferability of results. Despite these assumptions and limitations, valuable insights regarding the use of the BIM approach during the construction phase of projects and understanding its advantages and limitations are expected.

Methods

Various methods and approaches are used to achieve the research goals and verify the research as a whole, such as:

- Literature Review: An extensive review of the available literature will be conducted to gain insights into existing research and literature on the use of the BIM approach in general and specifically for monitoring construction projects. This will provide a better understanding of the advantages, limitations, and application of the BIM approach, as well as identify existing practices and guidelines.

- Case Study: A real construction project will be selected for using Bexel Manager software (*BEXEL Manager* n.d.) to create 4D and 5D BIM models. The time and cost analysis results will be obtained by monitoring the construction over a specific period.

- Data Analysis: The data obtained from the practical case will be analysed both quantitatively and qualitatively. Statistical methods will be employed for quantitative analysis, while inductive and deductive reasoning methods, along with content analysis, will be utilized for qualitative analysis.

The applied methods will enable a comprehensive understanding of the impact of the BIM approach on monitoring building construction and assist in verifying assumptions, limitations, and research objectives.

Process of creating a 4D BIM model

The development of information modeling in construction projects has led to the concept of 4D BIM, where a three-dimensional information model is enhanced with the dimension of time. This chapter will examine the process of creating a 4D BIM model, which integrates the time component into the existing three-dimensional model. This process enables the visualization and simulation of the sequence of events and activities over time, bringing numerous advantages for planning, execution, and management of construction projects. One of the key components in creating a 4D BIM model is determining the duration of individual activities in a construction project. This process allows for proper time coordination and animation of events and activities across different project phases. This subsection will examine how the duration of individual activities is determined and how it affects the final visualization of the 4D BIM model.

Determination of the activity durations for individual elements

Before determining the duration of activities, it is necessary to identify all activities and events occurring in the project. This includes all construction processes, assemblies, transports, and other key events that influence the project's progress. Activity identification is essential for proper simulation and time coordination. Each identified activity must be assigned an estimated duration. For the Center Rotovž project, the time was determined empirically due to the nature of the project. This means that historical data, expert knowledge from contractors, and estimates based on past projects of a similar nature are used. Each element was assigned a duration considering multiple steps in the construction process. In order to achieve this, it was necessary to identify all the activities and tasks required for the implementation of each construction element, such as concreting, formwork, or reinforcement. This includes preparatory work, actual execution, and any potential inspection and quality checks. Pre-measurement data for each activity related to the element were collected, including estimates of the required materials, labour hours, and other resources for each phase of execution. With the obtained pre-measurement data and considering knowledge of construction technology, the duration of each activity was then determined. This includes time for performing the work, preparation time, and time for any additional processes such as concrete curing or formwork movement. This process enables a realistic assessment of the duration of each activity for each structural element. This ultimately helps to better plan the project timeline, allocate resources efficiently, and ensure that activities are carried out according to the planned deadlines.

Creation of detailed 4D BIM model

Once the duration of activities for individual construction elements has been determined, links are established between these time attributes and the three-dimensional information model. This step allows the time aspect to become part of the model visualization, providing a clear representation of how the project evolves over time. For the creation of the 4D BIM model, the function of automatic scheduling was used with the help of zones and methodologies.

The Bexel Manager program allows for a 4D/5D integrated approach through rapid creation of a basic schedule by automatically linking activities with different model structures and positions based on classifications. This avoids repeated creation of the same activities and relations and potential errors. Through this process, the expected costs are added and create a 5D model and corresponding simulation. All of this can be done within the Schedule tab, where zones, methodologies, and templates can be created.

1.1.1 Creation of zones and zone objects

The creation of zones begins with the "Zone Editor" command located in the toolbar of the user interface. The command is divided into the workspace toolbar and information about individual zone elements. Using the command, individual elements were broken down by floor, zones were determined, and elements were assigned. In the practical example, the elements are divided into foundation slabs and basement (Figure 1. Zone Editor command).

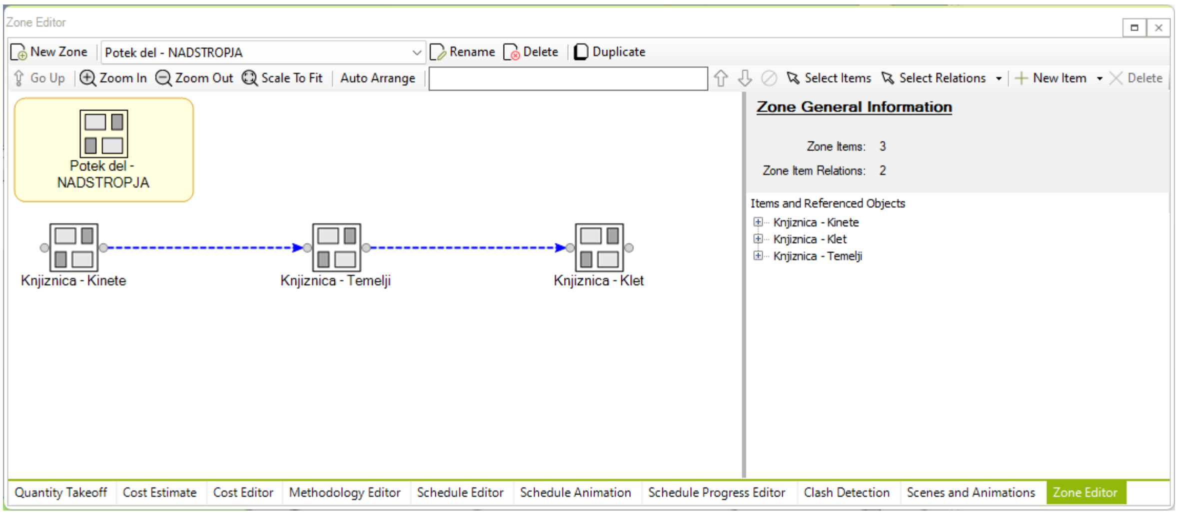


Figure 1. Zone Editor command

By sequencing from the lowest level to the highest, a certain sequence of construction is created. Taking into account the existing technology, it was decided that the construction will begin with slabs, followed by the foundations, and end with the basement. Among the defined elements, it is also possible to define temporal connections within the command, which was done in the practical example. Based on the known sequence of work execution, all links are defined as "Finish-Start" type connections. Within the defined zones according to levels, it is also possible to determine the construction sequence of certain family elements (slabs, walls, beams, columns) (Figure 2. Zone Editor - Display of work progress in the basement).(*Delovno gradivo za usposabljanje o programu BEXEL Manager* 2018)

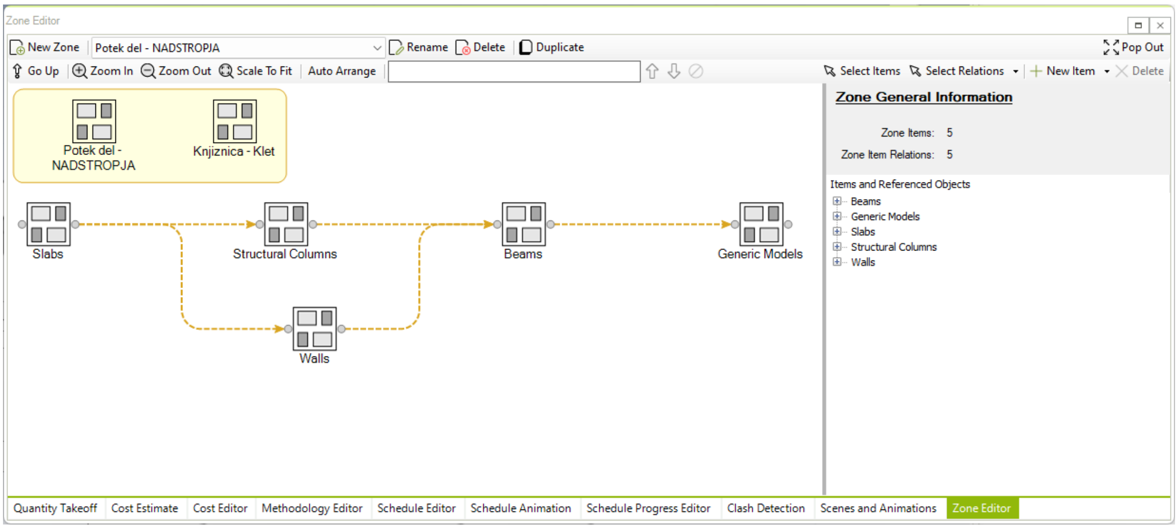


Figure 2. Zone Editor - Display of work progress in the basement

1.1.2 Creation of methodology

Methodology in Bexel Manager software represents a systematic approach to organizing and managing construction projects and their components. Its main task is to enable organizations and projects to consistently standardize their procedures, processes, and guidelines for carrying out construction activities. In this context, the Bexel Manager methodology relies on classifications such as Masterformat or Uniformat, allowing organizations to precisely structure their work according to different types of activities, such as formwork, reinforcement, concreting, and others. In our practical example, a method that determines the sequence of work execution was used (Figure 3. Creating methodology). Formwork is performed first, followed by reinforcement, with concreting last. This hierarchical approach ensures that each phase is carried out in the correct sequence, contributing to efficient and coordinated project progress.(*Delovno gradivo za usposabljanje o programu BEXEL Manager* 2018)

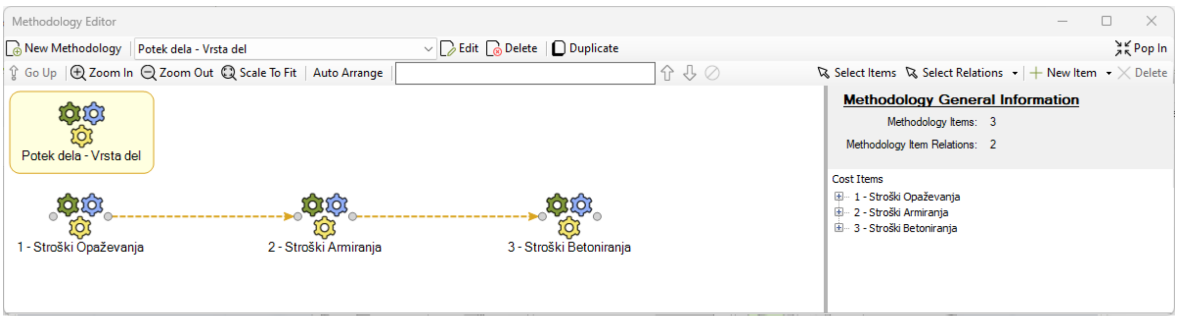


Figure 3. Creating methodology

1.1.3 Preparation of Template

After completing the process of defining zones and generating methodology, the preparation of the groundwork for the schedule begins. This step is performed using the “Creation Template” command located in the toolbar of the software user interface. In this step, it is ensured that all previously defined zones are included, which is crucial for the proper functioning of the project.

In creating the template for the schedule, a hierarchical approach was considered. This process began with a general breakdown by floor, then continued with a breakdown by type of work, and finally delved into the most detailed level, where the breakdown was carried out on the basis of element families and individual elements (Figure 4. Template creation). This hierarchical approach is crucial as it ensures that the final schedule is properly structured and organized. Adhering to the hierarchical order when entering zones into the schedule template is essential for clarity and efficiency throughout the schedule creation process. It helps avoid confusion and issues during project execution, ensuring that all steps and tasks are correctly aligned.

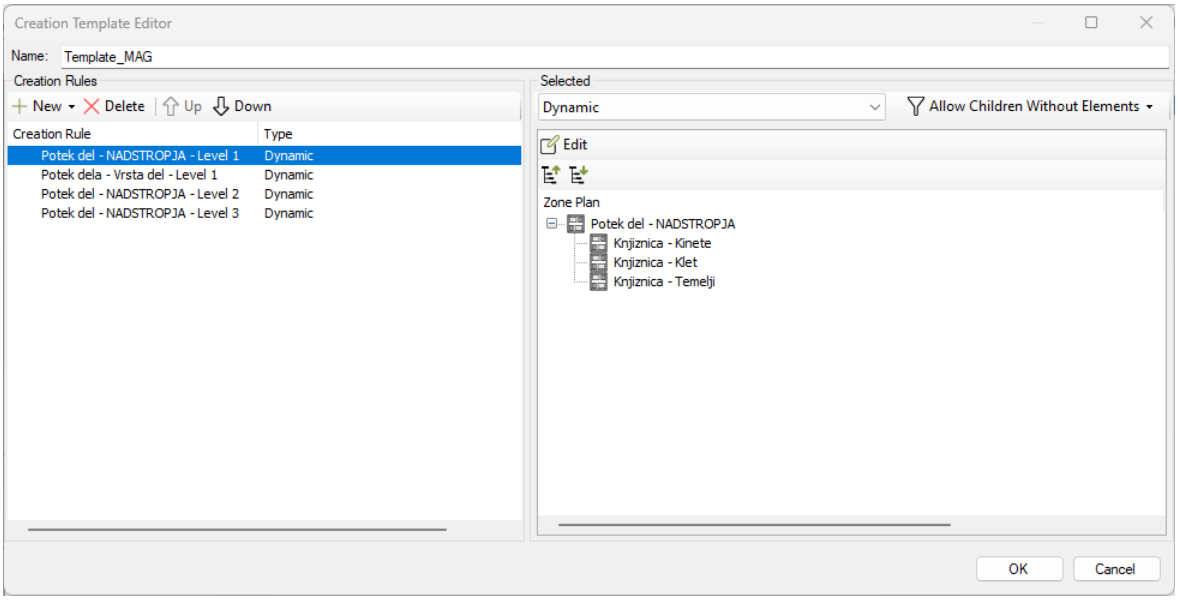


Figure 4. Template creation

In creating the 4D BIM model, the "New Task" command to import already prepared templates was used. For this purpose, the "Creation Wizard" function was used, which allows for easy import of previously prepared templates. Once the template was successfully imported, it was also possible to use the option to modify connections between activities or add new ones in the schedule view, known as "Logic." This functionality enables better control and coordination of work progress in the project. Figure 5. Schedule view shows an example of how connections between activities can be adjusted. The Gantt view was also used in the work, which enables the duration of individual activities to be adjusted if necessary. This allows for better project timeline management, progress monitoring and schedule adjustments as needed.(*Delovno gradivo za usposabljanje o programu BEXEL Manager* 2018)

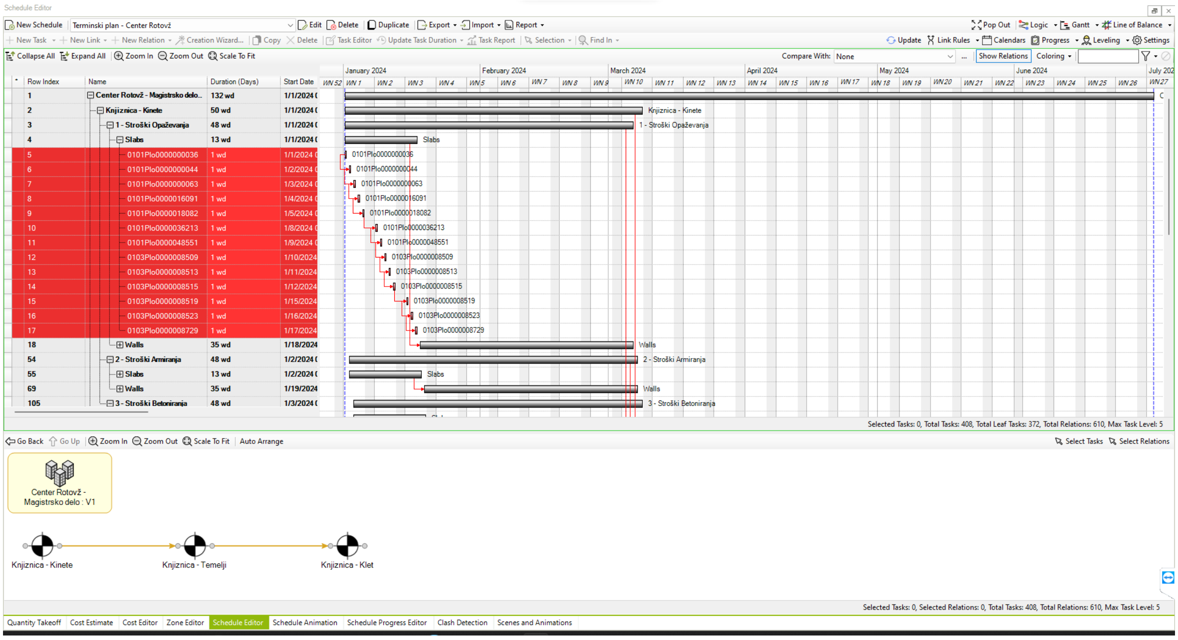


Figure 5. Schedule view

Construction simulation

Construction simulation or the sequence of executing individual activities in Bexel Manager software is created through the "Schedule Animation" module. This module allows for the creation of dynamic visualization that shows how the construction project evolves.

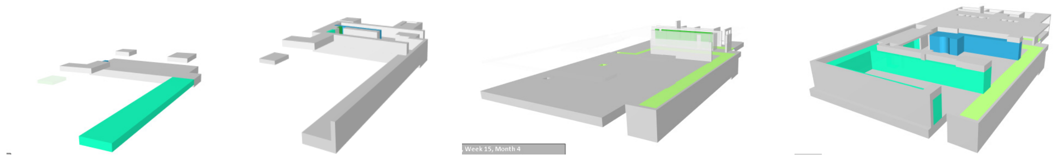


Figure 6. Construction simulation

Construction of the 5D BIM model

For the purpose of monitoring the construction of the Center Rotovž building, a 5D BIM model for the Center Rotovž project, Library section, was developed using Bexel Manager software. **(Medprostor d.o.o 2022)**The fifth dimension of the BIM approach represents a model where construction elements are linked with specific cost values. The key input data for determining costs consist of bills of quantities and pre-estimated quantities for predefined construction elements found in the 3D BIM model. The entire process leading to the preparation of bills and quantity take-offs for various construction elements was thoroughly investigated in Section 4.1.2, where this topic was specifically addressed. The quantities obtained from this process can then be fully integrated into the creation of the 5D BIM model.

Quantity of reinforced concrete structures

Quantities of reinforced concrete structures are typically expressed in cubic meters (m^3), and in this research, these quantities will be accurately analysed and presented. The quantities were broken down according to the type of work: formwork, reinforcement, and concreting of structural elements. Each type of work will use its specific unit of measure:

- For formwork, the unit of measure will be square meters (m^2), representing the area of the formwork.

- For reinforcement, the unit of measure will be kilograms (kg), referring to the weight of the reinforcement.

- For concreting, the unit of measure will be cubic meters (m^3), indicating the volume of concrete.

In calculating the volume of concrete, the attribute “concrete volume” was used. For calculating the surface area of formwork, the formula for the surface area of the sides, defined as the product of the height and length of the element was applied. When determining the weight of the reinforcement, the starting point was the bill of quantities and the assumption that there is approximately 160 kg of reinforcement per cubic meter of concrete.

Analysis of bill of quantities for items

In the case of the Center Rotovž project, the focus was on the pre-estimated items for concrete and carpentry works. The data for these items was obtained from the designer’s estimate, which provides a description of the work, unit of measure, and unit price. Due to the nature of the project, the cost data has been split into walls and slabs. The data were structured and presented in Table 1. Cost estimate for wall and slab items of the project.

Table 1. Cost estimate for wall and slab items of the project

Description			Unit price	Total
Supply and installation of reinforced concrete for walls.		70,00	106,50	745,00
Supply and installation of reinforced concrete for floor slabs.		43,00	100,57	4324,51
Supply, installation, and removal of double-sided formwork for concrete walls, height up to 2 m.		1203,00	29,52	
Supply, installation, and removal of formwork for edges of floor slabs, height up to 2 m.		1302,00	16,85	
Supply and installation of B500B reinforcing mesh.	kg	251,00	1,30	326,3
Supply, installation, and tying of moderately complex B500B reinforcement.	kg	370,00	1,23	455,10

Creation of a detailed 5D BIM model

The creation of the 5D BIM model using Bexel Manager software involved three main steps. Each of these steps plays a crucial role in creating a comprehensive 5D BIM model. The first step focuses on creating classifications, where the classification system sets the prices for each item, expressed in appropriate units of measure, considering all necessary resources. At the same time, the quantities for each element from the 3D BIM model were determined or were imported according to the corresponding unit of measurement. The second step involves assigning the cost value, i.e., the unit price. This means that for each component in the model, it was precisely defined how much the unit of that component would cost. The third step refers to the overall cost estimation of the entire building or individual components within the building. This step provides a clear overview of the structure of the project costs.

In addition to these three main steps, it is possible also to link the 5D BIM model with the 4D BIM model, which allows a temporal overview of the necessary and utilized resources during the project's implementation. This gives a comprehensive insight into the project's timeline and cost planning.

Within the used software, the module for 5D BIM modeling is positioned among various modules and is called "Cost Editor." This module includes three tabs for work, as shown in Figure 7. Display of the Cost Editor module:

- Classification Editor
- Cost Item Definitions
- Resources

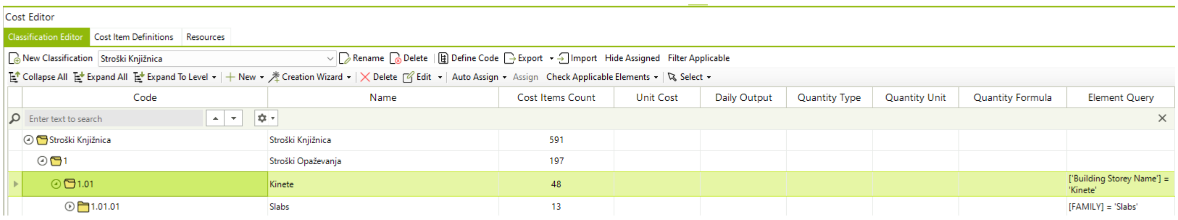


Figure 7. Display of the Cost Editor module

The analysis begins with the classification editor, where a classification system is created, tailored to the specific needs and requirements. The final structure of the classification system allows to define the cost item or price. This classification system structure is crucial in creating the 5D BIM model and offers additional possibilities for creating the 4D BIM model. However, we did not use these additional possibilities, as they relate to a specific work methodology not covered in our research. When defining the cost item of an element (Figure 8. Defining the cost item of an element), a code and name was set first. The classification code is used for better organization of the classification system and easier tracking. This is followed by defining the main properties of the cost item, where there two options:

- Directly determining the item price: in this case, the item price either as the designer's price or the total bid price can be set.

- Determining the bid price of the item through predefined resources: this approach involves cost calculation analysis for individual pre-estimated items, defining resources such as materials, labour, and machinery. When determining the bid price for a pre-estimated item, other indirect costs can also be taken into account.

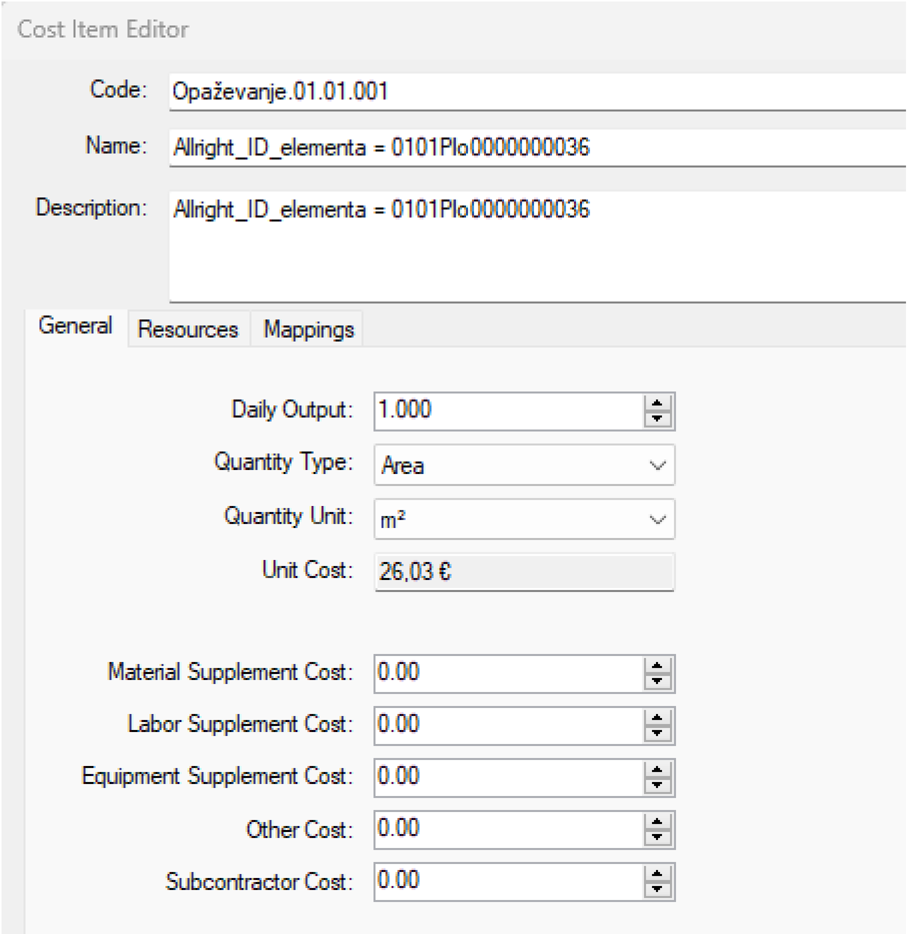


Figure 8. Defining the cost item of an element

In the practical case, the bid price of the item through predefined resources (Figure 9. Defining resources for executing the element) was determined, specifically for concrete works, including formwork, reinforcement, and concreting. The labour cost for executing a specific element was also included.

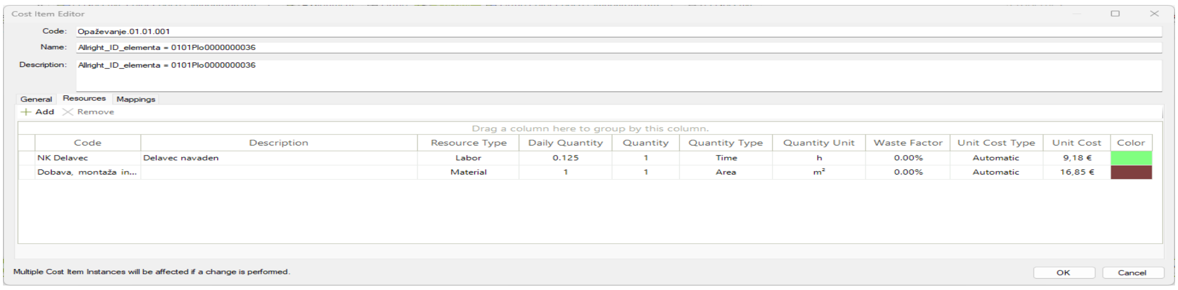


Figure 9. Defining resources for executing the element

In the following, the criterion for calculating the quantity of the item was determined, where the formula for calculating the total cost or price was also determined. In this practical example, the price of concrete works items, the volume of the element was used, while for formwork items the surface area of the sides was used, and for reinforcement, the weight of reinforcement in kilograms per cubic meter of concrete was used (Figure 10. Quantity calculation formula).

Figure 10. Quantity calculation formula

By assigning a cost item to an element, the display field of the element in the "Assignment" tab turns yellow (Figure 11. Display of the "Assignment" module). These visual indicators provide a clear overview of which elements have assigned cost items and which do not.

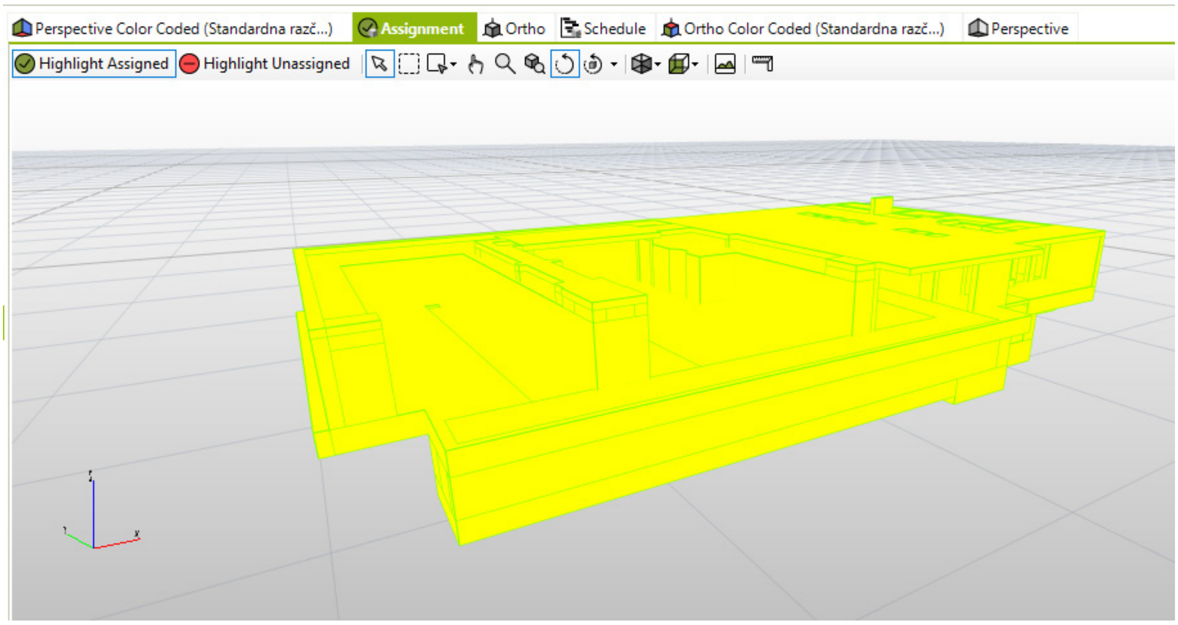


Figure 11. Display of the "Assignment" module

This functionality offers a significant advantage in cost estimation of construction using the BIM approach, as it reduces the possibility of overlooking or incompletely estimating costs of any element. The visual overview allows precise tracking and verification of cost assignments to each element in the project. When a specific element is highlighted, an additional window appears in the display field, immediately showing the specified or calculated value of that individual element (Figure 12. Cost display of the highlighted element).

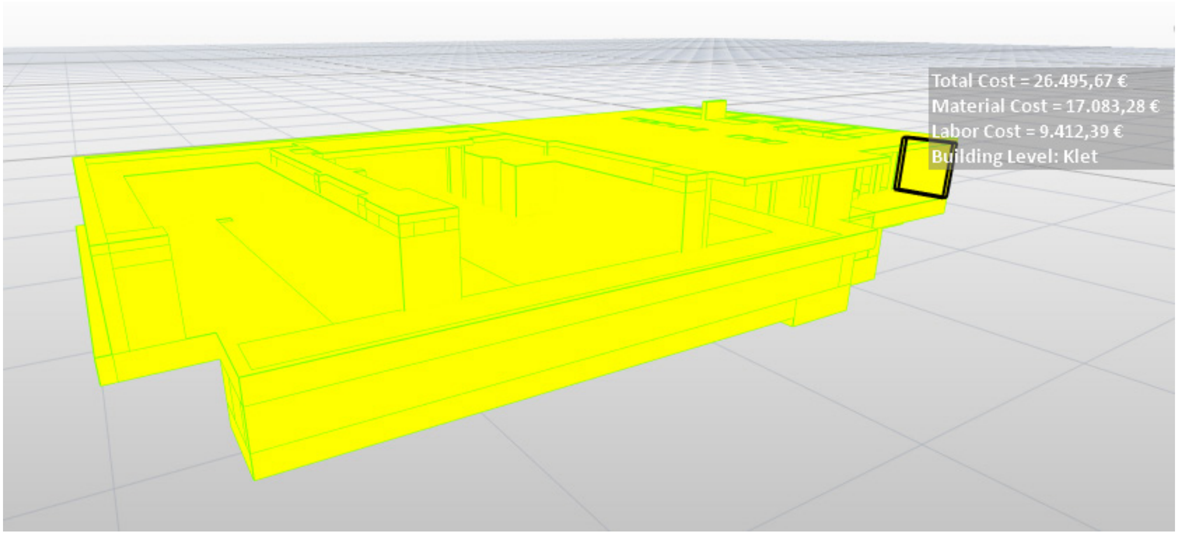


Figure 12. Cost display of the highlighted element

Monitoring the construction project

Using the Bexel Manager, it is possible to monitor the progress of the Center Rotovž project, providing a clear overview of the schedule, potential delays, and cost flow. Certain activities in the schedule are not linked to model elements and are called “Default Activity.” The progress of tasks associated with these activities is entered manually, while the progress of activities linked to model elements is tracked with created “Selection Sets.”

For the needs of manually entering the progress of tasks, data was collected daily from accessible documentation such as the construction diary, delivery notes, reports, certificates of installed materials and equipment, etc., and a daily visual inspection was carried out at the construction site itself. If necessary, to confirm the collected data, independent measurements were also carried out.

The monitoring process begins by copying the existing schedule. Then, activate the “Progress” command within the “Schedule Editor” tab. The “Schedule Progress Editor” window opens, where a new entry is created. In the “Progress Entry Editor” window, define the monitoring period, specify the start and end dates, and select “Planned.” A list of all planned activities for the chosen period is displayed and indicates whether the activities occurred according to the schedule. The process is completed by marking the last entry. Adding a new monitoring period follows a similar procedure. Selecting the “Progress” command activates the “Schedule Progress Editor”, where a new entry is then created, specifying the period and selecting “Selection sets.” A list of all activities for the chosen period is displayed, and their progress is determined. The process concludes by marking the last entry of the previous monitoring period.

After completing the monitoring, it is necessary to return to the “Schedule Editor” tab and activate the Gantt display. In the “Compare with” window, it is then possible to select the original schedule (Figure 13. Display of the original schedule) and compare them. The progress of work and any delays are shown with a dashed line. This results in a new and updated schedule that reflects all changes, becoming the current schedule.

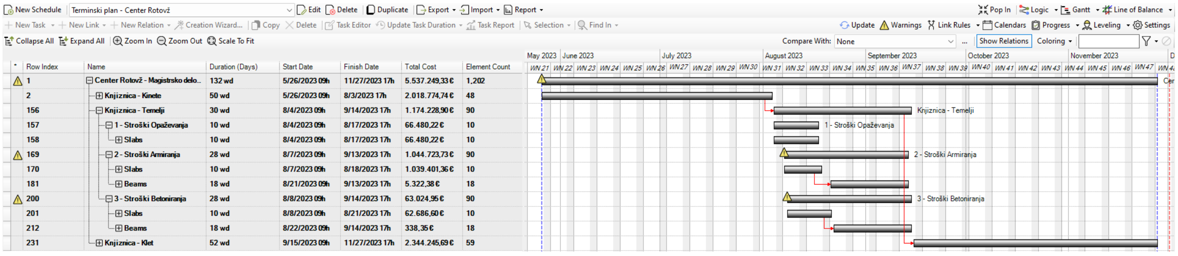


Figure 13. Display of the original schedule

During the first week of monitoring the Center Rotovž project, from July 31 to August 7, 2023, five key elements were successfully completed. The first element involved the successful formwork installation for the walls in the kinetic floor, a crucial phase executed according to the plans, contributing to the stability and structural integrity of the building. The next step was the successful reinforcement of the walls in the kinetic floor. This reinforcement ensures the necessary strength and resilience of the construction and represents an important phase of the building process. The third element included work on the foundation slab. Whitin this week also the formwork and reinforcement of the slab were successfully completed. Partial concreting was carried out, ensuring precision and compliance with the preliminary plans. The first week, being one of the most intensive, also showed the highest cost, amounting to €831,894.00.

In the second week of the project, the plan was to continue concreting the foundation slab. This crucial phase will further solidify the building's foundation and represents the next step according to the construction schedule. Along with the past successful week, this shows stable progress and consistent implementation of construction segments in the Center Rotovž project. Below are images that clearly show the comparison between the planned (Figure 15. Planned works for the first week of the Library building) and completed works (Figure 16. Completed works for the first week of the Library building) in the first week of the project. Additionally, a Gantt chart with the time deviations in this week from the original schedule is included (Figure 14. Comparison of the first week schedule with the original plan). These images provide additional visual explanation of the status and allow for a more precise analysis of the events in the first week of the Center Rotovž construction project.

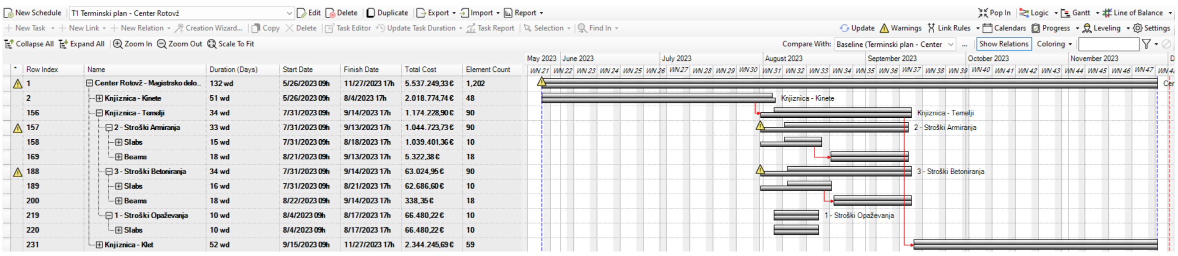


Figure 14. Comparison of the first week schedule with the original plan

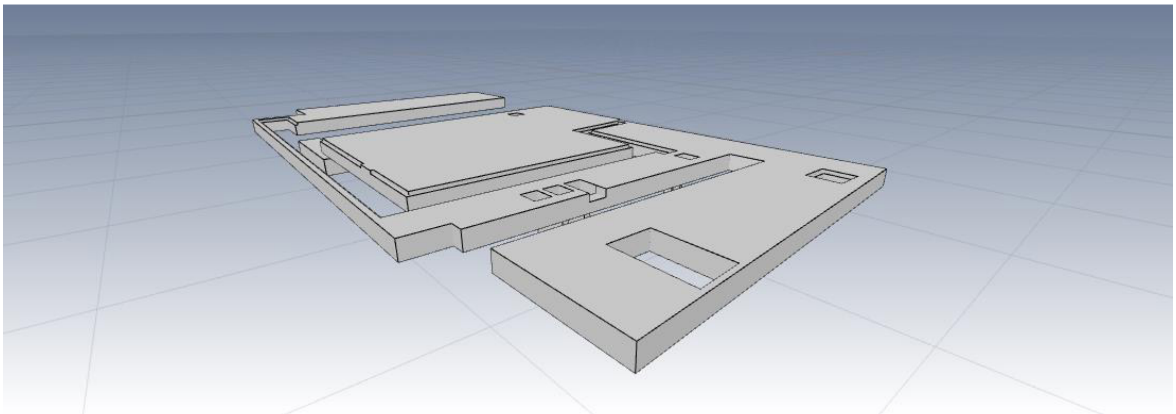


Figure 15. Planned works for the first week of the Library building

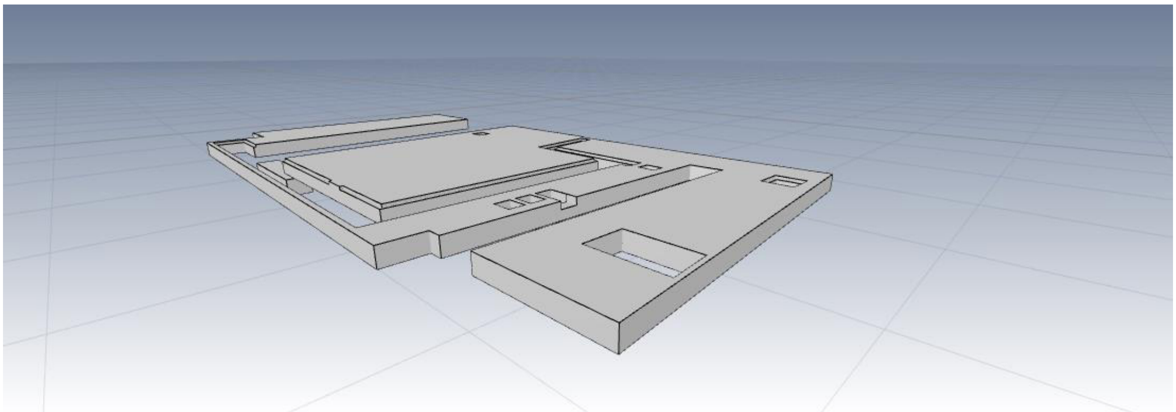
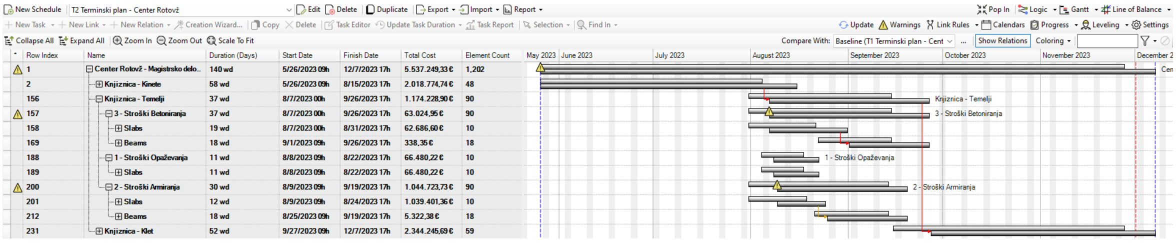


Figure 16. Completed works for the first week of the Library building

Following the successful implementation of the project monitoring system based on the information model in the first week, it becomes evident that the developed schedule is a crucial guide for the project's next steps. In the second week of the project, this schedule will become the basis for systematic progress monitoring and possible adjustments if needed. At the end of the second week of project monitoring, a thorough comparison of the current schedule with the schedule from the previous week will be conducted (i.e., week 1). This comparison will cover all aspects included in the construction process and will serve as a key tool for assessing compliance with the original project objectives. This important analysis will be carried out throughout the month, encompassing both the third and fourth weeks, aiming to maintain optimal progress according to the project timeline. During this period, Bexel Manager was continuously used to collect and analyse data, which enabled accurate monitoring of the construction progress. By focusing on the effective use of the information model, it was possible to ensure that all project stakeholders were well informed about the current situation, possible deviations from the planned deadlines and measures to achieve optimal results.

In the second week of the Center Rotovž project, construction activities continued, including formwork, reinforcement, and concreting of the concrete foundation slab. Additionally, it was planned to complete another foundation slab and install OMNIA plates, representing important further steps in the construction process. As shown in Figure 18. Planned works for the second week of the Library building, the larger foundation slab, marking a significant milestone in the construction process was successfully completed. However, Figure 19. Completed works for the second week of the Library building shows that the other two planned elements, the additional foundation slab and the installation of OMNIA plates, were not completed. This deviation from the plan will be closely monitored and addressed in the next, third week of the project.

It is also important to mention that the costs for the second week amounted to €75,859.19. These costs include material and labour costs associated with the activities carried out during this period. The cost analysis will help in tracking the project budget and identifying any deviations that require additional reviews or adjustments. With this information in mind, the remaining elements in the third week that were not completed in the second week will be monitored in continuation. The goal is to ensure that any deviations are quickly and efficiently addressed, maintaining the construction progress pace according to the defined objectives and plans of the Center Rotovž project.



Row Index	Name	Duration (Days)	Start Date	Finish Date	Total Cost	Element Count
1	Center Rotovž - Magistrsko delo...	140 wd	5/26/2023 09h	12/7/2023 17h	5.537.249,33 €	1,202
2	Knjiznica - Kinete	58 wd	5/26/2023 09h	8/15/2023 17h	2.018.774,74 €	48
156	Knjiznica - Temelji	37 wd	8/7/2023 00h	9/26/2023 17h	1.174.228,90 €	90
157	3 - Stroški Betoniranja	37 wd	8/7/2023 00h	9/26/2023 17h	63.024,95 €	90
158	Slabs	19 wd	8/7/2023 00h	8/31/2023 17h	62.686,60 €	10
169	Beams	18 wd	9/1/2023 09h	9/26/2023 17h	338,35 €	18
188	1 - Stroški Opaževanja	11 wd	8/8/2023 09h	8/22/2023 17h	66.480,22 €	10
189	Slabs	11 wd	8/8/2023 09h	8/22/2023 17h	66.480,22 €	10
200	2 - Stroški Armiranja	30 wd	8/9/2023 09h	9/19/2023 17h	1.044.723,73 €	90
201	Slabs	12 wd	8/9/2023 09h	8/24/2023 17h	1.039.401,36 €	10
212	Beams	18 wd	8/25/2023 09h	9/19/2023 17h	5.322,38 €	18
231	Knjiznica - Klet	52 wd	9/27/2023 09h	12/7/2023 17h	2.344.245,69 €	59

Figure 17. Comparison of the second week schedule with the first week schedule

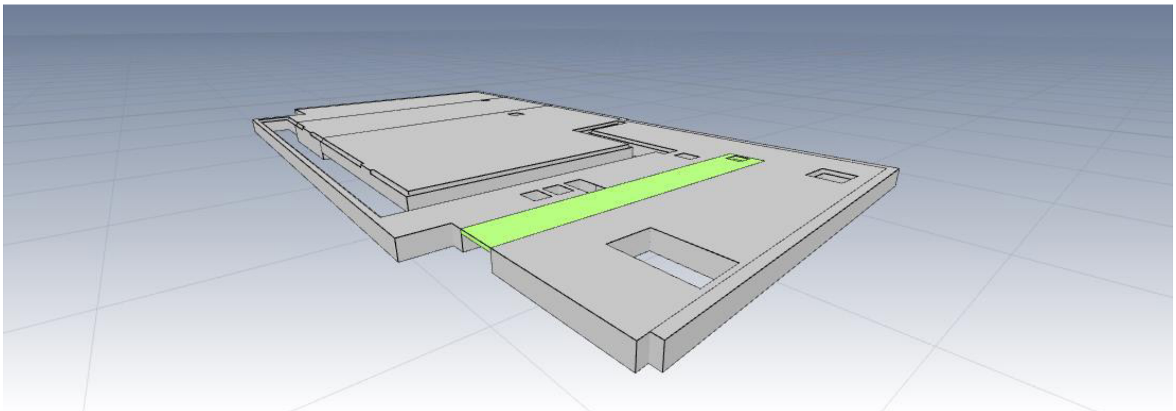


Figure 18. Planned works for the second week of the Library building

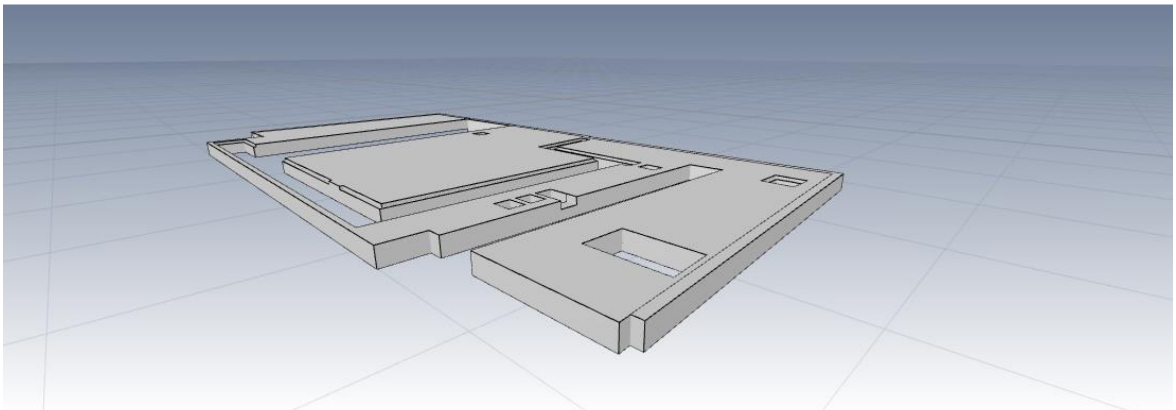
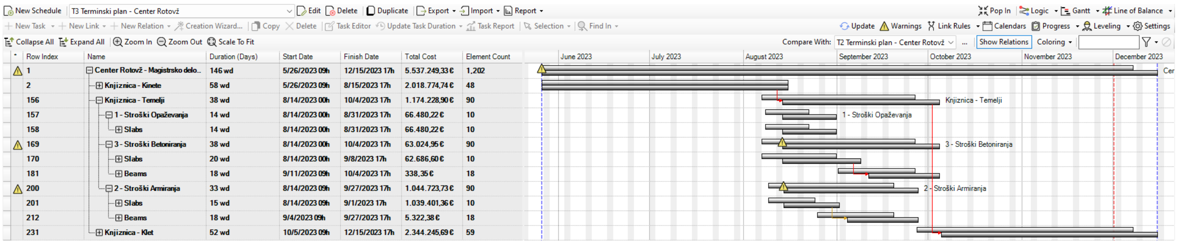


Figure 19. Completed works for the second week of the Library building

In the third week of the Center Rotovž project, the focus was on further aligning construction activities and achieving key milestones. Based on the events of the previous weeks, where a larger foundation slab was successfully completed, but the additional foundation slab and OMNIA plates installation were not completed, the commitment to rapid improvement and continuation of construction works is all the more important. Planned works for the third week included completing the additional foundation slab and installing the OMNIA plate, which remained unfinished in the second week, and creating additional OMNIA plates in the remaining openings. It was also planned to complete the edge of the concrete slab and concrete the openings for installation lines (Figure 21. Planned works for the third week of the Library building).

After successfully monitoring the project works for the third week, it was established that the additional concrete foundation slab and the additional OMNIA slabs were indeed completed. The opening for the installation lines and the edges of the concrete foundation slab was also successfully executed, as shown in Figure 22. Completed works for the third week of the Library building. Partially completed were also the main OMNIA plate, which will be finished in the coming week. The only element not completed was the additional foundation slab. Due to the priority of other works, it was decided that this foundation slab would be carried out in the coming months and will no longer be included in the monitoring.

The costs for the third week of the project amount to €273,495.31. This includes all material and labour costs associated with the planned construction activities during this period. Cost analysis will help in further tracking the project budget and identifying any deviations that require appropriate actions to maintain the project's financial stability.



Row Index	Name	Duration (Days)	Start Date	Finish Date	Total Cost	Element Count
1	Center Rotovž - Magistrsko delo...	146 wd	5/26/2023 09h	12/15/2023 17h	5.537.249,33 €	1,202
2	Knjiznica - Kinete	58 wd	5/26/2023 09h	8/15/2023 17h	2.018.774,74 €	48
156	Knjiznica - Temelji	38 wd	8/14/2023 00h	10/4/2023 17h	1.174.228,90 €	90
157	1 - Stroški Opaževanja	14 wd	8/14/2023 00h	8/31/2023 17h	66.480,22 €	10
158	Slabs	14 wd	8/14/2023 00h	8/31/2023 17h	66.480,22 €	10
169	3 - Stroški Betoniranja	38 wd	8/14/2023 00h	10/4/2023 17h	63.024,95 €	90
170	Slabs	20 wd	8/14/2023 00h	9/8/2023 17h	62.686,60 €	10
181	Beams	18 wd	9/11/2023 09h	10/4/2023 17h	338,35 €	18
200	2 - Stroški Armiranja	33 wd	8/14/2023 09h	9/27/2023 17h	1.044.723,73 €	90
201	Slabs	15 wd	8/14/2023 09h	9/1/2023 17h	1.039.401,36 €	10
212	Beams	18 wd	9/4/2023 09h	9/27/2023 17h	5.322,38 €	18
231	Knjiznica - Klet	52 wd	10/5/2023 09h	12/15/2023 17h	2.344.245,69 €	59

Figure 20. Comparison of the third week schedule with the second week schedule

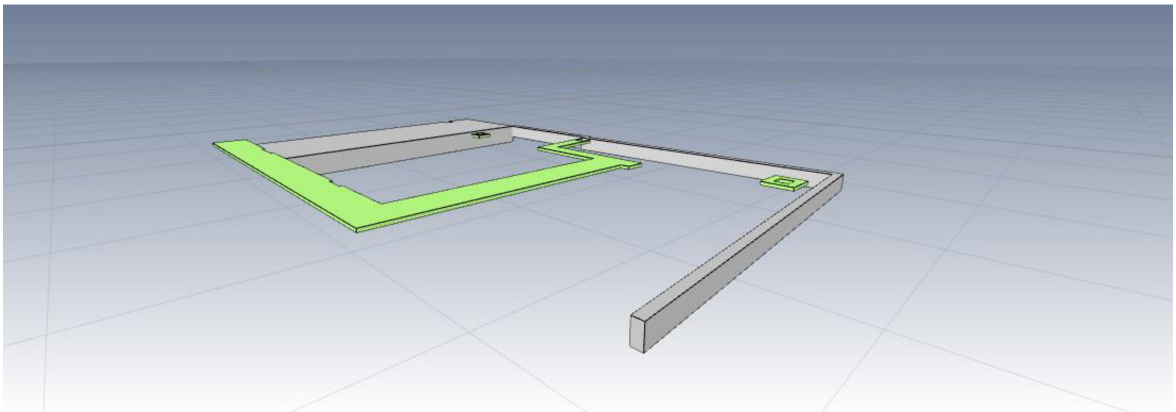


Figure 21. Planned works for the third week of the Library building

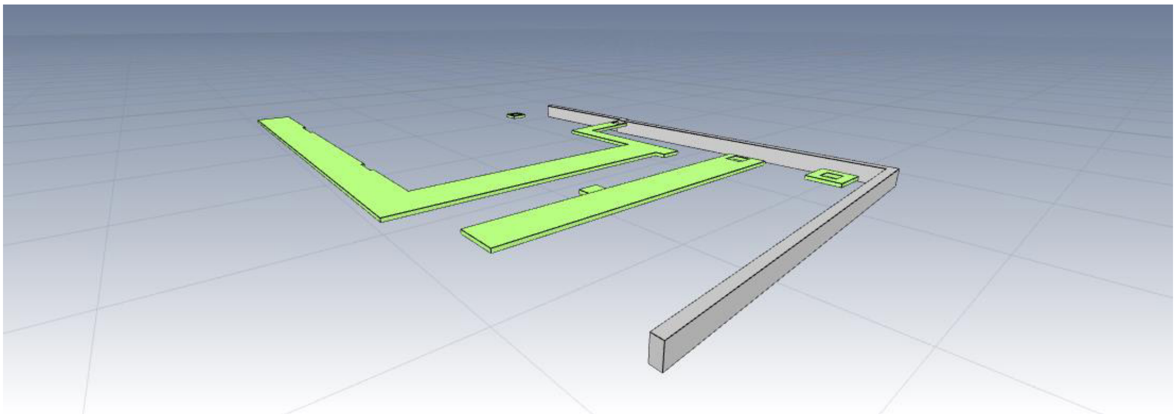
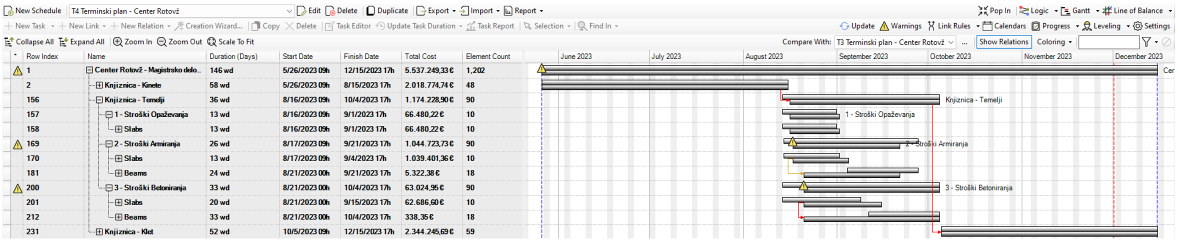


Figure 22. Completed works for the third week of the Library building

In the fourth week of monitoring the Center Rotovž project, after careful analysis of the past weeks, it was recognized that in the third week, most of the planned works, including the additional concrete foundation slab, additional OMNIA plates, the opening for installation lines, and the edges of the concrete slab were successfully completed.

In the final, fourth week, the focus was on completing the beams in the foundation floor and finishing the main OMNIA plate (Figure 24. Planned works for the fourth week of the Library building). The main OMNIA plate was successfully completed and partially completed also the beams in the foundation floor. Monitoring the project's progress in the last week allowed to accurately record the completed works and compare them with the original schedule. Despite potential challenges, it was possible to maintain the efficiency and quality of construction activities (Figure 23. Comparison of the fourth week schedule with the third week schedule).

The costs for the fourth week of the project amount to €14,600.06. These costs include all material, labour, and other related expenses necessary for carrying out the planned construction activities during this period.



Row Index	Name	Duration (Days)	Start Date	Finish Date	Total Cost	Element Count
1	Center Rotovž - Magistrsko delo...	146 wd	5/26/2023 09h	12/15/2023 17h	5.537.249,33 €	1,202
2	Knjiznica - Kinete	58 wd	5/26/2023 09h	8/15/2023 17h	2.018.774,74 €	48
156	Knjiznica - Temelji	36 wd	8/16/2023 09h	10/4/2023 17h	1.174.228,90 €	90
157	1 - Stroški Opaževanja	13 wd	8/16/2023 09h	9/1/2023 17h	66.480,22 €	10
158	Slabs	13 wd	8/16/2023 09h	9/1/2023 17h	66.480,22 €	10
169	2 - Stroški Armiranja	26 wd	8/17/2023 09h	9/21/2023 17h	1.044.723,73 €	90
170	Slabs	13 wd	8/17/2023 09h	9/4/2023 17h	1.039.401,36 €	10
181	Beams	24 wd	8/21/2023 00h	9/21/2023 17h	5.322,38 €	18
200	3 - Stroški Betoniranja	33 wd	8/21/2023 00h	10/4/2023 17h	63.024,95 €	90
201	Slabs	20 wd	8/21/2023 00h	9/15/2023 17h	62.686,60 €	10
212	Beams	33 wd	8/21/2023 00h	10/4/2023 17h	338,35 €	18
231	Knjiznica - Klet	52 wd	10/5/2023 09h	12/15/2023 17h	2.344.245,69 €	59

Figure 23. Comparison of the fourth week schedule with the third week schedule

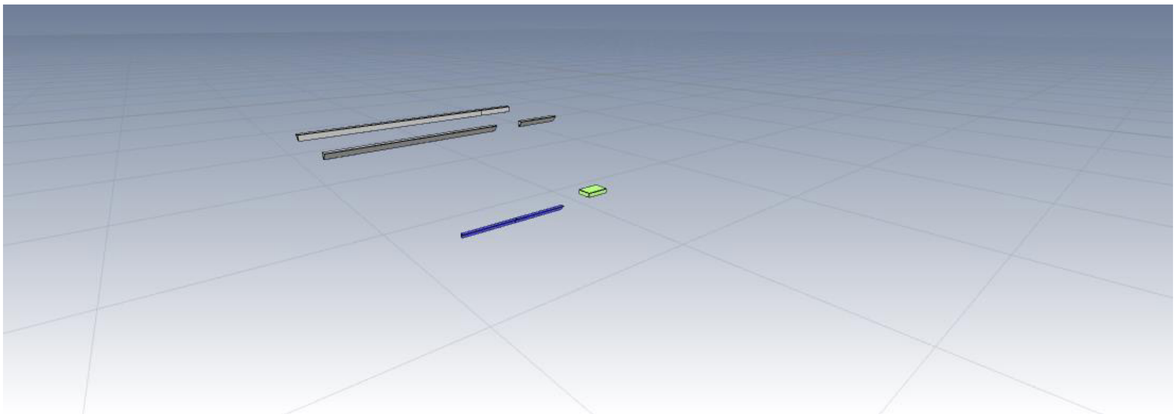


Figure 24. Planned works for the fourth week of the Library building

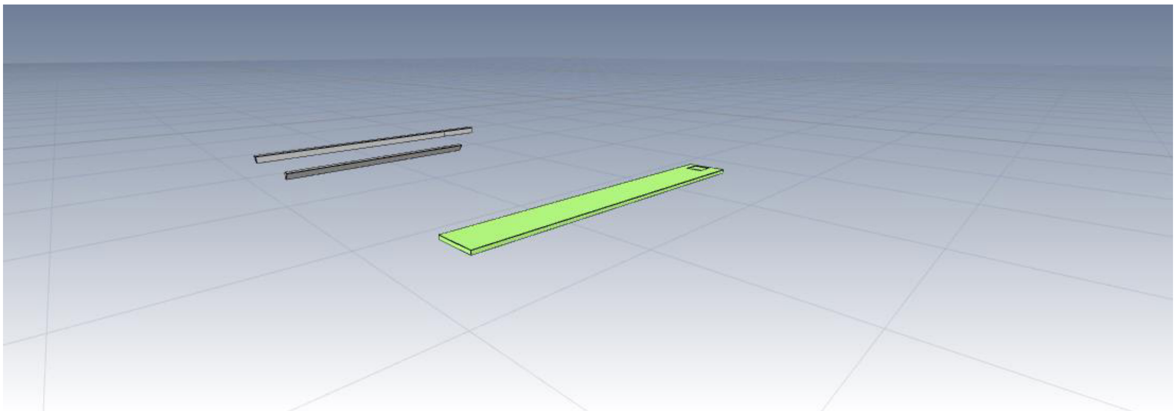


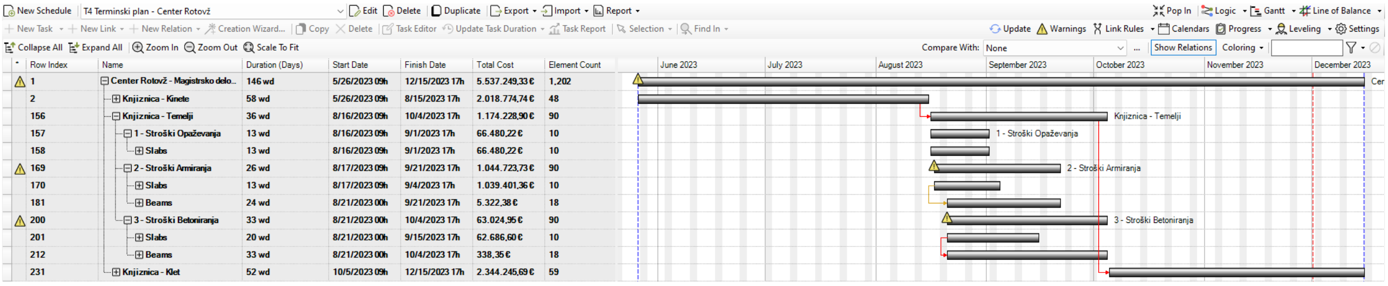
Figure 25. Completed works for the fourth week of the Library building

Results and Conclusions

Results from 4D BIM

After one month of monitoring the construction of the Rotovž Center project, specifically the Library building, significant conclusions have been reached. Due to certain unfinished activities, visible in Figure 25. Completed works for the fourth week of the Library building, the project schedule has been extended by 12 days. This insight was gained through meticulous weekly monitoring, enabling to swiftly identify the causes of changes in the schedule. The result of this analysis is a newly updated and current schedule (Figure 26. Updated schedule after one month of construction monitoring).

Due to delays in the execution of works, the completion of construction on the kinet floor involved a delay until mid-August. Following the completion of kinet, as clearly observed in Figure 27. Comparison of the current schedule with the original planned schedule, the execution of the foundation floor begins on August 16th, whereas it was originally planned to commence on August 4th. This deviation from the initial schedule was detectable and documented through monitoring using the information model. Precise monitoring of construction activities allows to promptly detect deviations from planned deadlines and take immediate action to maintain project schedule discipline. The new schedule reflects the actual status and will assist in further directing construction phases, reducing potential delays, and achieving optimal project execution efficiency.



Row Index	Name	Duration (Days)	Start Date	Finish Date	Total Cost	Element Count
1	Center Rotovž - Magistrsko delo...	146 wd	5/26/2023 09h	12/15/2023 17h	5.537.249,33 €	1,202
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169	2 - Stroški Armiranja	26 wd	8/17/2023 09h	9/21/2023 17h	1.044.723,73 €	90
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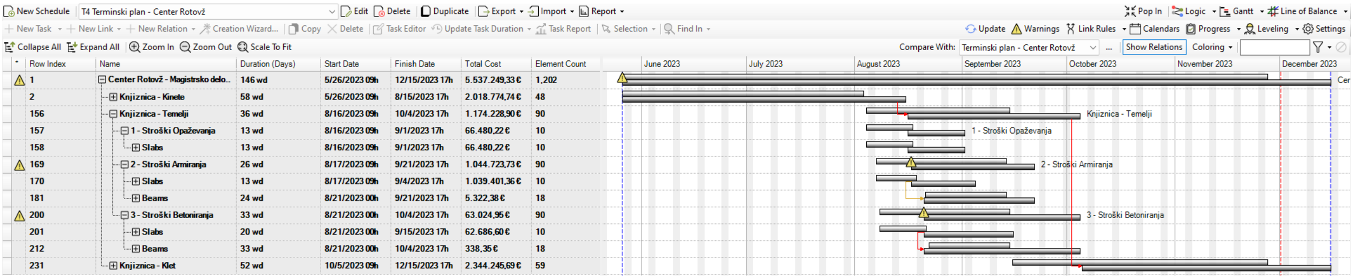
201	Slabs	20 wd	8/21/2023 00h	9/15/2023 17h	62.686,60 €	10
212	Beams	33 wd	8/21/2023 00h	10/4/2023 17h	338,35 €	18
231	Knjiznica - Klet	52 wd	10/5/2023 09h	12/15/2023 17h	2.344.245,69 €	59

Figure 26. Updated schedule after one month of construction monitoring



Row Index	Name	Duration (Days)	Start Date	Finish Date	Total Cost	Element Count
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231	Knjiznica - Klet	52 wd	10/5/2023 09h	12/15/2023 17h	2.344.245,69 €	59

Figure 27. Comparison of the current schedule with the original planned schedule

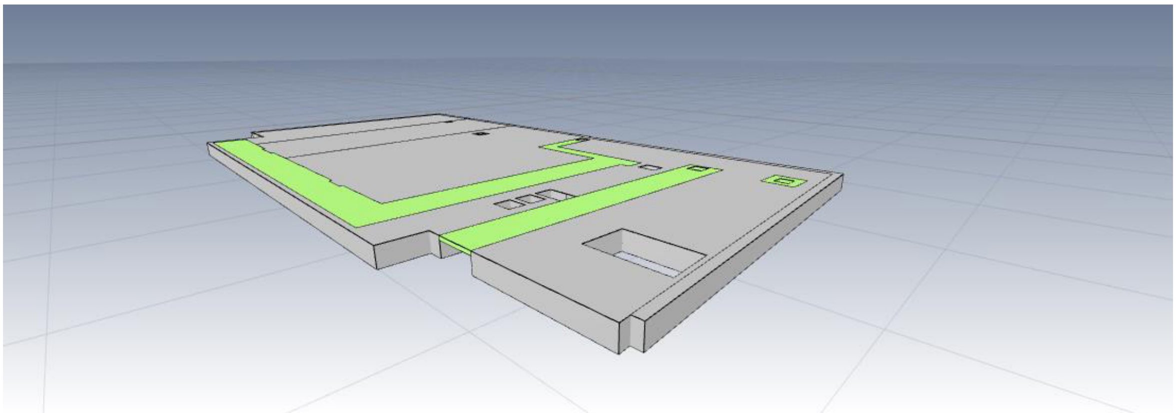

Figure 28. Display of total anticipated works at the beginning of the month

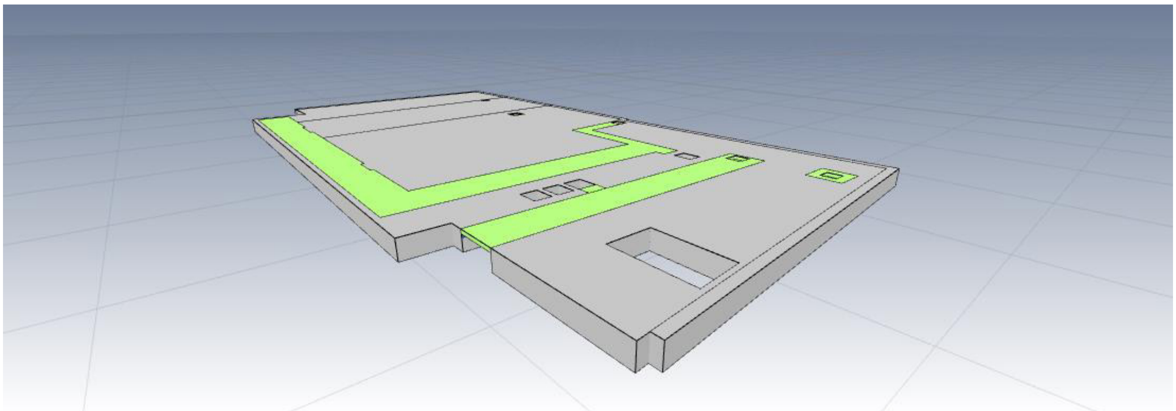

Figure 29. Display of total completed works at the end of the month

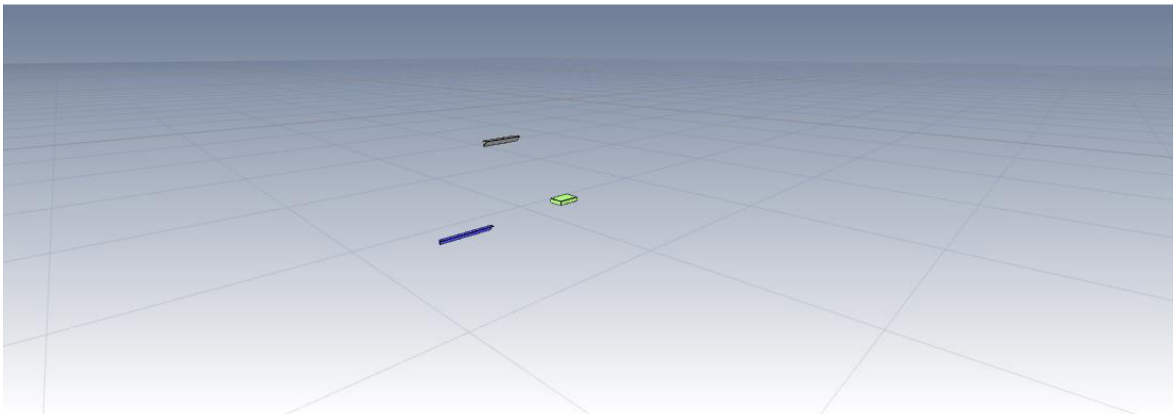

Figure 30. Display of unfinished works due to schedule delays after construction monitoring

Results from 5D BIM

In addition to thorough time monitoring of the Rotovž Center project, a detailed cost analysis was conducted. The objective was to determine whether there were additional or unforeseen costs during the execution of works in August, and whether there were any changes in cost dynamics due to schedule deviations or potential improvements leading to cost reduction.

The planned project costs amounted to €1,225,976.03, as indicated in Figure 31. Planned costs for August. After one month of construction monitoring, we recorded realized costs totalling €1,225,119.37, as shown in Figure 32. Realized costs for August. Due to unfinished works, the realized costs turned out to be lower than originally planned and the difference amounts to €856.66.

Name	Start Date	Finish Date	Actual Cost	Planned Cost
Enter text to search				
			Sum: 1.225.976,03 €	Sum: 1.225.976,03 €
Predvideni mesečni stroški	07/31/2023	08/31/2023	1.225.976,03 €	1.225.976,03 €

Figure 31. Planned costs for August

Name	Start Date	Finish Date	Actual Cost	Planned Cost
Enter text to search				
			Sum: 1.225.119,37 €	Sum: 1.225.119,37 €
Realizirani mesečni stroški	07/31/2023	08/31/2023	1.225.119,37 €	1.225.119,37 €

Figure 32. Realized costs for August

The lower costs are attributed to the unfinished works, as depicted in Figure 32. Realized costs for August. Identifying the causes of these deviations is crucial for effective cost management and process improvement. While lower costs represent a positive aspect, we recognize that unfinished works can impact the overall project timeline.

Discussion and conclusion

Construction monitoring was conducted over one month, with weekly analysis of progress and performance of construction activities. This process enabled us to closely track progress in accordance with the schedule.

Each week's progress involved creating lists of completed tasks, utilizing elements of the schedule and work breakdown structure through Selection Sets, and employing an Excel spreadsheet for unconnected activities. Progress was input into the program using Bexel Manager and compared in the third phase with the planned schedule or monthly situation. During the first week, key phases such as formwork and reinforcement of walls were successfully completed, critical for the stability and structural integrity of the building. Subsequently, the focus was directed on executing supports in the foundation floor and completing the main OMNIA slab. This monitoring allowed us to accurately record completed tasks and compare them with the original schedule. Analysis of the results revealed a 12-day delay in the schedule due to certain unfinished activities. This delay was swiftly identified and analysed, enabling us to make appropriate adjustments and improvements to the schedule. Our monitoring and adjustment of schedules facilitated effective management of the construction project and timely detection and resolution of deviations from planned execution. All of the above was possible to implement sovereignly and comprehensively in the observed time with the help of an advanced BIM approach in the implementation phase, where the 4D BIM model served as an object, information and communication digital model.

Due to unfinished works on the time side, the latter also had an effect on the cost side, where it turned out that the realized costs were lower than the planned ones in the observed time. Of course, it must be emphasized that this is a logical consequence, but it represents only an intermediate one-month scenario in the implementation of the construction project as a whole. Even in this case, the advanced BIM approach effectively and quickly illustrated the current state of costs compared to the planned costs, which provides a comprehensive overview of the cost flow in the implementation phase. The 5D BIM model is an indispensable source of information when monitoring progress on the cost side.

In the discussion of the results of the construction monitoring research with the BIM approach on the practical example of the Rotovž Center project, more precisely the building of the Library in a one-month period, we can summarize the essence that this is an example of good practice for everyone who undertakes the use of the BIM approach in the implementation phase of construction projects.

As a conclusion, we can state as an advantage that the monitoring of construction with the help of 4D and 5D BIM models is effective with always updated data that is accessible to everyone involved in the implementation. In this way, the management of construction projects acquires new dimensions, which ensures active communication and timely elimination of execution errors. The above contributes to eliminating or at least reducing the identified problems mentioned in the introduction, i.e. raising the level of digitization in the construction industry and also effective and productive engagement of employees to fill the gap of personnel shortage in the construction industry. The main goal here is to enable efficient management of construction projects with a modern BIM approach, which will successfully cope with the problem of timely completion and within the agreed budget in the implementation of construction projects. We are also aware that this research with a practical example does not reflect the universal state of implementation of the BIM approach in the construction phase, and thus additional research is needed, with a larger number of construction projects and a longer observed period, especially throughout the entire construction period, which is our main focus to continue research in this area.

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The Potential Of Artificial Intelligence In The Construction Industry: The Case Of Large Language Models

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Abstract:

Artificial intelligence (AI) is a rapidly developing field that is receiving a lot of investment and is becoming a part of everyday life. The speed of development and technological breakthroughs evoke mixed feelings, require rapid adaptation and pose legal, ethical, and regulatory challenges. Construction is a traditional industry with unique projects, many stakeholders, complex collaboration, high costs and liabilities, which makes the challenges of using AI even greater. The adoption of AI in this industry has been slower due to its conservative nature, but research shows that its use is increasing. In the first part of the paper, we discuss the definition and classification of AI as well as the benefits and current use cases of AI in the built environment. In the second part, we focus on Large Language Models (LLM) and discuss the potential of using AI-driven chatbots to visualise houses and retrieve information from regulations and technical plans. We tested several popular chatbots using different generative pre-trained transformer (GPT) models and compared the results. The results showed that the different GPT models performed differently depending on the input data we provided, and the type of output data requested. However, no tool completed the assigned tasks flawlessly, therefore the use of AI only makes sense if the user can recognise errors and provide correct guidance.

Keywords: *artificial intelligence; built environment; large language models; generative pre-trained transformers*

Introduction

The term artificial intelligence (AI) has been used so frequently in recent years that it can be found in the news, papers, social networks and even in everyday conversations. Due to the broad spectrum of all areas that the term is associated with, the realisation that the use of AI in everyday life is inevitable is slowly taking hold. The rapid pace of development has led to both positive expectations as well as rejection and fear of what this technology could bring. As the term is widely used, ignorance can lead to misunderstandings about what AI is and what it entails. It is important that scientists, developers and society understand both the advantages and disadvantages of such technology, its purpose and its current benefits. One of the areas where AI can be utilised is the built environment. In recent years, the use of AI has increased in certain areas of the industry. As more digital tools and information technologies are being introduced through development and digitalisation, the use of Building Information Modelling (BIM) tools, process automation techniques and AI is consequently increasing to increase productivity and efficiency in the industry (Saka et al., 2024).

This paper is structured as follows. After the introduction, the second section of this paper provides a general introduction to AI. The third section deals with the current use of AI in the built environment. The fourth section describes the role of Large Language Models (LLM), which are now widely used. The fifth section looks at the potential of AI for applications in architecture and construction and examines whether the use of AI could improve the way engineers and architects work. Areas explored include the use of AI to determine the appearance of single-family houses and the retrieval of information from regulations. The sixth section is dedicated to discussion and the final section presents the conclusions. The results of the paper can serve as a decision-making tool for companies or individuals considering the use of AI in their work in the construction industry.

Points of departure

The term AI refers to a broad field of technology such as cognition, machine learning and deep learning, hardware or software human interaction, emotion recognition, decision making (Lu, 2019) and natural language processing (Gradišnik et al., 2020). AI technology is already well developed (Yuan et al., 2020) and aims to solve everyday challenges (Gradišnik et al., 2020). The greatest potential for its use lies in areas where people perform repetitive or time-consuming tasks. In such work environments, AI could contribute to the automation and optimisation of processes.

In recent years, AI has changed our everyday lives (Huang et al., 2019), with current applications in the automotive industry in the form of autonomous vehicles (Li and Xu, 2001), financial markets (Feng et al., 2001), healthcare (Ravi et al., 2017), online commerce in the form of product recommendations (Erokhin, 2019), banking (Anyoha, 2017), the media industry (Nunavath and Goodwin, 2018), smart payment systems (Kullaya Swamy and Sarojamma, 2020) and cybersecurity (Evropski parlament, 2021). It is predicted that in the future, AI will be used in all phases of the software development cycle to reduce the burden on developers (Gradišnik et al., 2020). The best-known examples of AI-enhanced software are Alexa and Siri as home personal assistants (Mintz and Brodie, 2019).

The European Union considers the development of AI a priority, as it will play a key role in the social and economic digital transformation of Europe (Evropski parlament, 2021). It is predicted that the use of AI in the workplace could increase employee creativity and productivity by up to 40% (Accenture, 2016). The largest companies such as Google, Microsoft, IBM (Shi et al., 2007), Amazon and Facebook have also set up development departments for this purpose (Lufkin, 2017). In addition to large companies, AI is also used by smaller companies in their sectors, for whom neglecting the use of AI would mean missing out on business opportunities (Gradišnik et al., 2020).

11. 1 Areas of artificial intelligence

According to (Mills, 2016), the field of AI is categorised into machine learning, natural language processing, expert systems, vision and speech, planning and robotics (Figure 1). For the purposes of this paper, machine learning, natural language processing and vision are briefly introduced.

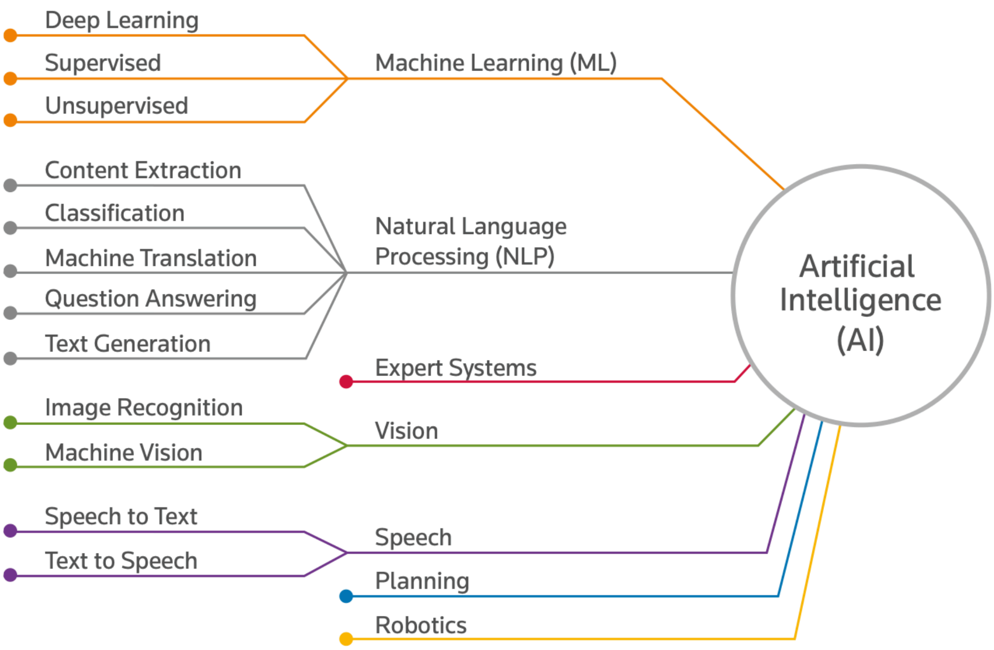

Figure 1. Areas of AI (source: (Mills, 2016)).

1. **Machine learning** is the ability to teach computer programmes to solve tasks that are narrow and specific. The underlying data is the basis on which the computer learns and makes decisions. Machine learning is categorised according to the degree of control exercised during learning.

   - Supervised learning: It is used to classify data into predefined classes. The name is derived from its properties: learning is called supervised because the quality of knowledge can be controlled and the machine learns on data with known target values. In supervised learning, the programme performs the tasks of regression and classification, which are sub-areas of supervised learning. In regression, the computer learns to predict the relationship between the dependent and independent variables, and in classification, the computer learns to categorise the data into predefined classes (Delua, 2021).
   - Unsupervised learning: This type of learning is used when the structure of the data or the relationships between the data are unknown. In unsupervised learning, three methods are used to process unlabelled data. (1) clustering, where the algorithm categorises the data into groups, (2) association, where the algorithm looks for different rules between the data to classify them, and (3) dimensionality reduction, where the algorithm reduces the number of inputs (Delua, 2021).
   - Deep learning is a subset of machine learning methods that are based on neural networks. Neural networks enable data processing modelled on the human brain. In fact, the neurons in neural networks communicate with each other in a similar way to the neurons in the human brain. Neural networks consist of several layers, each of which consists of many neurons that are connected to each other. Each neuron has a weight and a threshold. When the neurons in a layer exceed a threshold based on a sufficient number of corresponding numerical data values, they are activated and pass the data on to the next layer in the neural network. Neural networks consist of at least three layers, the input layer, the output layer and a hidden layer (IBM, 2021b).

- **Natural language processing (NLP)** is a form of artificial intelligence that refers to the ability of a computer to understand and produce text and speech in the same way as a human. NLP combines computational linguistics with statistical and machine learning models. Natural language processing is currently used in spam detection, virtual chat rooms, machine translation and text summarisation (Holdsworth, 2024).

- **Vision** is a subfield of AI that enables computers to extract relevant information from videos, photos and other inputs. Compared to human vision, fast data processing using algorithms and cameras enables much faster extraction of this information. The computer recognises patterns in the input, which it can then use to determine the content (Microsoft Azure, 2024). Computer vision requires a large amount of data to successfully extract information. It uses machine learning to process this data and learn to recognise it (IBM, 2021a).

1.1.2 Artificial intelligence & construction industry

There are many problems in the construction industry that cannot currently be solved using traditional methods. Therefore, in solving more complex problems, the use of AI comes into play, which has proven to be useful so far (Lu et al., 2012). As a result, it is being used more and more frequently due to its good results (Lagaros and Plevris, 2022).

Potential areas of application for AI in architecture, engineering and construction (AEC) include the design of high-rise and low-rise buildings, water supply systems and dams (Aluga, 2023) and the field of earthquake engineering (Lu et al., 2022). AI is also used to predict construction delays and costs, optimise resources, support project management and planning, etc. In this context, generative pre-trained transformer (GPT) models are playing an increasingly important role, whose visibility in the construction industry has increased with the development of the ChatGPT model (Saka et al., 2024). Approaches currently in use include various optimisation methods, machine learning, neural networks, combinations of different approaches (Lagaros and Plevris, 2022) and large language models or, more specifically, generative pre-learned transformers (Saka et al., 2024). All approaches are developing rapidly and it is expected that the rapid development of hardware will further accelerate the evolution of approaches (Lu et al., 2022).

Below are some areas of the construction industry where AI has shown potential and is already being used:

- **Road renovation and maintenance**. Lack of funding is one of the main reasons for poorly maintained roads (Alqaili et al., 2021). The increasing number of roads in areas with increasing urbanisation (Bao et al., 2021) makes the optimisation of resources in this area of paramount importance. For optimisation purposes, Han et al. (2020) have developed a tool based on machine learning and a combination of different algorithms, using a clustering algorithm and the PageRank algorithm. The algorithms enable the tool to group roads according to the urgency of their remediation.

- **Project planning.** Good planning in the initial phase of a project, before it enters the implementation phase, is one of the most important factors affecting the cost and schedule of the project. GPTs have proven to be useful tools for the planning phase of a project that can help manage or control the project in terms of planning processes. In this way, GPT models can contribute to lower costs, higher productivity and project sustainability (OpenAI, 2024b; Saka et al., 2024).

- **Earthquake engineering.** Approaches such as pattern recognition and machine and deep learning are gaining ground in earthquake engineering (Lu et al., 2022). Earthquakes can have catastrophic consequences by endangering human lives and causing property damage. After an earthquake, the damage caused must also be repaired and must therefore first be correctly identified. The most common method currently used to record building damage after earthquakes is human inspection. This method is time consuming, and the quality of the inspection depends on the experience and knowledge of the inspector. In the field of earthquake engineering, Junior et al. (2021) have developed a method based on a deep learning model, object segmentation and pattern recognition that can be used to identify cracks in ceramic facade elements. Silva and Schwerz de Lucena (2018) have developed a method based on neural networks, deep learning and the use of unmanned aerial vehicles that can also detect cracks in concrete surfaces. Cracks in concrete pose a risk to the corrosion of the reinforcement and thus impair the load-bearing capacity of concrete elements and must be recognised in good time. The method correctly identified cracks in 92.27% of cases. Liao et al. (2021) developed a method that can identify and distinguish ordinary shaking from shaking that occurs during an earthquake based on a deep transfer learning model.

- **Sustainable construction**. Energy consumption has demonstrably increased over the years (Ritchie et al., 2024), which has led to an increasing need to optimise energy consumption and build sustainably. To this end, Guo et al. (2022) have developed a model based on genetic algorithms for optimisation and correlation analysis methods. The model contains two different methods that help to design more energy-efficient buildings. The first method generates floor plans for the energy optimisation of the building, while the process uses parameters that influence the building's energy consumption, such as the ratio of window to wall area and the shape of the building, to make decisions. The second modelling method is used to optimise the building assemblies and facilitates decisions on the materials, composition and thickness of the external walls of prefabricated houses.

- **Modelling**. In the field of modelling, computer software is no longer only used to analyse the solutions specified by the designer, but also to create solutions. This includes algorithms that can generate different solutions to a given problem, from which the designer selects the most appropriate one depending on the nature of the project. One approach to finding such solutions is generative design. In practise, a generative design approach has been used in the field of modelling to find the most suitable shape for the wood fibre components. The main criteria for determining the most suitable shape were the optimal shading of the elements throughout the year, the most cost-effective construction of the building and the emphasis of the elements on appearance. It turned out that the generative approach led to a reduction in material consumption compared to the classic iterative approach to finding a solution. In this approach, the role of the designer was mainly to define the problem and select the final solution, while the algorithms were responsible for the intermediate steps (Gradišar et al., 2021).

11.2 Large Language Models

The field of large language models (LLMs) includes models that understand, predict, generate or summarise content. They are used in applications to retrieve the desired information from users. Language models are designed to generate and understand text like a human (Liao et al., 2021), which makes them generative artificial intelligence (Kerner, 2024a).

The AI architecture of LLMs is based on deep learning techniques and larger databases compared to smaller language models, making large language models more powerful. Large language models usually work with at least one billion parameters, the largest models even with significantly more. For example, a version of the ChatGPT model called GPT-3 runs with 175 billion parameters, the Megatron-Turing NLG 530B model runs with 530 billion parameters (Merritt, 2022) and the largest currently developed model called GLaM runs with 1200 billion parameters (Robnik-Šikonja, 2023). With a high number of parameters, software can generate human-like content (Nvidia, 2024), which is why language models are also part of generative AI (Kerner, 2024a).

In the area of LLMs, GPTs such as ChatGPT should also be emphasised. They are characterised by a special architecture called Transformer (Green, 2023). In combination with deep learning, models with this type of architecture use a mechanism of self-attention that allows them to assign different levels of meaning to the input data (IBM, 2023). GPTs are currently among the newest and most powerful models and are consequently displacing models with convolutional neural networks and recurrent neural networks (Merritt, 2022).

Before the introduction of GPTs, neural networks needed large databases of labelled data to learn. In databases with GPTs, labelled data is no longer needed, which contributes to their time and cost efficiency. Models with a transformer architecture can process data in parallel and are also faster compared to previous models (Merritt, 2022). In addition to self-attention, positional encoding is an innovation in these models. With positional encoding, each word is given a unique number so that the model does not need to look at the sequences of individual words, but instead uses the number to obtain information about the sequence of tokens at the time of input. When processing large amounts of data, self-attention allows the model to identify the essential parts of the input without having to pay equal attention to the entire input (Nvidia, 2024).

The learning of LLMs is a multi-step process. In the first step, the model learns unsupervised on unlabelled examples and forms relationships and concepts between different data (Kerner, 2024a) that may be undetected (Nvidia, 2024). In the next step, supervised learning is applied to data that has already been labelled by the model so that the model can learn to correctly identify different concepts. In a final step, deep learning techniques are applied to the model in combination with the Transformer architecture. Based on what it has learnt, the LLM can generate new text, summarise it or answer the question asked (Kerner, 2024a).

11. Potential of using large language models

We examined the potential of using AI in the daily work in AEC. We investigated the potential of using AI in architecture to create conceptual designs and the potential of using AI to summarise building and architectural regulations.

11.1 AI applications and services used

We used the following AI applications and services in our research:

- **ChatGPT** (OpenAI, 2024a) is a form of a large language model that uses natural language processing and can generate content, which also makes it a form of generative AI (Hetler, 2023). GPT refers to the transformer architecture that characterises generative pre-learned transformers. A paid version of GPT-4 was used, which enables the input and analysis of images. The generative tool DALL-E is integrated into the model so that the ChatGPT model can generate images indirectly from the input text. ChatGPT has up-to-date data through access to the web.

- **Leonardo** (Leonardo AI, 2024), **Gencraft** (Gencraft, 2024) and **Freepik** (Freepik, 2024) are generative tools that are enriched with artificial intelligence and can generate images based on the input text. The ability to generate content also classifies them as forms of generative AI. All three tools were used in the free version.

- **Copilot**, originally named Bing Chat (Microsoft, 2024), is a type of large language model that utilises natural language processing. In the free version, it is integrated into Microsoft Bing, Microsoft Edge, Microsoft 365 applications and Windows. Internet access enables the model to utilise the latest data from the web. It uses the Prometheus model, which has been adapted to the GPT-4 model (Ojukwu, 2024).

- **DALL-E** (OpenAI, 2024b) is a tool developed by OpenAI that can generate an image based on text entered by the user. It works on the principle of adding and removing noise, which classifies it as a diffusion-based generative AI model (Kerner, 2024b). In our study, DALL-E version 3 was used indirectly as an integrated tool for image generation in the ChatGPT and Copilot models.

11.1 The potential of AI for creating conceptual designs

When evaluating the potential for design concepts, we focussed on the freely available services ChatGPT (GPT-4 version), Leonardo, Gencraft and Freepik. As Copilot and ChatGPT use the same version of the DALL-E model to generate the images, we have omitted Copilot in this case.

We see the advantages especially when searching for ideas (e.g. in case of a creative block), when lacking time or when working directly with clients to visualise ideas faster. During the research, the conformity of the generated images with the specified requirements and descriptions of the expected appearance of single-family houses was checked.

We explored the potential by giving each tool instructions related to a description of the appearance of the typical appearance of modern single-family houses currently being built in Slovenia. This was repeated four times, each time with a new set of instructions. The generated images were checked for compliance with the instructions, with each version of the instructions consisting of individual elements. Each tool generated 5 images for each instruction, so a total of 80 images were generated (4 tools, 4 rounds, each tool provided 5 versions, i.e. 4*4*5=80). All instructions included requirements for a realistic appearance, sunny weather, a village as a setting and grass on the properties to enhance the clarity of the images. All instructions were given in English.

For example, the first instruction was: *'Create me a realistic image of a one-family house with 2 stories, in the village, white facade, gable roof of anthracite colour, balcony in the first floor, roof windows, sunny weather, modern style, garage, grass outside, big sliding windows in the ground floor leading outside.'*.

Table 1 shows the results of the first instruction. In this case, the instruction consisted of eight different elements. The numbers indicate how often the tool used managed to fulfil each part of the instruction, out of a total of five attempts, with 5 being the highest and 0 the lowest. The column on the far right of the table shows how often all tools together succeeded in fulfilling the respective condition. The bottom row of the table shows how often each tool fulfilled all the conditions of the first instruction. A total of 20 images were created for the instruction.

Table 1: Compliance of the generated images with the instruction of the first query.

Instruction/Tool	ChatGPT	Leonardo	Gencraft	Freepik	Total of 20
Elevation of the building	3	5	0	3	11
Façade	3	5	3	3	14
Environment	5	3	5	2	15
Roof	5	5	4	5	19
Balcony	3	5	1	5	14
Roof windows	4	5	5	5	19
Garage	5	4	1	2	12
Sliding windows	4	5	4	5	18
Total (of 40)	32	37	23	30	

The results showed that Leonardo was the tool that met the conditions most often, with 93% (37 out of 40 points) of the instructions being followed correctly, while Gencraft was the tool that met the conditions least often (only 58%). An example of an image generated by Leonardo can be found in Figure 2.

Figure 2. An example of an image created with the tool Leonardo for the given set of instructions.

Similar analyses were carried out three further times. Table 2 shows the percentages of correctly generated tool elements. The last row shows the average percentage of correctly generated elements of each tool in all four instruction examples. The rightmost column shows the average percentage of correctly generated elements for all tools in the instruction examples.

Table 2: Compliance of the generated images with the instruction of all queries.

	ChatGPT	Leonardo	Gencraft	Freepik	Average
1. example	80%	93%	58%	75%	76%
2. example	83%	77%	66%	71%	74%
3. example	63%	83%	43%	70%	65%
4. example	66%	66%	66%	47%	62%
Average	73%	80%	58%	66%	

The results show that Leonardo generated the highest percentage of all elements correctly, followed by ChatGPT and then Freepik. The lowest percentage of all elements was correctly generated by the tool Gencraft. According to the values in the tables, Leonardo and ChatGPT are the most suitable tools for quick conceptual designs, while Gencraft is the least suitable.

11.1 The potential of AI to summarise building and architectural regulations

In the architecture and construction industry, regulations play an important role in the work. For this research, the regulations on project documentation (Official Gazette of the Republic of Slovenia No. 0071-264/2007: 1-17), which were adopted in 2008 and expired in 2018, were used to assess the potential of using AI in working with regulations. The expired validity date made it easier to verify the source of the tools' information or to ensure that they were not referring to updated information from the internet when responding. The use of tools to retrieve information from policies could significantly speed up the retrieval of information in longer documents and increase user productivity.

The tools used to assess the potential in this case were GPT-4 and Copilot. To validate both tools, each tool was asked four questions about a short PDF document. To pass the validation, all questions had to be answered correctly. The tools were then asked questions about a more comprehensive document, namely the Slovenian Project Documentation Ordinance, which was adopted in 2008 and expired in 2018. 18 questions were asked for each of the two models. Of these, 10 questions related to the retrieval of information as specified in the regulation, while the remaining 8 questions related to various situations, such as missing elements in certain parts of the project.

For the situations, the tools were asked questions about the compliance of the project with the regulation. In the case of ChatGPT, this was checked by entering the PDF document of the regulation directly from the computer. Copilot did not allow direct document input at the time of the investigation, so in this case the PDF document of the regulation was opened in the Edge browser. The Copilot tool integrated into the browser was then used to enter questions about the open document. All questions were asked in Slovenian, the language in which the official document is written.

Table 3 shows the correctness of the answers of the two tools. The left column of the table shows the questions entered and the top row shows the two models used. The answers to the questions were scored according to their correctness, with points assigned to each answer as follows.

- Zero points: The tool gave an incorrect answer, even after additional guidance.
- One point: The tool gave an incorrect answer the first time, but a partially correct answer after additional guidance.
- Two points: The tool gave an incorrect answer the first time, but a correct answer after additional guidance.
- Three points: The tool gave the correct answer without instructions.

Table 3. Scoring answers.

Question	ChatGPT	Copilot
How are project documents classified under the regulation?	3	2
Which essential requirements does the designer have to meet when designing?	3	2
What information do I need to include on the outside of the covers of the executive folders?	3	2
What should the technical report contain?	3	1
What must be included in the management file if the building is to be removed?	3	0
What should be included in the technical report for an implementation project?	3	2
Which studies must be included in the project implementation phase?	0	0
What needs to be done if the construction does not deviate from the design for the building permit?	3	0
What does a building permit project for a single-family house need to include?	3	0
Does the investor have to include digital project documentation with the project to obtain a building permit?	3	2
Can an investor obtain a building permit without submitting the digital part of the project documentation?	3	2
Can the outside of the cover of the project folders be without the date of creation of the project?	3	2
Does the technical report meet the requirements if it does not provide descriptions of the designer’s calculation methods and assumptions?	3	3
Is a management file without plans compliant with the regulations if it is a building removal project?	3	2
Does the technical report comply with the regulations in relation to the design-build document if it does not contain an inventory of the quantities of materials?	3	2
Does the project comply with the regulations if it is not accompanied by a safety plan?	3	1
What needs to be done if there are changes in the construction, but they do not affect the building permit?	3	0

Does the project for obtaining a building permit for a single-dwelling house comply with the regulations if it does not include a structural plan?	3	0
Total	**51**	**23**

As shown in Table 3, the ChatGPT tool scored 94% of the possible points, with one question where the tool referred to the wrong chapter of the regulation being answered incorrectly. There were no partially correct answers and no additional clues were required to answer. Copilot scored significantly lower with 43% of the total possible points. Copilot did not answer a single question better than ChatGPT, but for 10 questions the tool provided the correct answer after guidance. The first answer attempt usually contained information that was not included in the regulation, and some answers were long and nonsensical. When answering the questions, Copilot initially mostly took information from its own database, even if there was an indication that it was an open document. After the first incorrect answer, it answered correctly by clicking on the function: "Answer from this page instead". In some cases, even on the second attempt, there was an indication that the answer referred to an open document, although the answer was completely different. For question 4, the tool partially answered correctly after additional guidance, in the only case where the answer was essentially correct but the tool quoted the wrong part of the regulation.

The results show that the ChatGPT model is much better suited for processing documents and is also suitable for work related to summarising information from regulations. The answers were concise, meaningful and largely correct, so that no further instructions were required. The main reason why Copilot needed guidance was that the initial response to the question usually indicated that it did not relate to the open document but received information from elsewhere. Using Copilot is therefore slightly less suitable for reading the regulations as the user also needs to be much more knowledgeable as they need to constantly check the answers and provide guidance, which can be more time consuming than if the user searches for the information manually.

11.1 Discussion

In recent years, there have been predictions that advances in AI will revolutionise both daily life and the corporate workplace. However, it is important to point out that despite its great potential, current capabilities and ease of use, AI technology is not without its drawbacks. Insufficient information about the advantages and disadvantages can lead to incorrect use of this technology and increase the risk of negative consequences.

The advantage of AI is that it is affordable for users once it has been developed and implemented, which saves money. AI can replace physical labour, but in a way that allows employees to focus on other, more human-friendly and less time-consuming work. The use of AI has the potential to reduce the human error factor, but only if it works well. The user can utilise AI around the clock, every day of the week (Bhosale et al., 2020). With the introduction of AI in the workplace and everyday life, there is a need to develop new professions such as AI ethics officers, analysts, software developers or AI content creators (Forbes, 2023). A major advantage of AI is the short learning time required to perform certain tasks. In fact, AI-enhanced hardware or software can accumulate more knowledge in a short time than a human can in a lifetime (Mintz and Brodie, 2019).

The biggest disadvantages of AI are the high costs and complexity of its development and research. If it replaces too large a proportion of the workforce, it can lead to unemployment in companies. In teamwork, AI does not contribute to team cohesion or team spirit. Major performance problems can also occur in tasks for which AI is not sufficiently trained (Bhosale et al., 2020).

The challenges or constraints that arise with large language models are manifold. Among the biggest obstacles are financial, as such models are expensive to learn and develop (Kerner, 2024a), but also consume large amounts of electricity and consequently contribute to carbon dioxide emissions (Robnik-Šikonja, 2023). To learn them, a sufficiently large database is needed. In some cases, this data may be private and confidential or may not yet exist for a particular learning (Kerner, 2024a).

Another important drawback is the bias of the model (Merritt, 2022), which results from the large amount of data on which the model learns (Barath, 2024) and which occurs when the model overfits the training set. The model can also give incorrect answers if the user queries data for which the model has not been trained (Merritt, 2022).

The generation of offensive content can also pose a problem for models (Merritt, 2022). For the ChatGPT model, the editors addressed this problem by correcting the responses to avoid offensive content by developing and adapting a new model that evaluated the responses of the first model to assess their quality. Also, some additional controls were built into ChatGPT to detect inappropriate questions, inappropriate vocabulary or politically sensitive topics (Robnik-Šikonja, 2023).

Models can also be closed or misleading. A model is categorised as closed if the data used to learn the model is unknown. A misleading model means that the model does not know if there is incorrect or unreliable information in the answer. The model may also experience hallucinations during text generation, where completely fictitious content is generated (Robnik-Šikonja, 2023).

11.1 Conclusion

The results of the preliminary investigations show that the potential of AI for use in different areas varies. In the case of determining the appearance of single-family houses, ChatGPT and Leonardo proved to be suitable for the task, as they were able to generate most of the requirements appropriately. However, the task also showed that the additional time required for multiple generation had to be considered when working with the tools. The images generated were not always found to be fully suitable for all tools and the work would have required several different images to be generated for the same instruction. The longer time required for multiple generations or subsequent image corrections can make the tools less suitable for working directly with clients, but they can still be used when working independently to find ideas or solutions. Gencraft and Freepik have been found to be slightly less suitable for use in the field due to poorer results. All the tools used are currently not reliable when it comes to finding solutions for details, as these are often cumbersome or incorrectly implemented. The tools are currently better suited to generating the more common appearance of houses, as the number of correctly generated elements was lower for the less conventional designs.

ChatGPT proved to be more suitable for the tasks of our research compared to the Copilot tool when querying information from the regulations, as it mostly provided correct answers. The Copilot usually provided incorrect information or referred to incorrect sources, and hints were often required when answering. When using Copilot (and any other AI tool for that matter) at work, the user should have sufficient knowledge to correctly recognise an incorrect answer and provide appropriate instructions, which can be time-consuming.

The use of AI in the construction industry still offers much room for improvement. Its current utilisation advantage lies mainly in working with text and many improvements would still be needed. As the field of AI is developing rapidly and is being funded intensively, these improvements can be expected in the near future.

However, our research has not addressed the issues of security and privacy when using AI tools, which is particularly important as we do not know where and how the data we input is processed and stored. This remains an open question for the future.

In the future, the potential of using large language models to utilise domain knowledge in construction needs to be addressed. The use of large language models to extract domain knowledge and apply previous solutions to new projects seems particularly interesting. However, as the use of AI also raises many security and privacy issues, which are also inevitably linked to maintaining a competitive advantage, LLM applications hosted by users themselves will be particularly interesting, as appropriate security measures and regulations can ensure that large language models operate in a controlled environment and benefit users in a secure and responsible manner.

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Impacts and Potential of BIM and Artificial Intelligence on Productivity in Construction Project

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Abstract:

Building information modelling has also changed over the last period due to the increasing digitalization in the construction industry. The available information technologies provide opportunities for streamlining work and improving qualitative and quantitative results. As a result, a research question has been raised on the use and impact of modern technological solutions such as BIM and artificial intelligence tools in construction project management. The research discusses the issue of the use of BIM and artificial intelligence and their impacts on productivity in construction project management. The data collection was done through a questionnaire survey. The research sample consisted of participants in construction projects in Slovakia. The impacts on productivity in the use of BIM were monitored based on data from economic reports. The survey focused on the potential and assumptions of productivity impacts in Artificial Intelligence. Data analysis was carried out using selected statistical apparatus tools such as correlation and regression analysis. The results of the research indicate the positive impact of using BIM on productivity in construction project management and the impact of artificial intelligence on productivity in construction project management is positively perceived.

Keywords: *Building information modellin; Artificial Intelligence; construction project management.*

Introduction

Information modeling of constructions based on sufficient data and their processing is a prerequisite for successful construction projects of the 21st century. The need for data is undeniable (Johansson et al., 2014; Kršák, 2004; Marović et al., 2022; Knapčíková, 2024). Their use is necessary in every sector. However, adapting and customizing requires a lot of attention to some of the activities that the effort is to automate (Ikudayisi, 2023). What is important, new technologies representing potential and better options for sustainability in the construction industry, including from the legislative side (Píry et al., 2023; Margorínová et al., 2018; Jandacka, et al., 2022). Several research are devoted to the BIM problem (Russell and Norvig, 2016). However, several studies point to the assumption of an increase in productivity in the construction industry.

However, the Ai area is still unexplored. Some studies point to an effort to impotence into the construction industry.

Artificial Intelligence (AI), commonly known as AI, is a discipline within computer science dedicated to the creation and development of devices capable of executing tasks that typically necessitate human intelligence. Russell and Norvig highlight that intelligence includes learning, solving problems, and understanding language (Russell and Norvig, 2016). Bock describes that AI in the construction sector involves the application of advanced computational techniques such as machine learning, computer vision, and data analytics to enhance and automate different aspects of construction workflows. This covers activities from the design and planning phases to the control and monitoring stages of the project, also referred to as the operational phase (Bock, 2020). Lee indicated that AI in construction project management involves leveraging algorithms and machine learning models to examine large data sets, which improves decision-making processes. Monitoring key performance metrics can increase productivity (Lee, 2019).

In terms of resource optimization, including cost management, AI integrates technologies like machine learning and deep learning into construction project management systems to predict project outcomes, optimize the allocation of resources, and reduce expenses (Egwim et al., 2024).

Regarding the perception of AI as a means to boost productivity, streamline processes, efficiently utilize resources, and cut costs, AI acts as a tool for real-time monitoring and analysis of construction activities, resulting in higher efficiency and fewer human errors (Kamat, 2019).

Optimizing resources in managing construction projects is a crucial area where AI technologies bring significant advantages to the construction sector. Smith's research emphasizes generating various design options based on specific criteria and limitations, such as materials, costs, time restrictions, and other variables (Smith, 2020). This approach allows for planning possibilities through multiple simulations and iterations, ultimately saving labor, time, and resources (Johnson, 2019). Quantitative planning can leverage historical data. Efficiently processing large volumes of information, such as schedules and budget analyses, can lead to forecasts and the creation of timelines and cost plans based on the available data (Martinez, 2021; Davis, 2020). Additionally, risk planning is also based on quantitative forecasts and the use of extensive data for probabilistic risk prediction. AI can be valuable in this domain as well (Brown, 2022).

Safety in the construction industry is increasingly important, and artificial intelligence (AI) can play a significant role in enhancing it. AI can improve construction safety through predictive risk analysis and the monitoring of building conditions using data from IoT sensors and visual information. AI can contribute to safety in construction by predicting risks and monitoring conditions based on data from IoT sensors and visual data (Zhang and Teizer, 2018; Johnson and Clark, 2024).

Building Information Modeling (BIM) is a tool that significantly impacts key performance indicators positively (Mesároš et al., 2021). In the realm of AI, it represents a major new capability that further showcases the advantages of employing digital technologies in Industry 4.0. BIM and Artificial Intelligence (AI) are increasingly collaborating, leading to a notable transformation in the construction sector. BIM enhances visualization and primarily handles graphic data, but it also includes non-graphical information. This comprehensive approach improves planning, design, and construction management, leading to cost savings and increased project efficiency (Zhang et al., 2022).

Moreover, AI introduces advanced analytical capabilities to BIM. AI can process large amounts of data generated by BIM, offering better predictions and recommendations for design, construction planning, and infrastructure management, which positively affect key performance indicators. In the context of AI, this is a powerful new tool that further highlights the benefits of digital technologies in Industry 4.0. BIM and AI are increasingly working together synergistically, causing a significant shift in the construction industry. BIM enhances visualization capabilities and primarily deals with graphic data, but it also involves non-graphical information. This approach allows for better planning, design, and construction management, ultimately reducing costs and boosting project efficiency (Umývač, 2021).

BIM technology presents both challenges and opportunities. With effective data management, construction projects can be efficiently planned, managed, and executed. Data plays a crucial role in planning and managing construction projects. Digital technologies significantly improve these processes, making them more efficient. A significant advantage is the ease of making changes to plans and preparing multiple scenarios when necessary. This is particularly beneficial for evaluating construction project investments, as it allows for simulating and modeling various options in advance, considering economic and financial parameters (Kravanja, 2021).

Conversely, AI brings new possibilities to BIM through advanced analytical capabilities. AI can analyze the large volumes of data generated by BIM, offering better predictions and recommendations for design, construction planning, and infrastructure management.

Therefore, the basic research question is whether BIM and AI affect productivity in construction projects.

1. Methodology

- 12.1 Research aims and gap

The use of digital technologies in the construction industry is often the subject of several studies and research, which often point to the positive impact of these technologies. With further innovations in the planning and management of construction projects, the technological ones are also increasing, mainly in the use and impact on measurable indicators. BIM and AI technologies are a space for improvement in the planning and managing of construction projects as part of innovations. These indicators should be measurable, and procedures should be defiled. Using BIM and AI can bring many benefits but also challenges. As part of key performance indicators, choosing an important indicator for the sustainable and continuous achievement of construction project results is important. Productivity is one of them.

Productivity in construction project management is a crucial factor that impacts the success and efficiency of the entire construction process. In construction, *productivity* is the ratio between inputs (time, resources, labor) and outputs (product, completed tasks). High productivity, which is achieved through the diligent efforts of construction project managers and engineers, results in efficient use of resources and time, leading to reduced costs, quicker project completion, and superior-quality results.

The research aims to analyze the impact of using BIM and AI on productivity in selected activities. This means determining correlations between the use of BIM and AI tools and quantifying the impact on productivity outcomes in these activities.

Based on theoretical research and the most frequently used and currently available solutions, the following activities were selected, which were the subject of research:

- Generative design,
- Resource planning,
- Cost planning,
- Schedule planning,
- Component production.
- 12.1 Data collection

A questionnaire survey, specifically designed to address the needs of the construction industry in Slovakia, was conducted. The survey targeted participants involved in construction projects implemented in the country. The research sample, carefully selected, included construction projects of various sizes. The respondents, all experienced project managers, were distributed across different age groups (Fig. 1): 30% aged 18 to 35, nearly 48% aged 36 to 50, and the remaining 21% were older.

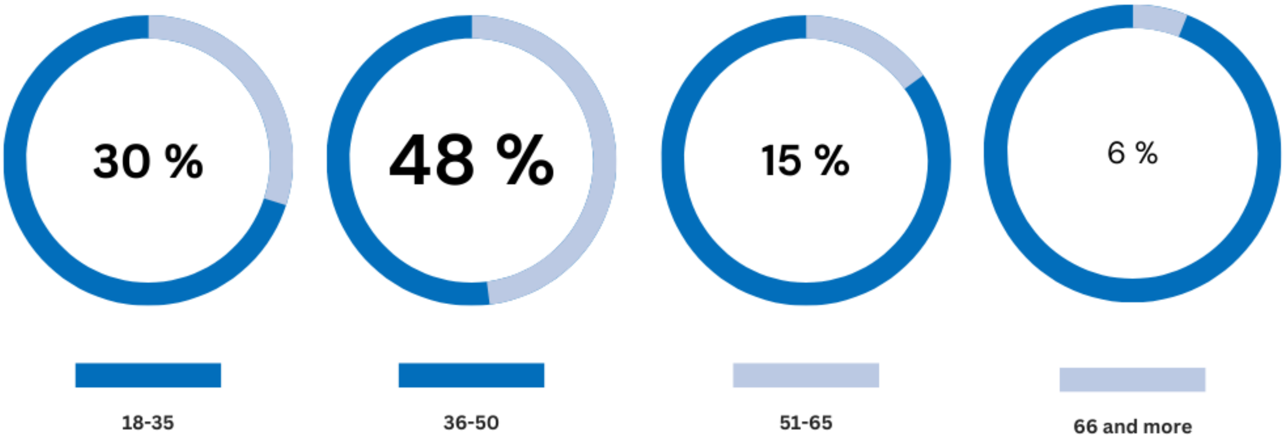

Figure 1. Research sample by age

Respondents answered questions about the extent of BIM and AI usage and their impact on productivity. The data was measured using a Likert scale (from 1 to 5, with 5 being the highest value) and was sourced from official documents, such as accounting records or other management reports, which are considered reliable and serve as the basis for decision making. The collected data were then analyzed and processed in the MS word environment.

12.1 Data processing

Data processing was secured using MS Excel. The data were evaluated within the basic indicators of descriptive statistics. An arithmetic mean was created from the data for each group. From this, an impact measure was created for a representative group of activities. This was realized for the results of using BIM as well as AI.

The results were compared among themselves in terms of groups and activities. As well as the comparative impact between BIM and AI. Subsequently, the data were subjected to correlation and regression analysis, where relationships - correlations between the use of technology and the impact on productivity in individual activities were examined. These correlations were subsequently quantified, and the results verified based on regression analysis, which was supposed to confirm the statistical significance of the results. If the correlation analysis values are close to 1 and – 1, it is a strong correlation. Due to the nature of the data, Spearmon's correlation analysis and Spearmon's correlation coefficient were used.

12.2 Research limitations

The research problem solves this topic locally. Since of the research sample, it is necessary to mention that the research results result from the data of this research sample and generalizations may point to a trend but may not reflect the pitfalls of other construction markets or conditions. Even though several results are marked as statistically significant based on the statistical tools used, it is possible that they do not reflect all environmental conditions for the management of construction projects.

Another limitation of research is the fact that AI is still poorly researched, and its tools are being improved every day. This is the assumption and prediction of the development and implementation of advanced technology, but it may not represent the identical development and progress as the last period.

Among the limits of the research, the methods used and the focus of the study, which has a socioeconomic character, can also be considered. These are not measurable indicators that can be quantified based on a specified unit and measurement tool, but data from reports and subjective perception based on strict recommendations. These data can be considered objective, but every use of statistical methods has its limits and pitfalls.

Finally, there are regional differences between construction projects. Internationally, the results may have similar results, but different construction markets may differ in several conditions and factors, which may again lead to a different application of the results in practice.

The structure of the research sample can also have an impact on the research results, especially given the innovative and technological theme, it can also be the age of the respondents. Since a significant part of respondents (almost 80% of respondents) are under 50 years of age, this issue was addressed in the target group for potential use. However, the results may not reflect the situation where the participants in the construction project are older people who may not have the same digital skills, and the same attitude and willingness to innovate.

1. Results and discussion

The issue of productivity and the introduction of innovations in the management of construction projects is a challenge for all participants in construction projects. Shortening the delivery of a construction project, optimizing costs and other resources, and providing qualitatively better construction solutions represent the goals of successfully managing construction projects. Implementing digital technologies in the form of BIM and artificial intelligence has taken on a new dimension in the last decade. From the point of view of motivating the introduction of digital technologies into the construction project management process, productivity is one of the main drivers. Therefore, the expectation that we will increase productivity through implementing and using BIM and artificial intelligence is an essential point of view.

Research has shown a significant rise in the use of BIM technology. However, the research sample also indicates that the potential of using BIM is yet to be fully exploited. The recent focus on the connection between BIM and artificial intelligence, which promises significant process automation in the construction industry, is a key trend in construction project management.

The use of BIM has demonstrated a significant positive impact on productivity, as evidenced by the data from the conducted research. In the following figure 2, you can see the substantial impact of using BIM on selected activities, providing a strong reassurance about the benefits of digital technologies in construction project management.

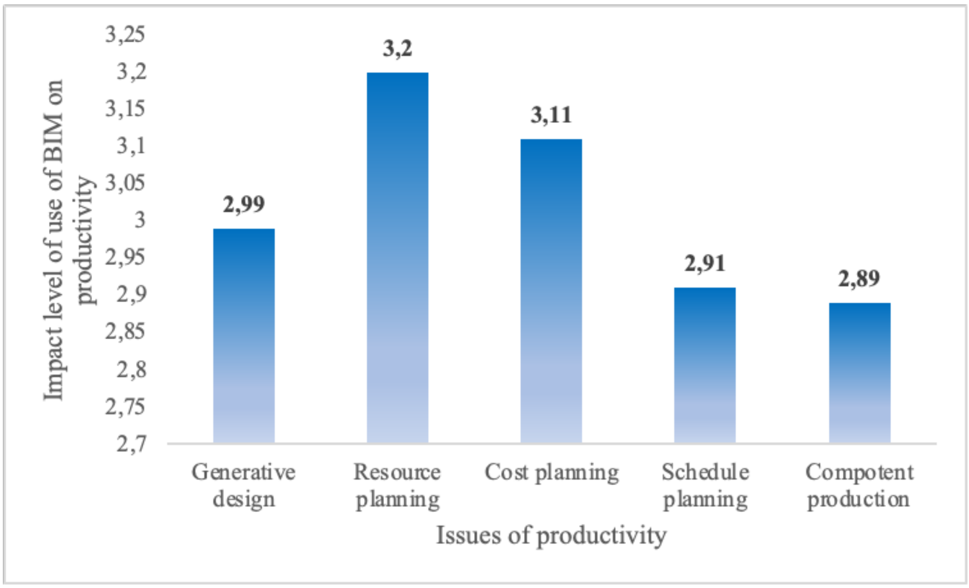

Figure 2. Potential impact level of BIM using in construction project management

On a scale up to the highest value of 5, which represents the highest level of impact, the use of BIM represented a significant impact on resource planning with a value of 3.20, as well as on cost planning with a value of 3.11 and 3D modelling of construction solutions with a value of 2.99. These values can be considered high. The impact on productivity in this area is significant—component production up to 2.89. Lower values recorded an impact on the project's planning and delivery time at the level of 2.91.

By using BIM in the planning and managing of construction projects, costs and other resources are optimized. It is based on better planning of construction details, which leads to lower material consumption and, thus, to cost optimization. On the contrary, the 3D modelling of structural solutions is time-consuming; thus, the positive impact should have been recorded or significant. From a qualitative point of view, these are more elaborate details that, during implementation, can save material and optimize costs associated with construction, material consumption, and a higher level of quality, which leads to fewer defects in the construction project. On the contrary, it increases the planning time, and the impact could be more optimistic regarding saving time.

Another figure 3 describes the potential positive impact of artificial intelligence in the management of construction projects. According to the research sample, the use of AI has a positive effect on productivity in time planning and cost optimization. The use of AI should also ensure a significant impact from the point of view of productivity in the field of generative design. Overall, all monitored areas were highly rated, with a value of 3 or more.

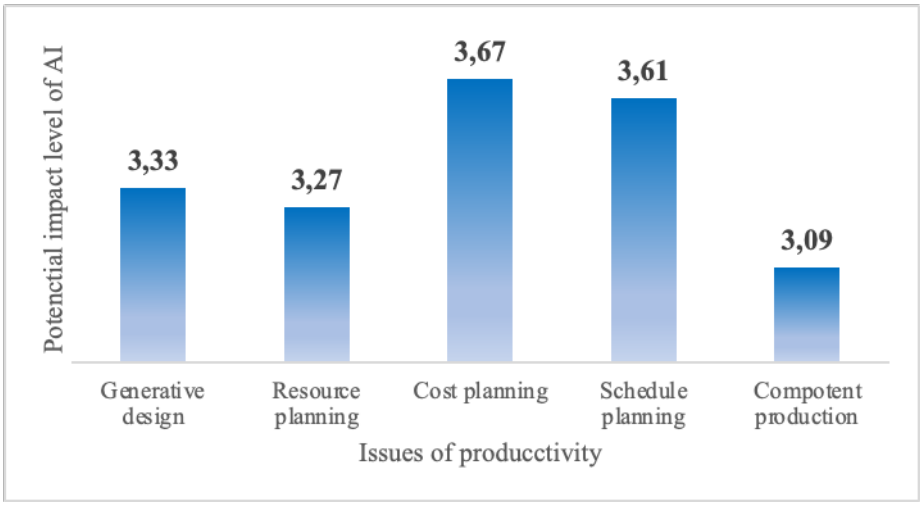

Figure 3. Potential impact level of AI using in construction project management

Regarding generative design, AI can work quickly, but how exactly remains? According to the respondents, input information is the basis. With a document description of the requirement, the outputs are better quality. The impact on productivity is also expected in optimizing cost planning, resource planning, and time planning. In general, AI can significantly speed up these processes, which impacts productivity.

Within the research sample, we found strong correlations between the use of AI in individual activities within the planning and management of construction projects and the impact on productivity in these activities during the design and preparation phases. The following table details these correlations. A positive and strong correlation between the use of AI and the impact on productivity was found in the design phase for generative design at the level of 0.679812, resource planning at the level of 0.544203, cost planning at 0.641099, and time planning at the level of 0.590070.

In the implementation phase, there was a strong correlation with component production, reaching the level of 0.619524. In the phase of use or Facility management, medium-strong correlations were achieved by correlation analysis in generative design, cost planning, time planning, and component production. The analysis underscores the significant role of AI in the design and planning phase, where it can have a powerful impact on productivity. This is a promising tool that should primarily be helpful in preparation and planning, as evidenced by the strong correlations. The design phase of a construction project represents ample space for the implementation of AI and, therefore, to increase productivity in several areas.

Table 1. Results of correlation analysis between the use of AI and the impact on productivity in selected areas

	Generative design	Resource planning	Cost planning	Schedule planning	Component production
Design phase	0.679812	0.544203	0.641099	0.590070	0.203098
Execution (construction) phase	0.199253	0.272901	0.32883684	0.273622	0.619514
Facility Management phase	0.440182	0.197762	0.37919192	0.393423	0.380167

Correlation analysis indicated strong relationships. Furthermore, a regression analysis was performed, the results of which are described in Table 2. At the significance level of p = 0.05, correlations in the design phase were confirmed for almost all activities, such as generative design, resource planning, cost planning, and time planning. There was a statistically significant correlation with component production in the construction phase.

Table 2. Results of regression analysis between the use of AI and the impact on productivity in selected areas

	Generative design	Resource planning	Cost planning	Schedule planning	Component production
Design phase	0,0000135	0,001060	0,000058	0,000301	0,256967
Execution (construction) phase	0,2662748	0,124394	0,061688	0,123364	0,000121
Facility Management phase	0,0103611	0,269942	0,029532	0,023505	0,029082

Our research has yielded statistically significant results, particularly in the planning and use phases, notably for cost planning, time planning, and component production. The correlation and regression analysis have shown a strong positive relationship between AI use and productivity, particularly in the design phase for generative design, resource planning, cost planning, and time planning. In these areas, AI's influence on productivity is undeniably positive. This was further confirmed in the execution phase of component production, providing reassurance about the validity of our findings.

Differences in productivity impacts between using BIM vs. AI in planning and managing construction projects consist of several facts according to a statistical sample. The main difference between these digital tools and the perception of productivity is in looking through quality or quantity. Based on the definition of productivity, to do more in each quality, the AI tool is highly productive. If quality is maintained, there is a high assumption of higher productivity in several use areas. Ai does activities efficiently, saves time and therefore can produce more in the same amount of time. Its impact is the same on this side.

Regarding quality, it should always be emphasized here that the assessment of the result can be subjective. As for the results of using BIM, this tool is more focused on quality. This means that within the framework of increasing productivity, we do not only deal with quantity but also quality. The goal is to increase quality, for example, through the influence of 3D solutions, to improve construction solutions that will optimize resources. However, this requires more time in the planning and design phase. Therefore, these two technologies and their impact on productivity are perceived differently. Both increase productivity in several activities (which is statistically significantly confirmed), but on the other hand, there are certain pitfalls when the given technology can increase productivity.

Conclusion

The research issue of the use of BIM and AI technology and the impact on productivity is required by practice. It is the field of new technologies that has not yet been explored at a sufficient level, and especially the field of using AI has a high potential for complex research.

The research results pointed to the impact of using BIM and AI in the planning and management of construction projects. Based on research data based on a research sample, BIM has an impact primarily on the optimization of costs and resources, as well as in the field of 3D modelling and design generation. From the point of view of time planning, this assumption was not confirmed. It is important to mention that these results show differences when compared to AI technology, which can still be part of BIM. BIM has an impact on productivity, but it does not save time. On the contrary, more detailed 3D modelling of structural elements brings a more refined model, less error rate, minimal misunderstandings, but requires more planning time. The result is a better-quality model, better use of resources, etc.

AI points to the possibilities of increasing production, especially for fast processing of time plans. It also works effectively when planning costs or resources. Within the framework of generative design, positive and statistically significant results are also recorded. AI represents the potential of effective use within selected processes and activities that can be computer (technologically) performed. As with BIM, human resources and know-how are also an important element, which in combination with technological solutions can be a very productive solution.

Future research should go in the direction mentioned at the beginning of the conclusions. This area is unexplored, and the research carried out in the local area of one of the EU countries is not sufficient for the global level. Therefore, the following space for the continuation of research is aimed precisely at expanding the scope and research sample, at least within the EU countries. Likewise, AI needs to be perceived more comprehensively, and therefore research should also be directed in this way. From the drivers that influence the rate of use, through the success factors to the economic evaluation of the benefits in the field of AI, it is important from the point of view of Further direction of research.

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Seizing benefits of projects to achieve organizational growth - an investigation into a Croatian company

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Abstract:

Although, in recent years, there has been significant discussion regarding the rising number of projects within organizations and the process of projectification, further investigation of the organizational benefits of projects is still necessary. Projects benefit the organization and its strategic goals and continue to produce benefits for the organization after fulfilling specific project goals. Therefore, the value of a project expands beyond its financial worth and encompasses benefits created and collected from the project. This research used dynamic capabilities theory to examine an innovative Croatian company that started in a garage and became internationally recognized. Our findings demonstrated that organizations can achieve growth by seizing the tangible and intangible benefits of projects, which opens up a new and intriguing area for future research.

Keywords: *project, benefits, organization, growth, dynamic capabilities theory*

Introduction

Many organizations struggle to define the beneficial effects of projects, especially the intangible or tangible benefits that are hard to quantify. However, taking advantage of the benefits management strategy can significantly enhance an organization's capacity to determine the most beneficial projects. Benefits management implementation in companies still needs to be improved (Aubry et al., 2021), and realizing project benefits is becoming challenging for organizations that depend on projects for innovation, change, and value creation (Keeys and Huemann, 2017). Establishing clear project management procedures, supporting project investment decisions, and improving project and organization efficiency can be possible by setting practical goal benefits (Zwikael et al., 2018). Therefore, *"projects create greater value when they realize their expected benefits"* (Zwikael, 2024), and *"benefits are the principal reason why an organization may seek to enact change through programmes and projects"* (Williams et al., 2019).

This paper focuses on the role of project benefits in a company's growth and, through an example, seizing project benefits and their influence on a company's growth in the case of a Croatian innovative company. The growing volume of projects and the influence of projectification across many sectors and industries have been among the most critical organizational and managerial changes in the last 25 years (Kuura, 2020). In practice, a company can significantly improve its value with a better understanding of the project's benefits.

During times of significant developments in technology, a company's competitive advantage comes from its dynamic capabilities. Therefore, companies rely on their dynamic capabilities to seize project benefits that will create new value for various acceptable products, potentially leading to company growth. *"The aspect of benefits realization as a dynamic process"* (Williams et al., 2023), and dynamic capabilities refer to specific activities in organizations like product development, strategic decision-making, and collaboration (Eisenhardt and Martin, 2000). The purpose of the study was to seize project benefits, both tangible and intangible, to achieve the growth of an organization. After analyzing the literature, we used the Zwikael (2024) project benefits group map to develop interviews and evaluate the hypotheses in this study.

This paper contributes to the project-benefit literature and project practitioners. Using a comprehensive study of the literature on the dynamic capabilities theory, we tested the hypothesis against the Zwikael (2024) map that specific project benefits for achieving the organization's growth. The interview was conducted to test the hypothesis in a Croatian company that evolved from a start-up to a globally recognized innovator. The investigation's findings offer practical recommendations and insights into how companies can contribute to company growth by seizing project tangible and intangible benefits. This case study hypothesized that "*the seizing of project benefits contributes to the organization's growth",* and it is the first of several articles discussing this connection.

The paper is organized as follows: The next section evaluates the relevant publications regarding seizing project benefits to achieve organizational growth. The third section presents the materials and procedures used in the case study. The fourth section provides a clear overview of the research results. The fifth section compares the research findings with relevant academic papers. The study's conclusion covers the findings and limitations.

1. Literature review

1.1 Creation Benefits by Projects

Project outcomes are measurable benefits that a project produces for its primary stakeholders and owner organization (Zwikael and Huemann, 2023). Since the organization is investing resources, achieving project benefits should be the project's main focus the entire time. Project management is the core activity of a project-oriented company (Huemann, 2000); therefore, project success or failure affects all segments of the company's life development. We can see a project's definition as a unique, nonrepetitive activity emphasizing the company's value. Therefore, if a project meets its objectives, stays within budget, and finishes on schedule, it is considered successful (Agbejule and Lehtineva, 2022; Reich and Peppard, 2022). In addition, when projects deliver their planned benefits, their value grows (Zwikael, 2024).

A paper by Zwikael and Huemann (2023) defined vital terms regarding managing benefits in projects and programs. Their paper highlights benefits as project-desirable outcomes, while disbenefits are undesirable ones. Emphasizing how project benefit outputs contribute to anticipated outcomes, value model generation supports the creation of value (Tillmann et al., 2012). Based on the definitions provided in Table 1, project value includes more than just the financial value of a project. It is recognized as creating and seizing benefits from projects, including intangible elements like knowledge, new technologies, innovations, and patents. Therefore, the benefit result from the project throughout and immediately after it is finished, as it captures the knowledge of creating and implementing.

Table 1. Definitions of key terms in benefits management of projects and programs (source: by authors according to Zwikael and Huemann, 2023)

Term	Definition	Comment
Output	An artifact produced through the execution of a project or program	A project may have one or more outputs.
Life-cycle cost	The financial and non-financial costs required to develop, operate and decommission the output(s) of a project or program.	These costs arise for the project owner, operator and other stakeholders.
Outcome	A measurable end effect generated from a project or program for its funding organization(s) and its key stakeholders.	Outcomes can be desirable or undesirable, as well as anticipated or unanticipated.
Benefit	A desirable outcome generated from a project or program.	Benefits can be both financial and non-financial, as well as both anticipated and unanticipated.
Disbenefit	An undesirable outcome generated from a project or program.	Disbenefits can be both financial and non-financial; can be both anticipated and unanticipated.
Value	The net worth of a project or program to its funding organization and its key stakeholders.	Value is perceived as the benefits realized from a project, after also considering the disbenefits and life-cycle cost.
Impact	The effect on project stakeholders directly attributable project or program and distributed to its stakeholders.	Impact can be positive or negative; can occur anytime from immediately after a long lead time.

1.1 Seizing Benefits by Benefit Management

Many organizations need help identifying the benefits that projects provide, particularly the soft or intangible benefits that are difficult to put a financial value on (PMI, 2016). The first step in creating a benefit management strategy for a project is knowing the strategic factors influencing the organization and how it intends to react to them (Ward and Daniel, 2012). As a result, the benefits management strategy can significantly improve an organization's ability to decide which projects are the most beneficial to undertake and the advantages each project can bring when it is complete due to fresh ideas and more effective management.

Managing benefits is a complex, linear process (Aubry et al., 2021; Williams et al., 2023), and institutionalizing benefits management and project management frameworks affects project success. Therefore, successful companies go beyond organizational strategies to develop the processes required to implement specific goals and project strategies (Peter and Ashley, 2004). Establishing an institutional structure of benefits management agents and project management improves an organization's ability to carry out a successful digital transformation project (Badewi, 2022). Companies that apply project management and business modeling in a single project benefits framework for project management can achieve much greater success than other companies that employ project management or business modeling only (Badewi, 2016).

The transitional project process involves the participation of benefit owners, the project manager, and the benefits manager, all highly motivated to achieve success (Romero et al., 2017). Figure 1 illustrates the challenges of achieving benefits in a context with many stakeholders, indicating that successful project management requires collaboration with various stakeholders to gain benefits. During every phase of a project, project managers must be extensively aware of the project's benefits and value rather than just focusing on its completion (Keeys and Huemann, 2017). Throughout the project, many individuals have been crucial in facilitating the transfer of information across organisational divisions, resulting in maximising benefits at different stages of the project (Breese, 2015).

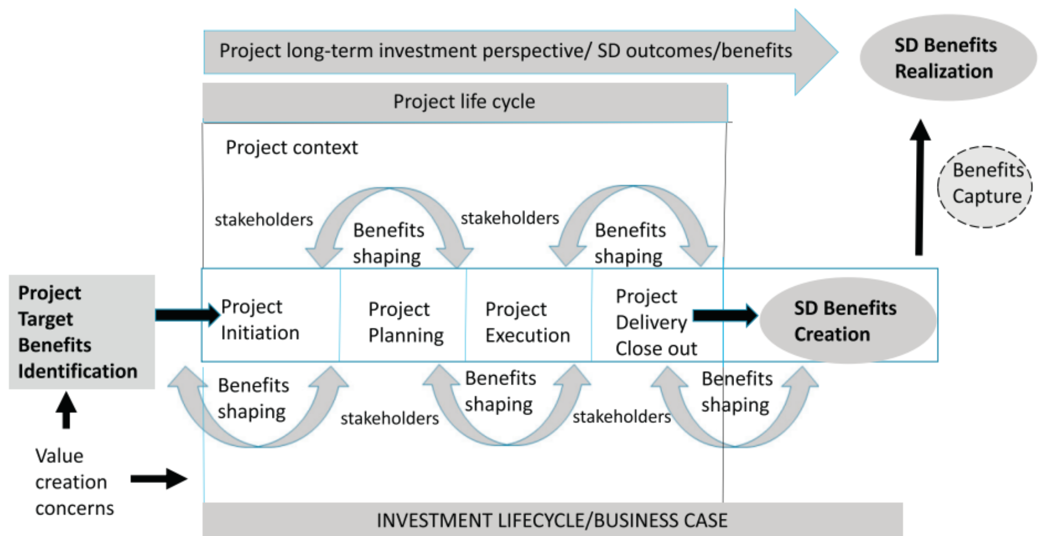

Figure 1. Development of benefits through project life cycle (source: Keeys and Huemann, 2017)

Furthermore, project management strategies have an essential effect on project investments' success compared to organizations' modelling approaches. Thus, by adopting a benefits management strategy from the beginning of the project, it is achievable to encourage individuals to examine the interconnections between technology, changes, and benefits while maintaining the team's focus on objectives and reaching benefits that connect alongside the requirements of all relevant organizations (Gomes and Romão, 2016). For this paper, we adopted the PMI (2016) definition: "Managing benefits during the project's identification, implementation, and sustainability is part of benefit realization management". Therefore, using benefit management, companies can seize project benefits in and beyond the project life cycle.

1.1 Seizing the benefits for the organization using a model of dynamic capabilities

Organizations separate project capabilities into operational and strategic levels (Davies and Brady, 2016). For example, leading the company with a clear strategy and recognizing the project dynamics and benefits can positively contribute to value creation and company growth. "Dynamic capabilities are positively related to performance, and this relationship is stronger in industries with higher levels of technological dynamism" (Fainshmidt et al., 2016; Darvizeh M., 2018). Building dynamic capacities for innovation initiatives relies on project maturity (Skyttermoen and Wedum, 2023), as shown in Figure 2. The dynamic capabilities framework seeks to go beyond traditional methods of understanding competitive advantage. It aims to explain the strategic factors and decision-making processes necessary to seize opportunities once they are identified, as well as how a company can adapt and reorganize itself when the market and/or technology go through inevitable transformations (Teece, 2007).

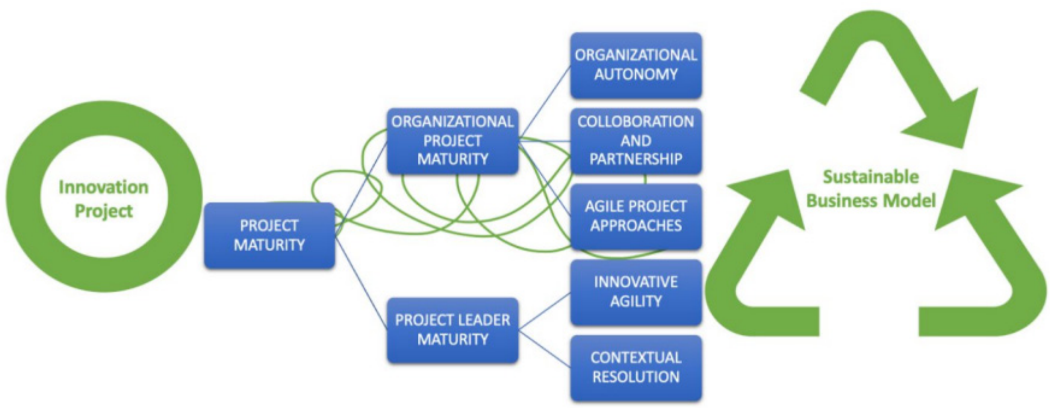

Figure 2. The key elements of project maturity in innovation projects (source: Skyttermoen and Wedum 2023)

According to the Hermano and Martín-Cruz (2016) study, there are two different project capabilities: *"one situated at the operational project level whose objective is to secure project performance under conditions of uncertainty and the other situated at the portfolio level (i.e., portfolio dynamic capabilities) whose objective is to achieve portfolio goals through individual project performance and knowledge."* They propose that top managers, as the organization's leaders, should set up procedures that enhance project performance (boosting project operational capabilities) and other procedures that integrate project learning and increase portfolio performance (boosting portfolio dynamic capabilities).

In periods of rapid (technological) change, dynamic capabilities provide the basis of enterprise-level competitive advantage (Li and Liu, 2014; Teece, 2007). Figure 3 shows the kind and quantity of intangible assets an organization creates and/or collects and the amount of economic profit it can make, depending on how much it develops and uses its superior (nonimitable) dynamic capabilities. Implementing strategies can enhance project, innovation, and commercial success for companies (Gemünden et al., 2018). Thus, a corporation might adopt a strategy across different organizational levels to achieve its long-term objective (Hyväri, 2016). Consequently, companies apply their dynamic capacities to identify the benefits of projects that would provide opportunities in many profitable sectors, which encourages the company's growth potential (Steen et al., 2021).

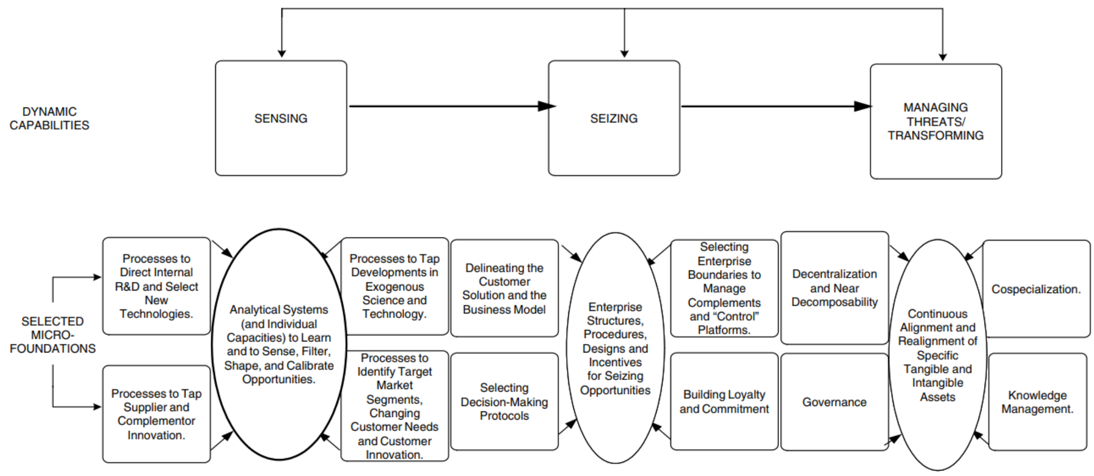

Figure 3. Foundations of dynamic capabilities and business performance (Source: Teece, 2007)

Methodology

The literature review highlighted a need for a more comprehensive approach to capturing project benefits during and beyond the project life cycle. Therefore, based on the extensive literature review and definitions presented in Table 1, we have developed an analytical framework to identify project benefits for organizational growth. Figure 4 demonstrates the process by which companies can seize project benefits for growth during and after the project's life cycle. The framework offers insight into the project's life cycle, with the collection of tangible and intangible benefits as a crucial component. It also provides an overview of the research approach for seizing the effects of tangible and intangible project benefits from the beginning, covering all project activities until the organization successfully uses recognized benefits for its continued growth.

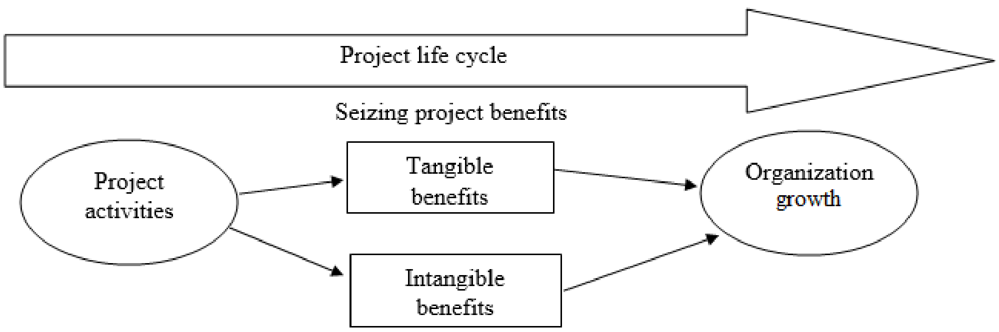

Figure 4. Analytical framework for seizing the project benefits for organization growth (source: by author)

11. Overview of the company

The research was conducted in the Croatian innovative company established in 2009 and developed from a small, local organization to a significant, worldwide known company with large-scale multimillions of value in ongoing projects. The company employs 1300 people and operates in multicultural surroundings with English as the official language. Today, as the appropriate Tier 1 supplier in the auto moto industry, they are innovative suppliers and provide innovative solutions for their customers. The company is well known for its engineering, development, manufacturing, and supply of high-performance battery systems, electric drive units, electronic systems, and user interface components.

1.1 The research approach

The investigation is based on the dynamic capabilities theory, which aims to uncover the precise advantages that can encourage a company's growth. The company was analyzed to evaluate the project's advantages and impact on the organization's expansion. The interview methodology was developed based on the research conducted by Yeong, May Luu, et al. in 2018. The project benefits (Table 2) were analyzed using the improved technique proposed by Zwikael et al. (2024). An online interview was done in May 2024 with a chosen Croatian innovative company. This study represents the initial publication in a sequence of studies that examines the project's significance for the organization and how companies effectively utilize project benefits to optimize its expansion. In this study, we used interview findings to fully understand the key benefits and their impact on the company's growth trajectory.

Table 2. Project benefits group distribution (source: by authors according to Zwikael, 2024)

Benefit Group	Benefits Examples from Data
Revenue generation	Increased market share, increased number of new customers, increased brand awareness
Cost Savings	Decreased operations cost, decreased service cost, decreased maintenance cost
Productivity Enhancement	Decreased production time, increased business culture level, increased decision-making quality, increased cooperation level among employees, decreased employee turnover, increased demographic inclusion and project team diversity, increased transparency level, increased level of customer satisfaction, increased reputation
Quality Improvement	Decreased number of errors, decreased amount of rework, increased service quality, increased product quality

Compliance	Increased compliance levels, Decreased number of regulation breaches
Learning	Increased employee self-learning opportunities, increased level of employee knowledge, increased number of known technologies
Social	Increased health level, increased mortality, increased well-being, increased level of education, increased access to government service
Innovation	Increased level of the company growth
Competence organizational level	Increased level of number of customers and patents
Competence project level	Increased level of critical success factors for project
Effective Target Benefits	Increased level of a specific company target value

Results

This section presents the interview findings tested against the Zwikael project benefits map. For this research, we investigated an innovative Croatian company that started in a garage and became globally recognized. In our interview, through the first part of the discussion, we identified four project benefit groups (innovation, competence from organizational and project levels, practical company target benefits) and seven project benefit groups regarding the Zwikael paper. Table 3 presents a visual illustration of the tangible and intangible findings inside the framework for seizing the benefits from a project for the company's growth. The project's tangible benefits results detect revenue generation, cost savings, innovation, competence from the organizational level, and practical target benefits. On the other hand, the intangible benefits are productivity enhancement, quality improvement, compliance, learning, social, and competence from the project level.

Table 3. Results regarding the map of the project benefits (Source: upgraded by author according to Zwikael, 2024)

Tangible	Intangible	Benefit Example
Revenue generation		Increased number of new customers

Cost Savings		Decreased operations and maintenance cost
	Productivity Enhancement	Increased efficient in production
	Quality Improvement	Decreased number of errors, amount of rework and increase product quality
	Compliance	Be considerate of all fresh legislation that come from third parties
	Learning	Increased level of employees' experience
	Social	Increased level of a balanced and healthy workplace
Innovation		Increased level of the company growth
Competence organizational level		Increased level of number of customers and patents
	Competence project level	Increased level of critical success factors for project
Effective Target Benefits		Increased level of a specific company target value

The opening part of the interview highlighted the company's trajectory; for example, the interviewer discussed: *"We are still a young company; we left a start-up phase, as we now have two big multibillion-euro revenue projects underway, and we are trying to be a very innovative company."* Regarding the benefits of innovation, we discussed that innovation projects lead to increased company growth and the development of new processes and products, as well as improved services and delivery techniques for better outcomes, efficiency, effectiveness, and quality (Taylor S.P., 2017). Then we continued our discussion about the organizational structure and company strategies: *"Recently, we reorganized our company completely, now we have a matrix organizational structure, and we have strategies to consolidate and be efficient through projects; we need to be profitable as an organization"* (Interviewer). The interviewer mentioned the connection between projects and their effect on the company: *"Projects have a major role in the development of a company. The company needs reasonable growth with profitable projects, which is the key* *starting point of all future development."*

1.1 Project benefit groups

Providing each benefit category and any associated characteristics, whether or not they were financial, served as the basis for the project benefit grouping (Zwikael, 2024). The benefits from our data are illustrated here, along with a quotation from an interview for each benefit group.

1.1.1 Revenue generation

The benefits group encompasses financial benefits that contribute to the project owner organization's revenue growth (Zwikael, 2024). The interviewer explained: "*We do not need 50 projects; we need to have five, allowing us to have a stable future. We never want to be a big player; we want to be different and be an innovative supplier that can provide innovative solutions for OEMs. The attraction of new customers is not a crucial factor. However, it is very interesting because the company cannot only rely on one or two customers".* One of the benefits mentioned by our interviewees that apply to this group is "increased brand awareness," which corresponds to the company's ability to deliver projects to customers successfully.

1.1.1 Cost Savings

Financial advantages that concentrate on decreasing the organization's long-term operating costs are included in this group (Zwikael, 2024). The interviewer explained: *"The company's primary objective right now is cost savings".* The benefits resulting from our data that apply to this group are "decreased operations and maintenance costs ". Regarding the company, decreasing is connected to *"the costs for running day-to-day operations and maintenance of their productive lines and facilities"* (Interviewer).

1.1.2 Productivity Enhancement

This group focuses on non-financial benefits to enhance the efficiency of the project owner organization (Zwikael, 2024). For instance, during the interview, the following topics were discussed: *"We are trying to decrease employee turnover; this is one of the major goals of the company, to become the best employer in Croatia."* The benefits of improving productivity involve "higher decision-making quality," and "a higher degree of customer satisfaction," which is closely linked to *"the high productivity and efficient production, improve the decision making, to be quickly but make right decisions, and if you disappoint customers, it will be tough to get full-up projects"* (Interviewer).

1.1.3 Quality Improvement

This category of intangible benefits aims to improve the quality of a service or product (Zwikael, 2024). For example, the interviewer stated that the company aims to "decrease the number of errors and amount of rework." In addition, he emphasized, "increased product and service quality," regarding: "The goal should be better quality at the beginning, the less efforts and issues the project team will have later at the field" (Interviewer).

1.1.4 Compliance

Specific projects were started to ensure compliance with new legislation, industry standards, or company policies (Zwikael, 2024). For example, the interviewer addressed a project meant to satisfy external stakeholders like countries, governments, and politics: *“Company needs to put on compliance regarding sustainable future.”*

1.1.5 Learning

Benefits may include gaining new organizational knowledge, even without immediate tangible outcomes (Zwikael, 2024). Our interviewer highlighted the “increased level of employee knowledge” as a slightly significant benefit for this group; for example, *„it is important to educate employees and offer them a chance to improve, learn, and grow, but it is not the end of the game, and others can perform better automatically.”* Witch refers to the employment of people with previously gained knowledge and developed skills: *„Sometimes it is easier or better to replace people or make clever decisions on the way to positions regarding their capabilities”* (Interviewer).

1.1.6 Social

This category contains non-financial benefits for people in general, such as health, education, and equality (Zwikael, 2024). The interviewer highlighted “increased health level” and “increased level of education.” For example, *“for the company, it is important to maintain a good work-life balance,”* and *“education is relevant to the company, and employees have opportunities for additional education”* (Interviewer).

2.Discussion

We explored the influence of project benefits on company development from two perspectives: tangible and intangible benefits. In addition, based on the framework from Zwikel and data collected by interview, the project benefits conceptual framework was developed.

The following part answers on testing the hypothesis that specific benefits (tested against the Zwikael benefits map) helped the organization to grow and build dynamic capabilities through analysis (Table 3).

2.1 Increased number of new customers

The case study’s findings suggest that while attracting new clients is intriguing for the business, it is not a critical component. Companies use projects to accomplish strategic change (Martinsuo and Hoverfält, 2018); providing advantages to clients is associated with benefit management planning prior to project initiation and benefit management actions during project implementation (Jørgensen, 2016). As a result, the organization has shown its ability by completing new projects for OEMs.

2.2 Decreased operations and maintenance cost

According to the interview data, tangible benefits such as cost savings from reducing day-to-day activities are the most important to the company. Data also shows that maintenance costs are part of operations costs and must be as efficient as possible. Maintenance is a crucial task in a manufacturing company, and companies need to view it as a possible source of cost savings and competitive advantage in this highly competitive industry (Jain et al., 2014).

2.3 Increased efficient in production

The most challenging things for companies to manage about innovation, technology, digital transformation, and growing interdependence are the skills and qualifications of their employees, such as problem-solving abilities, failure analysis skills, and the capacity to deal with constant change and entirely new tasks that enable businesses to create values and meet customer demands (Mohamed, 2018). The data indicates that the company should be more efficient in its manufacturing. It has many spreads and downtime and is not very effective. The company performed two major restructurings to boost efficiency, and it is still monitoring the effectiveness of the new structure. Therefore, the ability of any company, whether manufacturing- or service-oriented, to adapt to these changes methodically and continuously to increase the value of its product may be the determining factor in its survival (Sundar et al., 2014).

2.4 Decreased number of errors, amount of rework and increased product quality

Reworks are initiated to change or adapt the layout of a project as it is being produced (Safapour et al., 2018). Based on the data, it is beneficial for the company to prioritise enhancing product quality at the beginning of the project. This approach would lead to reduced work and less issues in the latter stages of implementation. These challenges may lead to significant costs for the company.

2.5 Be considerate of all fresh legislation that come from third parties

Over the past two decades, businesses have significantly adopted sustainability standards to improve their supply chain's social and environmental practices and educate consumers about these sustainable approaches (Lambin and Thorlakson, 2018). Data compliance is crucial for the company due to legislation imposed by external parties such as countries, governments, and political parties.

2.6 Increased level of employees' experience

The interview data shows that while the company needs to educate its employees and provide them with opportunities to learn and develop, there are situations when it is preferable to replace employees or make wise hiring decisions based on candidates' qualifications. Instead of a specific project, employee experience refers to professional development activities, including formal education, work experiences, professional relationships, and personality, skill, and ability assessments that support employees' professional development (Noe et al., 2014).

2.7 Increased level of a balanced and healthy workplace

The intangible benefit of a balanced and healthy workplace is always crucial for the company. The degree to which the workplace affects employee satisfaction depends on their choices for privacy versus social interaction. Employee productivity is contingent upon certain work patterns and the degree to which the work environment facilitates job-related tasks (Voordt and Jensen, 2023).

2.8 Increased level of the company growth

New structures and procedures provide successful solutions for innovation; although people are vital, procedures are more effective in fostering innovation than individuals (Sankaran et al., 2023). Therefore, innovation contributes to significant increases in company outcomes, efficiency, effectiveness, or quality while adding to the growth of the companies by supporting the creation and implementation of new processes, products, services, and delivery systems (Taylor S.P., 2017; Satispi et al., 2023). The case study findings reveal a similarity with the literature: the benefits of the innovation project and occasional restructuring have stimulated the company's growth from a startup to a globally respected company.

2.9 Increased level of critical success factors for project

The importance of a multinational project team and the integration of team expertise, competencies, and capabilities are critical factors for a project success (Ruuska and Vartiainen, 2003). Based on the findings, the company recognized the benefits of a multicultural environment, paid attention to the competencies at the project level, and ultimately benefited from employing a multicultural project team.

2.10 Increased level of number of customers and patents

Innovation is a crucial factor in a company's capacity to gain an ongoing competitive advantage by continually exploiting its ideas through new products. However, companies may suffer if they rely too much on essential customers or if their customer portfolio grows too large (Noh et al., 2018). According to data, the company's goal has never been to be the leader in the marketplace; instead, it wants to stand out as an innovative provider capable of providing innovative solutions with suitable projects. Accordingly, the case company has numerous interests and chances for new projects/customers, and they decided to be selective about the projects and choose the appropriate ones for the right time, with the proper KPIs.

2.11 Increased level of a specific company target value

Target value is a tangible benefit that increases a company's target value, supports its long-term goals, and advances its present strategy. Establishing clear project management direction, supporting project investment decisions, and improving project and organizational performance are all made possible by setting practical target benefits (Zwikael et al., 2018). The case study results show that practical target benefit is a vital project benefit for the company.

3. Conclusions

This study examines the importance of project benefits throughout the project life cycle for the organization's growth. Furthermore, this paper demonstrates the potential of the dynamic capacities theory by seizing project benefits, using an innovative Croatian company as an example. The study highlights eleven tangible and intangible benefits, as follows: revenue generation, cost reduction, innovation, organizational competence, specific target benefits, increased productivity, enhanced quality, compliance, learning, social benefits, and project-level competence.

This paper also demonstrated that projects play a crucial role in a company's continued growth and that periodic reorganization can have a positive impact on its growth. Furthermore, through an extensive review of existing literature and the definitions outlined in Table 1, we have constructed an analytical framework for successfully determining the project benefits that contribute to a company's growth.

Project benefits are dynamic and dependent on company strategy, customer requirements, and project strategy; therefore, "each benefit is "multiple" in the various versions it comes to take, whether because of technical changes or inherently diverging judgments stakeholders impose on it" (Williams et al., 2023). The case study hypothesis was investigated, and it was demonstrated that seizing project benefits enhances the dynamic capabilities of project participants and supports the company's growth.

An investigation also highlighted that innovative companies do not need to rush to become market leaders and have many projects; they must to be selective and choose the appropriate ones for the right time with the proper KPIs. The results indicate that changes to strategies, structures, and procedures can result in major improvements in innovation. In a particular case, a Croatian innovative company effectively obtained all the advantages of a project and expanded from a startup to a company with worldwide recognition.

While this research provided essential perspectives on the topic, it is evident that there are limitations. This study has a restricted number of interviewers from the governance and management project area, and the example is based only on one innovative company. However, the study's originality presents a restriction that makes broad generalizations challenging. Although it offers a chance for a comprehensive review, using an individual company for the case study restricts its applicability to additional development. Nevertheless, this case study confirms other studies conducted in different domains, implying they are potentially valuable.

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Dynamics of Trust in Construction Projects

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[2]Croatian Roads, Croatia

Abstract:

Building trust in construction projects is vital for projects success. According to many researchers and practitioners, trust has been argued to be a key success indicator for collaboration between projects participants. Cultural issues are very important and have an impact on trustworthiness among international projects stakeholders. Inter-organizational trust is key to achieving outcomes among different companies. Project managers generally agree that it is not easy to develop trust between project parties, but that it can easily come apart, following which it is even more difficult to build it again. This study investigates the dynamics of trust in construction projects through an analysis of a case study involving a large infrastructure project. Interviews were conducted with client's and contractor's representative to explore the main elements of inter-organizational trust and the three types of trust defined by the literature review: system-based, cognition-based, and affect-based trust. It is concluded that trust among project participants is not static but evolved with the project's progress, requiring continuous effort to sustain and rebuild it when necessary. Also, the importance of cultural awareness and effective communication in fostering and maintaining trust in multicultural project environments is crucial for project success. The study provides valuable insights into how trust evolves over time in construction projects, highlighting the critical moments when trust is built, decreased and rebuilt. For practitioners in construction project management, the study offers a foundation for understanding and monitoring trust levels throughout a project's lifecycle.

Keywords: *trust; trust dynamics; project management; construction projects; culture*

1. Introduction

In recent studies it has been shown that trust fosters collaboration and communication among stakeholders (Cerić, 2016; Cerić *et al.*, 2019; Ivić and Cerić, 2024) and play a vital component of construction project success. According to Wu *et al.* (2020), trust amongst stakeholders is essential to project success. It also influences project teams' improved performance (Rezvani *et al.*, 2018) and can serve as a relational governance mechanism (Wang *et al.*, 2020).

However, there are several difficulties in measuring trust—a complicated and multidimensional component of human connection. Trust is by its nature dynamic and context-specific, changing based on particular circumstances and interpersonal connections.

According to Rousseau *et al.* (1998), trust is typically defined as a psychological state that includes the intention to accept vulnerability based on favorable expectations of another's actions or intentions. Because trust can assist secure durable partnerships across divergent parties, it is crucial in today's globalized environment to develop effective interactions across organizations. This is particularly emphasized in situations that are ambiguous and full of uncertainty, such as when project parties come from diverse cultural backgrounds (Dietz *et al.*, 2010).

The dynamic nature of trust is still not well understood in the context of construction project management, despite its acknowledged relevance. The problem of establishing and maintaining trust across different cultures is notably greater. The distinct values, attitudes, behaviors, and presumptions that people with different cultural backgrounds bring can make it difficult for people to work together and connect effectively (Branzei *et al.*, 2007). As a result, miscommunications, embarrassment, a decline in self-assurance, and even psychological discomfort are often brought on by cross-cultural encounters (Molinsky, 2007). By examining the variations and factors that influence trust among project participants over the course of the large infrastructure project involving participants from different cultural backgrounds, this study seeks to close this gap.

The aim of this study is to explore the dynamics of trust between construction project participants through an analysis of a case study involving a large infrastructure project in a multicultural environment. In the following sections the literature review on trust in construction projects and the interaction between trust and culture is presented. Furthermore, this paper explores the dynamics of trust in a multicultural infrastructure project. The methodology and research findings are presented, along with conclusions and recommendations for further research.

2. Dynamics of trust

Due to its positive impact on project success, trust is a common topic in recent research in the field of construction project management. However, there are few studies that address the quantification of this dynamic and complex aspect of human nature. Specifically, trust is very difficult to quantify due to its ambiguity, dynamism, and complexity. Often, trust means one thing to one participant and something else to another. Trust depends on the specific situation and context. Therefore, when thinking about trust, we refer to person A trusting person B regarding a certain behavior X in context Y and at time t. Consequently, for successful trust management in a construction project, it is necessary to monitor the level of trust throughout its duration. Figure 1 shows a conceptual diagram of the change in trust levels among project participants, according to Cerić (2016).

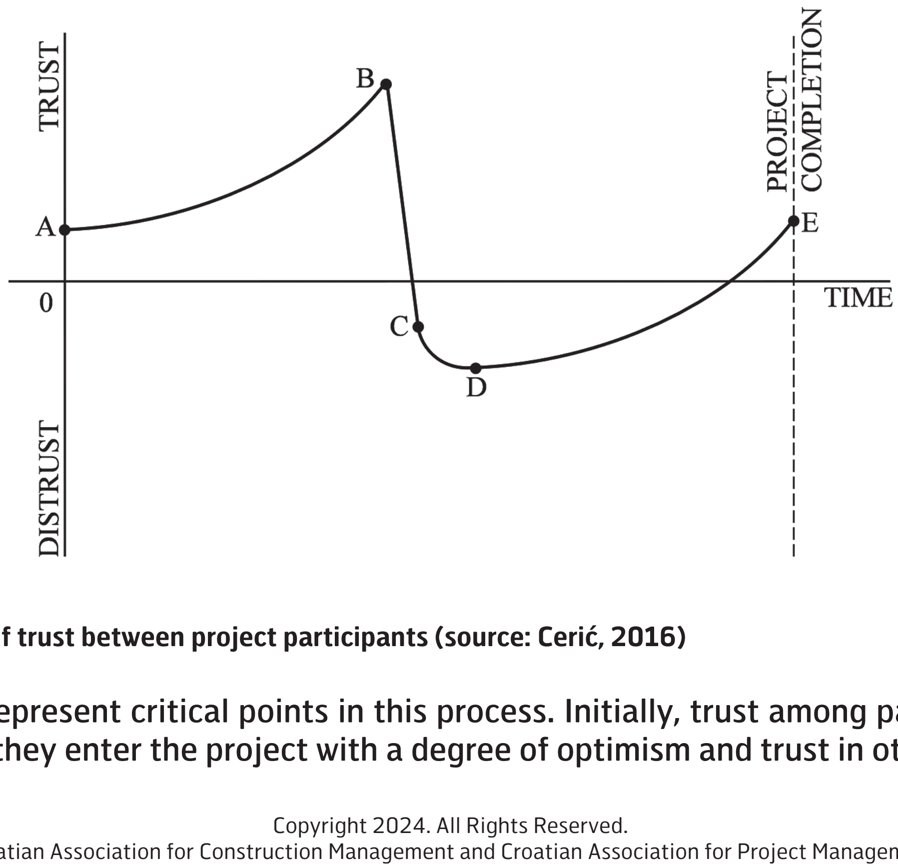

Figure 1. Dynamics of trust between project participants (source: Cerić, 2016)

The letters A-E represent critical points in this process. Initially, trust among participants is at a positive level as they enter the project with a degree of optimism and trust in others (point A). At the start of a project, initial trust is often based on the reputation and perceived competence of team members. This form of trust is particularly relevant in temporary project teams where members may not have prior relationships (Meyerson *et al.*, 1996). As time progresses, trust increases as participants get to know each other and share information (point B). All team members must continue to put in effort in order to build trust over time. According to Kramer and Lewicki (2010), maintaining trust throughout the project lifetime requires critical acts such as consistent communication, meeting commitments, and proving reliability and competence. However, if a conflict arises in the project, there is a breakdown of trust, and it falls into the negative sphere of mistrust (point C). Project managers concur that building trust between the project participants is difficult but it may also easily break down, making it even harder to rebuild (Cerić, 2016). When the collaboration of all project participants is particularly important near the end of the project, a breakdown in trust is particularly dangerous. This is the point where mistrust might cause a project to be delayed. Trust violations can occur due to misunderstandings, unmet expectations, or mistakes. At this point, participants need to repair trust through communication and other aspects that enhance trust (Mesquita, 2007) (point D). In order to effectively restore trust, a participant may need to admit the violation, extend sincere regrets, give justifications, and implement corrective measures (Kim *et al.*, 2009). Once trust is restored to a normal state, project participants start making more effort to increase it again, and by the end of the project, it can return to a positive level (point E).

The process shown in Figure 1 is presented in a conceptual form; however, it rises the need of investigating the dynamics of trust in actual projects, thereby providing a basis for monitoring its level during the execution of construction projects. To be able to investigate the level of trust between project participants, it is necessary to define the elements of trust that need to be measured. Such elements have been explored by scientists in several previous studies on measuring trust in construction projects.

In construction projects, project teams are composed of individuals coming from different organizations. In such conditions, inter-organizational trust is key to achieving outcomes of the project. According to Lau and Rowlinson (2009), inter-organizational trust can be modeled including four elements of trust: keeping commitments, predictability, fair negotiation, and avoiding taking advantage of the other party. Keeping commitments and promises increases trust between organizations in projects. Knowledge of other organization increases predictability and reduces uncertainty. Fair negotiations include honest communication about the intentions and open book arrangements between organizations. Finally, avoiding taking advantage of the other party exhibits the party’s willingness to cooperate and share values.

Wong (2007) distinguishes between three types of trust elements: *system-based* trust, *cognition-based* trust, and *affect-based* trust. These trust elements represent different dimensions or sources of trust for an individual. Formal and procedural agreements, or contracts among participants, are the source of *system-based* trust. In order to ensure responsibility and clarity, contracts are essential in outlining each party’s obligations and expectations. Strong organizational rules and well-organized communication protocols serve to further strengthen stakeholder trust. Throughout the course of the project, these formal methods offer a solid basis for collaboration and dispute resolution. *Cognition-based* trust develops based on objective knowledge about the partner and their reliability, i.e. through the consistent and transparent sharing of information among project participants. Mutual understanding and trust are facilitated by open lines of communication, progress updates, and regular meetings. Finally, *affect-based* trust stems from the human need to connect with others and invest in mutual relationships. A sense of mutual support is fostered by the team members’ commitment and effort. Conflicts and difficulties can be navigated with empathy and concern for one another’s needs, which strengthens trust even throughout challenging project phases.

This study offers a view into dynamics of all three types of trust—*system-based* trust, *cognition-based* trust, and *affect-based* trust—in a construction project execution period. The aim of this study is to explore the dynamics of trust among project participants coming from two different cultures. Therefore, the interaction between trust and culture is investigated in the following section.

3. Interaction of trust and culture

The relationship between trust and culture is multifaceted, particularly when parties from different cultural backgrounds interact. This complexity arises because trust is often built on shared norms, values, and social experiences, which are inherently shaped by culture. On the other hand, culture influences our thinking and behavior, including our foundational understanding of trust and trustworthiness (Zaheer and Zaheer, 2006).

Gibson *et al.* (2009) defined culture by a range of cultural levels and facets. As per this definition, culture is comprised of basic assumptions about individuals and their interactions with the outside world that are held by a community. Values, beliefs, social norms, and artifacts like institutions and physical items all represent these assumptions. According to Smircich (1983), culture is the common values, aspirations, and beliefs of a community that help to define identity, promote commitment, maintain social order, and direct behavior. Similar to this, Schein (1997) claims that culture influences our behavior, emotional reactions, and interpretation of events, all of which assist us cope with uncertainty and unpredictability.

Geert Hofstede's cultural dimensions theory provides a useful framework for understanding how national cultures influence trust (Hofstede, 2001). Hofstede (2001) identifies six dimensions: power distance, individualism versus collectivism, masculinity versus femininity, uncertainty avoidance, long-term versus short-term orientation, and indulgence versus restraint. Each of these dimensions can impact how trust is built and maintained. In high power distance cultures, trust may be hierarchical and based on respect for authority. Subordinates are less likely to question superiors and more likely to trust their decisions implicitly. In contrast, low power distance cultures may foster trust through egalitarian relationships and open communication. Collectivist cultures emphasize group harmony and long-term relationships, and prioritize benevolence and integrity more heavily than individualist cultures, which may focus more on ability and competence. Cultures with high uncertainty avoidance prefer clear rules and structured environments, which can lead to a reliance on institutional (or system) trust. In such cultures, trust is often placed in formal systems and regulations rather than in individuals.

Saunders *et al.* (2010) explore the development of trust across different cultural spheres—national, inter-organizational, and intra-organizational. They argue that trust building is particularly challenging in cross-cultural contexts due to the alien values, beliefs, and behaviors that parties bring to the relationship. Trust-building strategies that work in one cultural context may be ineffective or even counterproductive in another.

When individuals from the same cultural background interact, trust tends to develop more easily due to the presence of shared norms and familiar trust cues. These cues, such as actions or behaviors that signify trustworthiness, are understood similarly by all parties, leading to quicker trust formation. For example, when both the trustor and the trustee have shared cultural experiences, the trust-building process is straightforward, and trust is established rapidly (Doney *et al.*, 1998; Griffith *et al.*, 2000; Branzei *et al.*, 2007).

However, when individuals from different cultures interact, the situation becomes more complex. When party A from culture #1 meets party B from culture #2, they face a mix of shared goals and different backgrounds, creating potential distrust (Banai and Reisel, 1999). The assumptions of symmetry in trust processes may need adjustment (Zaheer and Zaheer, 2006). Both parties will send and interpret trust signals based on their cultural backgrounds, which influence their behavior and perceptions. Cultural filters or schemas shape how these signals are processed and prioritized, affecting trust judgments and decisions (Gibson *et al.*, 2009).

Diverse cultural perspectives can result in different ways of interpreting trust signs. For example, a conduct that is considered trustworthy in one culture could not be in another. The main cause of this comprehension gap is because differing cultural schemas or filters affect how information related to trust is interpreted. Branzei *et al.* (2007) emphasize the difficulties presented by cultural variety in trust-building by pointing out that cultural norms and values that are beneficial to trust in one context may be deceptive or even harmful in another.

In cross-cultural business relationships, trust often emerges when parties establish common goals and rules that transcend cultural differences. For instance, Möllering and Stache (2010) stress the need of establishing ground rules to promote trust, implying that mutual understanding and active participation are frequently necessary for success in these kinds of environments. Furthermore, the concept of "cross-cultural code-switching" is essential to developing trust. According to Molinsky (2007), this process entails people changing their behavior to conform to the cultural norms of others around them. This adaptation calls for a great deal of work and cultural sensitivity, yet it can help close gaps in understanding and promote trust.

Furthermore, culture also impacts how trust is repaired once broken. When trust is violated, the process of rebuilding it can be significantly hindered by cultural misunderstandings. For example, cultures that place a high value on personal relationships might find it easier to rebuild trust through direct interpersonal efforts, while others might rely more on formal mechanisms such as contracts. In professional relationships between project participants trust can be damaged if cultural expectations are not met. Repairing the trust requires open communication and a willingness to adapt behaviors to meet the other party's cultural needs (Avakian *et al.*, 2010). This often involves acknowledging cultural differences and making concerted efforts to realign the relationship according to other party's cultural expectations. In environments where institutional trust is weak, personal relationships and informal networks play a critical role in trust repair (Möllering and Stache, 2010). In these contexts, trust is rebuilt through repeated interactions that demonstrate reliability and integrity.

In their exploration of the dynamics of trust, Dietz *et al.* (2010) identify a number of critical variables that affect the development, maintenance, and repair of trust between individuals with diverse cultural backgrounds in teams. Team members bring their own cultural prejudices to the first meeting, shaped by their cultural awareness and flexibility. Proficiency in cross-cultural awareness can serve as a bridge across cultural divides, promoting smoother interactions and trust. Immediate cultural judgments and past relationships impact first trust stances. Based on similar upbringings or unpleasant histories, parties may begin with mutual trust or mistrust. It is more advantageous for successful engagement to allow first exchanges to shape views, which can be achieved by being willing to suspend judgment. Early on in their contacts, team members test hypotheses, exchange knowledge, adjust expectations, and communicate. Establishing a foundation of trust requires a commitment to resolving miscommunications. Successfully establishing trust can, on the one hand, result in finding common ground or resolving conflicts, which fosters trust across differences in culture. Conversely, a lack of knowledge or ability to work through differences leads to mistrust. There are two effects of distinct trust pathways. A mistrusting relationship ends in suspicion, whereas a trusting one develops through mutual understanding.

Dealing with trust issues in intercultural settings is essential to understand the cultural backgrounds of all parties involved. The ability to manage these cultural differences and build a shared understanding is key to successful trust-building in globalized and multicultural settings. To explore the dynamics of trust in construction projects, a case study of a large infrastructure project, involving Croatian and Chinese participants, is presented in the following section.

4. Dynamics of trust in construction project: Pelješac Bridge project

The construction of the Pelješac Bridge in Croatia is selected as a suitable example of dynamics of trust between participants with different cultural backgrounds. The importance of the project is described below, following the description of the research methodology and findings.

4.1. About the project

The Pelješac Bridge is the first of four phases in the project titled "Road Connection to Southern Dalmatia." The other three phases of the project include the construction of access roads. The project client is Croatian Roads, a Croatian state company. The project holds significant geostrategic importance for Croatia and the European Union, as the Pelješac Bridge connects the previously divided territory of Croatia, and consequently, the European Union. Prior to the bridge's construction, Croatia's coastline was split by the Neum Corridor, a 20 km land strip belonging to the neighboring country of Bosnia and Herzegovina. This study focuses on the first phase of the project, the construction of the Pelješac Bridge.

The project was co-financed by the European Union. The public procurement process for selecting the contractor began in 2016, with the client's goal being to find a contractor with the necessary capacity and expertise to execute very complex specialized works within the set deadlines (Puž, 2022). Ultimately, the consortium of Chinese companies led by China Road and Bridge Corporation (CRBC) was chosen as the contractor. The construction officially began at the end of July 2018. For the Chinese consortium, this was the first project funded by the European Union. The client, Croatian Roads, was responsible for all major decisions, with each phase of the project being separately overseen and managed by phase managers. The bridge was successfully finished in January 2022, 42 months after the start of construction.

The achievement of project objectives in this case was highly successful. Despite the Covid-19 pandemic, the initially planned deadline was exceeded by only a few months. Specifically, the only deadline exceeded was the one offered by the contractor in their bid, while the original deadline set by the client was met. The planned costs did increase, but this was in accordance with a contractual sliding scale clause. Puž (2022) reports significant challenges in project realization due to disrupted supply chains and substantial market price increases, which almost jeopardized the project's completion through the contractor's cash flow disruptions. Given the force majeure circumstances, it can be said that the objectives were successfully achieved because there was a strong will among all stakeholders to continue (Puž, 2022).

This study used a large infrastructure project successfully executed in a multicultural environment, Pelješac Bridge, as a case study to explore the dynamics of trust between the client and the contractor. The specific cultural context of the two main project participants is explored in the following section.

4.2. Cultural context

This study deals with dynamics of trust between key stakeholders of construction process of the Pelješac Bridge. This refers to the client, Croatian Roads, and the main contractor, Chinese company CRBC. The Chinese and Croatian culture, analyzed through the 6-D Model (Hofstede insights, 2024), reveal distinct societal values and behavioral norms, explained bellow.

China has a significantly higher power distance (80) than Croatia (73), which is indicative of a greater acceptance of hierarchical structures in Chinese society. Power is concentrated at the top and the subordinate-superior relationship is more polarized in China, whereas hierarchy is revered and equality is given slightly more weight in Croatia.

Both China and Croatia have higher scores for collectivism than individualism (43 and 42, respectively). In China, the collective typically dominates the individual, with decisions made on a personal and professional level influenced by in-group loyalty. Collectivism has a similar important role in Croatia, where it emphasizes loyalty and communal responsibility while building strong family and group bonds.

One important distinction is highlighted by the motivation towards of success and achievement. With a score of 66, China is a highly competitive nation that values achievement and success above all else, frequently at the sacrifice of interpersonal and familial relationships. Croatia, on the other hand, scored 40 and prioritizes consensus, quality of life, and work-life balance. Success there is more about personal fulfillment than it is about competitiveness.

Another area where the two cultures contrast is in their avoidance of uncertainty. Croatia received a high score of 80, indicating a strong preference for security and strict regulations as a means of avoiding uncertainty. China, on the other hand, scored lower (30), indicating a more pragmatic approach that prioritizes flexibility and adaptation and a more laid-back attitude toward ambiguity.

China's long-term orientation score of 77 indicates a pragmatic approach with a heavy emphasis on adaptation and future-oriented aims. Croatia, with a score of 40, is more normative, prioritizing immediate outcomes over long-term planning and tradition.

Finally, in indulgence, both cultures are restrained, rating 24 and 33 respectively, suggesting an affinity for regulated satisfaction and a more pessimistic view of life.

Given the significance of Pelješac Bridge project, the specific mix of cultural backgrounds of project participants, and a multitude of challenges that they faced during the construction, this project is chosen for the research on trust dynamics between project participants. In the following sections the study methodology and findings are presented.

4.3 Methodology

The case study findings presented below are based on the interviews with the representatives of the client and the contractor. The client's representative worked as the site project manager. The contractor's representative initially worked as the communications manager for the project, later taking on responsibilities related to the construction site. The client's representative has 10 years of experience, while the contractor's representative has 14 years of experience in construction. Each respondent participated in one interview, with overall duration of 2 hours. Special attention was given to creating an atmosphere of trust to ensure that respondents felt as relaxed and open as possible when answering questions. The interviews were conducted in the respondents' company premises.

For this research, the semi-structured interview was chosen due to its clear value in explaining respondents' attitudes. A semi-structured interview is somewhat more flexible than a structured interview in that it still retains a pre-prepared set of questions but in the form of discussion topics. The protocol in this case serves as a guide, but the interviewer is allowed to ask follow-up questions, change the order of questions, or phrase questions differently, ensuring that the essence of the questions is maintained (Treece and Treece, 1986). The value of the semi-structured interview lies in the interviewer's freedom to clarify any unclear or ambiguous word or phrase and to ensure that the collected data truly reveal what they are intended to reveal (Barriball and While, 1994).

Most of the questions were pre-structured to enable as objective an analysis of the collected data as possible, but respondents were allowed to answer openly. The order of questions was changed during the interview, or follow-up questions were asked only when it was deemed suitable for the respondent to facilitate the flow of their thoughts.

The first part of the interview focused on general information about the respondent. This section included questions regarding their work experience in construction and their role in the project. The second part of the interview involved recalling specific moments from the Pelješac Bridge construction project (following the diagram shown in Figure 1) and describing the level of trust between the client and the contractor at those times. Open-ended questions were formulated for this part, following the main elements of inter-organizational trust and the three types of trust defined by the literature review: *system-based*, *cognition-based*, and *affect-based* trust.

Client and contractor representatives described the relationship between the client and the contractor at specific points in the project (following the diagram shown in Figure 1) and commented on changes in the level of trust throughout the project. The interview findings are presented below.

4.4 Findings

The client representative emphasized that building trust, in their opinion, is the most crucial skill for project managers, especially highlighted in large projects involving numerous participants from diverse cultural backgrounds.

Point A – beginning of the construction

The Pelješac Bridge project was highly idealized at its inception due to previous unsuccessful construction attempts. The contractor was participating for the first time in the European Union and eager for promotion. The official language of the project was Croatian, requiring the contractor to communicate in an unfamiliar language. Translation teams were engaged, and site representatives used automatic speech translation devices. Despite language barriers, frequent communication between the client and contractor was established through formal procedures. At the beginning of the Pelješac Bridge construction, trust between the client and contractor was positive due to shared optimism and the common goal of successfully building the bridge.

System-based trust

At the project's start, trust in the contract was high. The FIDIC contract, familiar to both the contractor and the investor, provided no uncertainties that might induce insecurity. However, trust in the processes was somewhat lower, as it took time to establish them. This also applied to communication between the client and contractor and the establishment of reporting systems. The implementation of project processes and flawless communication was hindered by cultural and language barriers between the Croatian client and the Chinese contractor. Nonetheless, there was optimism that processes and communication would soon reach a satisfactory level.

Cognition-based trust

At the start of the Pelješac Bridge construction, the client was familiar with the contractor's reputation and references. To promote their skills, the contractor prominently advertised their past successes in bridge construction, even more complex than the Pelješac Bridge, through large billboards at the construction site. However, there was some uncertainty about the contractor's behavior—"we didn't know what to expect." The client representative soon noticed the contractor's different culture compared to the European Union, particularly regarding work safety and environmental protection. Given the high level of environmental protection required for this project, the client initially had concerns about the contractor's behavior. However, trust in the contractor's competencies was established when the client saw how well-organized the construction site was and the major construction equipment brought from China.

On the other hand, the contractor's representative noted that their confidence in the client and supervision was low. They doubted the client's and supervision team's knowledge and experience.

Affect-based trust

Due to cultural differences, establishing mutual trust on a personal level between project participants was initially challenging. The client was frustrated that the contractor avoided admitting mistakes or project issues at the beginning. However, there was still optimism in personal relationships at the project's start, as participants were united by a common goal—building the bridge. According to the client representative, "It was evident that the contractor wanted to make a good impression on this project, and for us (the client), this was the most important project at the time. We gathered around that goal."

From the contractor's perspective, initial relations with the client were satisfactory. This context included joint meetings, lunches, and coffee breaks where they worked on mutual relationships. The contractor initially faced pressure from Western media reports on the low labor costs and overtime of Chinese workers. These cultural prejudices troubled the Chinese contractors, fearing it could affect their relationship with the client. However, the contractor's representative noted that, from the project's start, it was clear there were no significant differences in the views of the client and contractor and that they could find common ground to achieve their shared goal.

Point B – highest level of trust

The peak of positivity in the project and the highest point of trust between the client and contractor was marked by the completion of the last pile, the foundation of the bridge, in May 2019. The moment of driving the largest pile was marked by the joint pressing of a button by the Croatian and Chinese prime ministers, marking the highest optimism for the project's successful completion.

System-based trust

As the project progressed, processes were successfully established, initially progressing slower. This was particularly true for the exchange of project documentation and client-contractor communication. Both client and contractor became more familiar with the established processes and the contract, becoming "more confident in what they were working with."

Cognition-based trust

Positive project results and construction progress according to plans built trust between the client and contractor. The optimism for successful project execution grew. The client representative highlighted specific events that increased trust in the contractor. It was when the contractor proposed changes to certain project elements. One example was the contractor's proposal to drive piles in one piece, which was not originally planned, but successfully executed thanks to the contractor's efforts. Conversely, the contractor's representative recalled the moment when a large boat arrived in Croatia, bringing a pile-driving machine from China. He remembered how everyone "relaxed" at that moment. A week later, the piles were quickly driven into the seabed. The technical competence and reliability of the construction team were recognized and valued by the client, contributing to a positive perception of the contractor's capabilities. This objective assessment of the contractor's expertise and performance was pivotal in maintaining a high level of trust. The project's highly positive progress also resonated with the public and media.

Affect-based trust

As the project progressed, client and contractor representatives at the construction site slowly got to know each other. This was aided by the fact that both client and contractor staff lived in a small town near the construction site. The client representative noted that, as the project progressed, they already knew each other "by name and surname" and knew what to expect from each individual. This mutual familiarity led to increased trust.

Point C – decline of trust

In late 2019 and early 2020, the global pandemic caused by the Covid-19 virus broke out. The pandemic started in China, leading to strict quarantine measures and business shutdowns in China. The pandemic policy in China was differed from that in Croatia. This unforeseen situation caused problems at the Pelješac Bridge construction site, affecting all aspects of the described relationship between the client and contractor, including *system-based*, *cognition-based*, and *affect-based* trust.

System-based trust

Under the pandemic's influence, it was necessary to adapt existing processes and enhance controls at the construction site, such as organizing the measurement of body temperature for individuals entering the site and quarantining those coming from other countries or falling ill. All these measures disrupted previously established processes that could no longer function as before. The frequency and quality of communication and information exchange decreased.

Cognition-based trust

The pandemic, an unprecedented global event, left project participants unable to predict the conditions under which bridge construction would continue. Trust in the contractor's competencies and mutual understanding was tested due to significant uncertainty.

Affect-based trust

At the beginning of the pandemic, contractor representatives began avoiding meetings and suggested partial remote work. Such behavior was unacceptable to the client, who disagreed with these proposals. Additionally, the contractor independently organized body temperature measurements for people before entering the construction site, which the client did not accept, believing that the client had the right to control entry into “their own yard.” The contractor’s representative recalled how the client pressured them to continue site operations according to established procedures, not understanding what was happening in China. Such situations and misunderstandings between the client and contractor created “great conflicts.” This was the first major test of the client-contractor relationship, causing doubt among the client’s team about whether the bridge construction could continue.

Point D – rebuilding of trust

The period required to rebuild trust between the client and contractor lasted until the summer of 2021 when the bridge’s span structure was completed. The moment the bridge physically connected the mainland with the Pelješac island was marked by the arrival of important politicians and public announcements.

System-based trust

During the extended period following the decline in trust, it was necessary to follow defined processes that functioned during the Covid-19 pandemic. The client accepted the need for strict epidemiological measures at the construction site, recognizing that this approach could successfully control workers’ health and all site personnel, ultimately ensuring the bridge’s construction according to the previous plan.

Cognition-based trust

The contractor invested significant efforts and financial resources to ensure a safe health environment at the construction site, attempting to minimize the pandemic’s impact on project progress. To ensure the quality of welding on the steel parts of the bridge, the contractor successfully organized the transport of welders from China. With strict epidemiological measures and considerable efforts to negotiate this with the Chinese government, workers were successfully brought to Croatia via a direct flight from China. The client recognized the contractor’s efforts in those uncertain times. Trust was rebuilt when the contractor completed the bridge’s span structure and began clearing the site. According to the client’s representative, the project’s end was already in sight, and optimism returned among project participants.

Affect-based trust

Under the strict conditions at the construction site and globally during the pandemic, the client and contractor representatives were located at the same town when travel was banned. The client representative noted that within the site boundaries, everything ran normally, adhering to additional health safety measures. The teams present at the site had to jointly combat the pandemic’s impact and maintain the highest health standards. The client representative mentioned that frequent changes in contractor representatives at the site hindered building trust. According to him, just as participants at the site got to know each other and learned to work together, the contractor's representatives would change. This meant starting the relationship-building process from scratch, making rebuilding trust much more challenging than at the project's start.

During the trust rebuilding period, it was also necessary to work on relationships with the contractors of the Pelješac Bridge access roads. The Chinese contractor showed readiness to allow the access road contractor to transport materials through the unfinished Pelješac Bridge to significantly save time. Great attention was paid to controlling these passages, and new protocols were defined to ensure the safety of this process.

Point E – end of the construction

In January 2022, the Pelješac Bridge was completed and received its use permit.

System-based trust

The client representative mentions that trust in the contract and processes was in continuous growth throughout the period of the construction. As the contract and processes are more utilized, a greater sense of security and trust in the system is created. Towards the end of the project, some new processes related to the contractor's claims for additional funds emerged, which were successfully resolved based on established procedures.

Cognition-based trust

The client representative emphasizes that by the end of the project's construction, "all masks had fallen," meaning the level of familiarity with the contractor, its competencies, its culture, and its representatives was extremely high. People had gotten used to each other by the end of this multi-year project.

Affect-based trust

The client representative notes that towards the end of the bridge construction, the client's focus was no longer on the relationship with the bridge contractor but had shifted to relationships with the access road contractors. A feeling of "relief" among the participants on the construction site is mentioned, especially at the end of the bridge's construction, as it was extremely important for both the client and the contractor to complete the Pelješac Bridge. There is also mention of improved interpersonal relationships at the end of the project because "a great burden had been lifted," meaning that expectations had been met and the project was successfully completed. The client representative stated that they were extremely satisfied with the relationship with the contractor and the way the contractor approached this project. It is highlighted that during the difficult times of the pandemic and uncertainty, it was possible to expect even a hold-up in works and additional claims, but the Chinese contractor prioritized the construction of the bridge, leaving uncertainties to be resolved later. The contractor's representative recalls a somewhat tougher situation for the contractor at the end of 2021 when the works on the bridge were nearing completion. He recalls the client's pressure to finish the works, although the contractor believed it had the right to extend the deadline. Although a compromise was eventually reached, from the contractor's perspective, trust at the end of the project was at a lower level than desired.

Regardless of the fluctuations in trust between the client and the contractor during the construction of the Pelješac Bridge, both representatives emphasize that they are extremely satisfied with the relationship between the client and the contractor. Additionally, there is a highlighted satisfaction with the successful completion of the project and the achievement of the common goal, which built trust throughout the entire construction period of the Pelješac Bridge.

5. Conclusion

This study aimed to investigate the dynamics of trust in construction projects through an analysis of a case study involving a large infrastructure project in a multicultural environment. The findings of this study proved the dynamics of trust in construction projects. In particular, trust in construction projects can evolve following the conceptual diagram with five distinct points.

Furthermore, the analysis of the Pelješac Bridge project showed the multifaceted nature of trust in construction projects. The project's success was significantly influenced by various elements of trust, categorized into system-based, cognition-based, and affect-based trust.

Interviews with the client's and contractor's representatives provided valuable findings about the dynamics of trust on the Pelješac Bridge project. The representatives emphasized that trust was not static but evolved with the project's progress, requiring continuous effort to sustain and rebuild when necessary. The insights from these interviews corroborated the literature review, offering a comprehensive understanding of the trust dynamics in the Pelješac Bridge project.

The study also showed that interaction between trust and culture is a multifaceted and dynamic process that plays a critical role in project success. Understanding how cultural dimensions influence trust can help construction project participants navigate the complexities of cross-cultural interactions. By fostering cultural awareness and open communication project participants can build and maintain trust in diverse cultural settings.

While this study offers valuable insights, it also has some limitations. The unique cultural and project-specific factors in the Pelješac Bridge project may not apply to other construction projects, especially in different cultural or organizational contexts. Furthermore, the data collected for this study was qualitative, gathered through semi-structured interviews. While providing deep insights, this type of data might introduce the subjective perspectives of the interviewees.

For future research, it would be beneficial to conduct comparative studies across multiple projects and cultural contexts to validate and extend the findings. Additionally, integrating quantitative measures of trust dynamics, such as surveys, could provide a more comprehensive understanding of how trust evolves in construction projects. Expanding the scope to include more diverse project types would also help in developing a more generalized model of trust dynamics in construction projects.

Overall, the study provides valuable insights into how trust evolves over time in construction projects, highlighting the critical moments when trust is built, eroded, and rebuilt. For practitioners in construction project management, the study offers a foundation for understanding and monitoring trust levels throughout a project's lifecycle. This can help project managers proactively manage relationships, anticipate potential trust breakdowns, and implement strategies to rebuild trust when necessary. The study also emphasizes the importance of cultural awareness and effective communication in fostering and maintaining trust in multicultural project environments.

The findings from this study provide valuable lessons for future projects, emphasizing the critical importance of trust in construction project management. The results of this study will advance our knowledge of how trust grows, erodes, and may be successfully managed to guarantee the success of construction projects.

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Enhancing Predictive Financial Models of Construction Works: A Study on Contract Amendments in EU co-financed Water Infrastructure Projects

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Abstract:

This paper investigates the analysis of contract amendments in infrastructure projects within the water sector, particularly those co-financed by the European Union. Focusing on contracts formulated under the FIDIC Red and Yellow Books, the study aims to scrutinize the increments in contracted prices and time extensions. The overarching objective is to glean insights for improving predictive financial models within project portfolios. By delving into the dynamics of contract variations and their implications, the research endeavors to provide a comprehensive understanding of the factors influencing cost and schedule adjustments in such projects. Through empirical analysis and case studies, this paper seeks to offer valuable data-driven perspectives for project managers, policymakers, and stakeholders involved in EU-supported water infrastructure ventures. The findings aim to contribute to more accurate financial forecasting and risk mitigation strategies, thereby enhancing the overall effectiveness and efficiency of project management in the realm of water resource development.

Keywords: *Contract adjustments; EU co-funding; FIDIC contracts; Financial modeling; Infrastructure projects*

1. Introduction

Infrastructure projects, especially those related to water management (Tortajada, 2014), are critical for the sustainable development of any country. In Croatia, such projects are mostly co-financed by the European Union (EU), which emphasizes the importance of sound financial planning and effective risk management. When projects are supported by EU funding, there is little room for financial errors, as missteps can lead to severe financial consequences. For this reason, accurate financial forecasts and strong risk mitigation strategies (Burlacu et al., 2022; Bodislav et al., 2020) are vital to ensuring the success of such projects.

Managing EU co-financed projects is further complicated by frequent contract amendments, often formulated under the FIDIC Red and Yellow Book terms (Fédération Internationale des Ingénieurs-Conseils). These amendments typically involve extensions of time and increases in contract value, which are not always adequately accounted in the initial financial forecasts. This oversight can lead to insufficient input data for accurate predictions, thereby increasing the financial and operational risks associated with project delivery.

Given the existing challenges, this study focuses on enhancing predictive financial models by analyzing contract amendments in EU co-financed water infrastructure projects. There are two main goals of this research:

1. Determine the average percentage of cost and time related amendments for different contract types in order to gain more accurate forecasting models

2. Determine main risks related to occurrence of budget and time contract amendments

The methodology involves a detailed examination of contract changes, specifically those resulting in extended durations and additional costs, as documented in the amendments to FIDIC Red and Yellow Book contracts. The research further incorporates a case study with portfolio manager to identify potential factors/risks influencing these amendments.

The structure of this paper is organized as follows: a comprehensive literature review to contextualize the study within existing research; a detailed description of the methods employed for data collection and analysis; presentation of the results derived from the empirical analysis and case study; and a discussion on the implications of these findings. The paper concludes with a summary of the key insights and recommendations for improving financial forecasting and risk management in EU co-financed water infrastructure projects, as well as emphasize the significance of the research and outline specific future research directions.

By providing a data-driven understanding of the factors that drive contract variations, this study aims to equip project managers, policymakers, and stakeholders with the knowledge necessary to enhance financial forecasting models. Ultimately, this will contribute to more effective and efficient management of water resource development projects, ensuring their timely and within-budget completion.

2. Literature review

Financial planning and forecasting are key components of managing complex projects and portfolios (Shahriar et al., 2021), particularly in the infrastructure sector. In this context, good financial planning helps to ensure that projects are completed on time and within their allotted budgets (Adugna, 2015), thus minimizing cost overruns and delays. Forecasting, in particular, gives project managers and decision-makers the ability to predict financial performance and plan accordingly based on expected future outcomes. In complex infrastructure projects, the accuracy of financial forecasts can significantly influence project's success.

Inaccurate forecasting can lead to funding shortfalls, unanticipated cost escalations, and project delays, all of which can jeopardize the project's viability and lead to substantial financial losses (Flyvbjerg, 2005). For example, study of Flyvbjerg et al. (2010) in transportation infrastructure sector showed that cost estimates used in decision are highly, systematically and significantly misleading. Therefore, more accurate financial planning and forecasting processes are essential to manage the inherent uncertainties and complexities (Cavalieri et al., 2019) associated with large-scale projects.

Risk management is another crucial aspect of managing complex projects (Kardes et al., 2013). It involves identifying, assessing, and mitigating risks that could potentially impact the project's objectives. In the context of infrastructure projects, risks can arise from various sources, including technical challenges, regulatory changes, environmental factors, financial uncertainties, etc.

Effective risk management ensures that potential issues are identified early and appropriate measures are taken to mitigate their impact. This proactive approach helps in avoiding or minimizing disruptions and keeps the project on track. In EU co-financed projects, where compliance with strict funding requirements is mandatory, precise risk management is even more critical to ensure that project adheres to its planned timeline and budget (Sjekavica Klepo et al., 2023).

Financial planning, forecasting, and risk management are interconnected processes that collectively contribute to the successful delivery of complex projects. Accurate financial forecasts depend on a thorough understanding of the potential risks and uncertainties associated with the project (Ghallab and Hosain, 2020; Steininger et al., 2021). Similarly, effective risk management requires detailed financial plans that account for various risk scenarios and their potential financial impact.

In EU co-financed infrastructure projects, this interconnection becomes particularly important. These projects often involve significant financial investments and are subject to rigorous oversight and compliance requirements. Therefore, integrating financial planning, forecasting, and risk management processes is essential to ensure that the project remains viable and meets its objectives.

The accuracy of financial forecasting models largely depends on the quality and comprehensiveness of input data, otherwise, a well-known *garbage in - garbage out* problem may occur (Briloff, 2001). Key input data for financial forecasting models in infrastructure projects should include:

- Historical financial data: Historical cost data from similar projects provide a baseline for estimating future costs (Flyvbjerg, 2005). This includes data on labor, materials, equipment, and other expenses.
- Project scope and timeline: Detailed information about the project's scope and timeline (Chan et al., 2004) helps in estimating the costs associated with different project phases.
- Market conditions (Zou et al., 2007): Data on current market conditions, including inflation rates, labor costs, and material prices, are crucial for making accurate cost predictions.
- Risk assessments: Data from risk assessments, including identified risks and their potential impact on costs and timelines (Al-Momani, 2000), provide valuable inputs for financial models.
- Contract agreements: Information about the terms and conditions of contract agreements, including payment schedules, milestones, and penalties, is essential for financial forecasting.
- Contract amendments: Changes to the original contract, such as duration extensions and cost increases, significantly impact the financial forecasts.

Contract amendments, particularly those involving extensions of duration and increases in contract value, play a crucial role in financial forecasting for construction projects (Potts and Ankrah, 2014). However, stakeholders often overlook or inadequately account for contract amendments in financial forecasts (Teicholz, 1993). This oversight can lead to inaccurate predictions and increased financial risks.

Contract amendments occur due to various reasons, including unforeseen site conditions, design changes, regulatory requirements, and delays caused by different factors. These changes can impact project's costs and timelines. Failing to incorporate them into financial forecasts can result in substantial deviations from the planned budget and schedule, which can lead to credibility issues regardless of forecasting technique used.

In the context of EU co-financed projects, where strict adherence to budget and timelines is essential for compliance and funding purposes, overlooking contract amendments can have serious implications. Therefore, it is imperative to consider these amendments as critical input data for financial forecasting models, and all with the aim to enhance existing forecasting models in term of cost and time. Namely, time and cost have always play a crucial importance in project management areas, regardless different project characteristics (Assaad et al., 2020).

Due to this, this study aims to enhance predictive forecasting models for construction works for infrastructure projects in water-utility sector.

Currently, in Croatia, several different techniques, as well as their combinations are used when assessing overall cost performance of water infrastructure portfolio, some of which are:

- Models that include expected variation in contracted value in accordance to planned value (Knezevic et al., 2023)
- AI-based prognostic models for forecasting of winning bid, i.e. contracted amount and possible range of contracted value (Sjekavica-Klepo et al., 2024)
- S-curves based cost forecasting models during project implementation (Sjekavica-Klepo et al., 2022)

Cost performance forecasting is used mostly for the need of EU grants absorption prediction. Time performance forecasting is used for the means of project indicators, i.e. measures of project success, fulfilment prediction.

None of the existing models included expected contract amendments in accordance to initially planned/contracted values. The first two models are linked to better prediction of contracted value based on planned procurement value. Although certain cost increase prediction is calculated via S-curves approach, the amount of expected amendments value is not made on the transparent manner, disabling the opportunity to forecast final project value and/or duration before the actual implementation starts, and before the new, increased by contract amendments baseline becomes current baseline.

3. Methods, results and discussion

In addressing the challenges outlined in the introduction, this study adopted a two-step research methodology. Each step corresponds to one of the two main goals of the research. The first step involved a descriptive statistical analysis of historical data on contract amendments for FIDIC Red and Yellow Book contracts.

By examining past trends in contract amendments, authors calculated the average increase in costs and time extensions across various types of projects. These averages provide a useful baseline for predicting future amendments in similar projects. Additionally, historical trends were reviewed to identify any patterns or shifts in contract amendment practices over time.

Second step included qualitative approach based on case study analysis. Case study consists of water infrastructure EU co-financed portfolio (Table 1). Portfolio manager was interviewed in order to gain a deeper understanding of materialized risks or factors in general, that can explain phenomena discovered in the first step of the research.

Sample consisted of 56 EU co-financed large projects of water-utility infrastructure, through which water and sewage systems, wastewater treatment plants, drinking water facilities and sludge treatment plants are constructed. Red FIDIC Book contracts are thereby mostly used for construction of pipework and Yellow Book for treatment plants. Details on the sample can be seen in Table 1.

Table 1. Portfolio (case study) sample details

Portfolio feature	Value
PROJECTS	
Number of projects	56
Portfolio total value	3.397.051.458,70 EUR
Portfolio eligible costs	2.698.064.550,03 EUR
Portfolio grants value	1.906.156.706,84 EUR
CONTRACTS	
Number of works contracts with amendments	157
Number of works contracts with amendments – Red FIDIC	113
Number of works contracts with amendments – Yellow FIDIC	44
Number of works contracts amendments	956
Number of works contracts amendments – Red FIDIC	769
Number of works contracts amendments – Yellow FIDIC	187
Average number of contract amendments per contract – Red FIDIC	7
Average number of contract amendments per contract – Yellow FIDIC	4
Number of changes' types via amendments	1.166
Contracts eligible costs	2.306.014.877,93 EUR

Through 956 contract amendments, a total number of 1.166 change types were made. Distribution of change types can be seen on Figure 1. This research is focused on time and price extensions, so authors made further calculations on those two type of contact amendments.

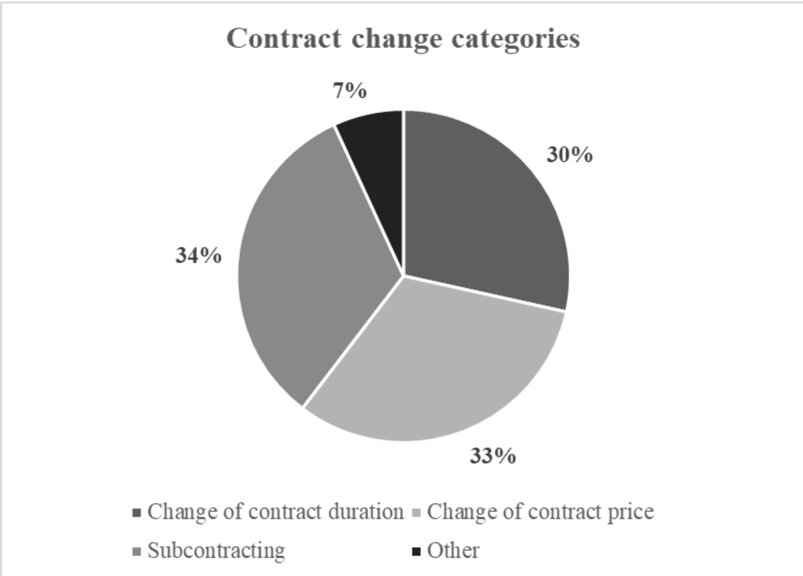

Figure 1. Contract change categories

Maximum percentage of price increase or duration extension per contract in the sample was calculated. Based on this calculation, an average value of expected increases and extensions per contract type was calculated, given in Table 2.

Table 2. Average maximum price increase and duration extension per contract type

AMENDMENT TYPE	%
PRICE INCREASE	
Red FIDIC	7,58
Yellow FIDIC	7,19
DURATION EXTENSION	
Red FIDIC	45,66
Yellow FIDIC	39,09

In addition to this calculation, average increase and extension values were analyzed by contract type through years. Results of this analysis can be seen on Figures 2-5.

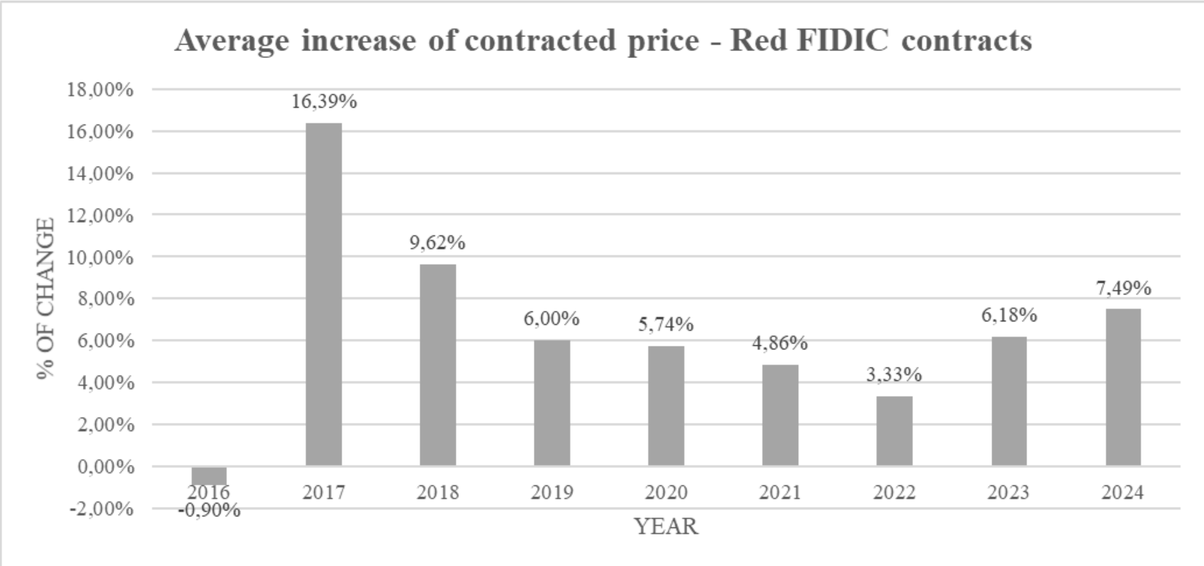

Figure 2. Average increase of contracted price – Red FIDIC contracts

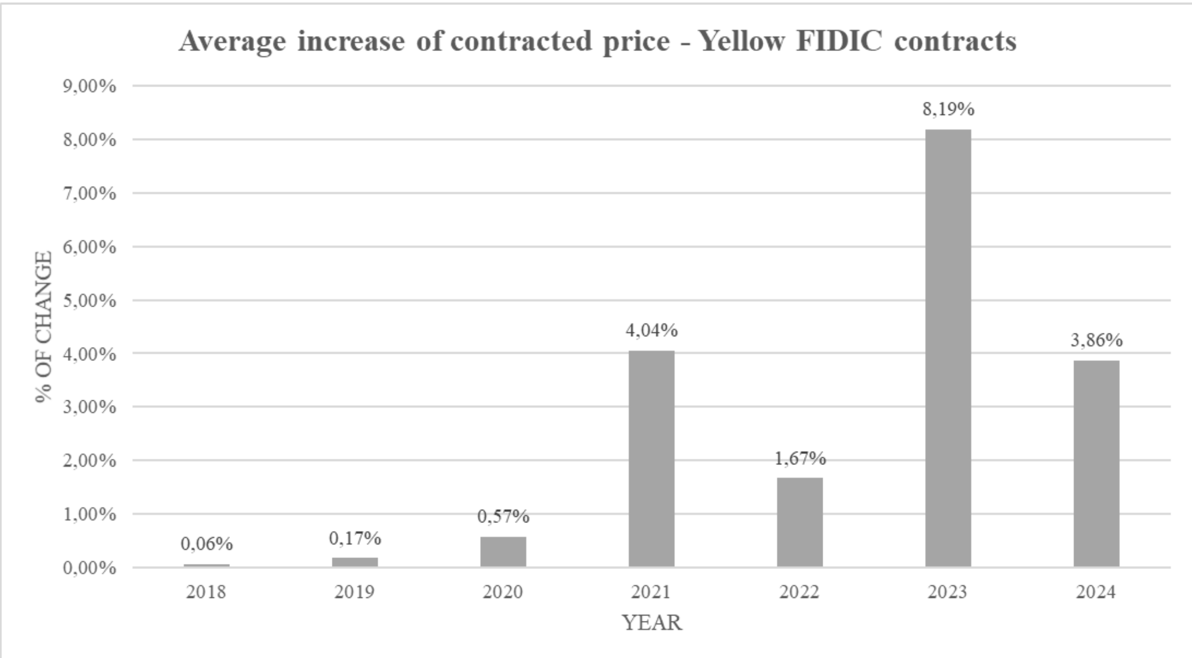

Figure 3. Average increase of contracted price – Yellow FIDIC contracts

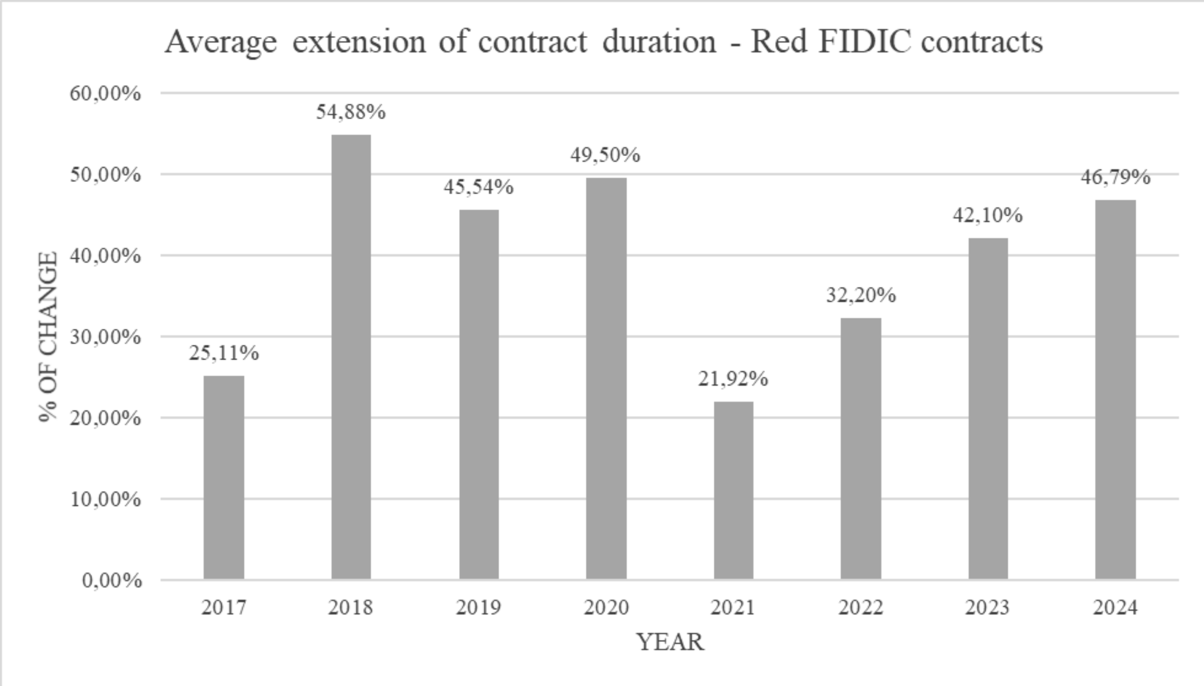

Figure 4. Average extension of contract duration – Red FIDIC contracts

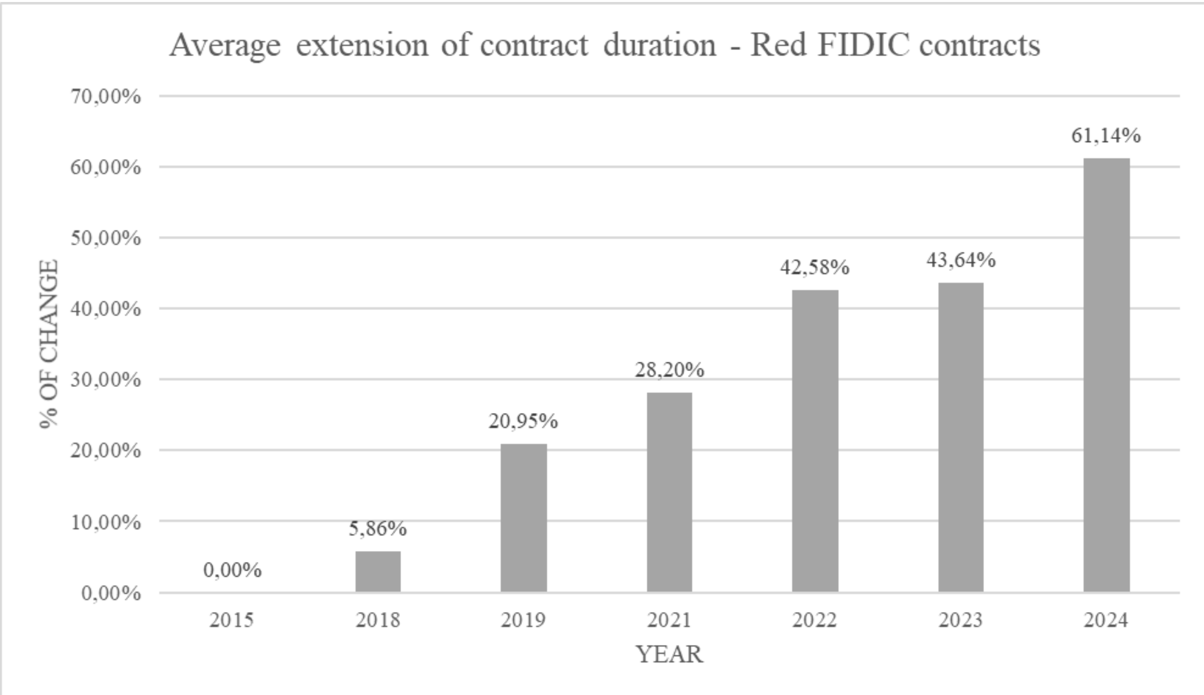

Figure 5. Average extension of contract duration – Yellow FIDIC contracts

After conducting descriptive analysis, in order to gain deeper understanding of presented results, portfolio manager was interviewed. Portfolio manager has 15 years of work experience on construction projects, out of which 8 on EU projects, has collage degree in construction management and is IPMA certificated. Interview was semi-structured, allowing interviewer to explore deeper certain elements that portfolio manager brought up. Based on answers to interview questions, a discussion on results is made.

Firstly, one of the main advantage of these results are shown in Table 2. These percentages of expected price increase and duration extensions should be calculated into financial and physical implementation prognostic models.

It is quite significant that current value of portfolio with increased contracts is 6.114.964.727,64 EUR, which is increase of 5% in accordance to initial value of these contracts.

Regarding the phenomena of price increase on Red FIDIC contracts (Figure 2), in the period before 2017 the contracted prices on the contracts were mostly below the procurement estimated values. Therefore, it can be concluded that due to the relatively small number of large infrastructure projects, the construction sector may had offered lower or even dumping prices that did not necessarily reflect the real value of work on the market. As it is common for projects to contract additional works, i.e. extra budgetary works, the assumption is that Contractors probably contracted amendments according to real market prices. Therefore, in 2017, there was a significant increase (16,39%) in contract values in comparison to the initially contracted values.

Given the fact that the number of investments of large infrastructure type, has increased over the following years, the market has responded in such a way that the offered prices, and consequently the contracted values, have exceeded the estimated procurement values. Throughout the years, the increases in bids prices (as well as initial contracted values) have grown more and more. This was consequently reflected in a reduction of the percentage increase through contract amendments over the years 2019-2022.

In 2023 and 2024, there was again a slight increase in the percentage of price changes, which can be associated with the increase in contract values from the aspect of contracting price differences as consequence of market disruption.

Due to their specificity, in Yellow FIDIC contracts, percentages of increase in contract values compared to the initial contracted values are significantly lower than those in Red FIDIC contracts (Figure 3). Namely, through this type of contract, the bidder defines its designed solution and accordingly – the price of this solution. This reduces extra budgetary works and the need to contract them in the execution of the contract. . Extra budgetary works therefore primarily result from additional requirements of the Client that were not foreseen in the public procurement process.

Additionally, a significant percentage increase was also evident during 2023 and 2024, which, is associated with the contracting of price differences, as well as in Red FIDIC contracts.

Namely, for a long time, the construction market in Croatia has been facing the problem of labour shortages and, particularly, significant increase in the prices of raw materials such as plastic and iron. This increase has further extended to other materials (stone aggregate, cement, concrete), potentially leading to a slowdown in project implementation dynamics.

In addition to the existing problem of material prices rise, followed by increase in material costs, in 2022 we have also witnessed a significant rise in energy prices. This had not only affected the increase in material costs but also the cost of labour (machine work).

Also, situations occurred where bidders refuse to sign contracts due to time elapsed from the bid submission to the Decision of bid selection because of: long lasting procurement procedures, necessity for authority approval for concluding contracts exceeding the estimated values, and monthly increase in material and energy prices.

Throughout 2023, issues related to the calculation and approval of price differences continued, especially in the regard of EU eligibility of these extra costs. During 2023, several contracts were even cancelled, which will affect the extension of the implementation of certain projects.

During 2023, different project categories were systematically defined, based on the projected completion possibilities. Thus, projects were proposed for continued financing through phasing or securing national funding for completion.

Duration extensions on these type of projects are mostly consequence of materialized risks that prolonged construction duration and fulfilment of project indicators.

In the analyzed period, the most significant risks of those kind were: property and legal affairs, archaeological findings on site, difficulty in material supply due to disruptions in distribution chains, COVID-19 pandemic, public authorities and offices delays in issuing construction and occupancy permits and their amendments, changes in the environmental documentation procedure, and changes of bided technology (the last one specifically regarding to Yellow FIDIC contracts).

4. Conclusion

This research focused on analyzing contract amendments in EU-financed water infrastructure projects, with the goal of improving predictive financial models. By calculating the average cost increases and duration extensions for FIDIC Red and Yellow Book contracts, the study provides important data that can be used to enhance financial forecasts for future projects. In accordance to presented results, average inputs to be added to current prognostic models were obtained, which can be of significant use to broad number of stakeholders – Contractors, Grants Beneficiaries and Competent Authorities.

By introducing new elements regarding contract amendments in existing prognostic models, which were not in use up to this point, authors managed to make a novel approach, with potentially significant impact on the forecasting in industry. Authorities in charge for strategic planning can make their projections more effective, potential Beneficiaries can make more realistic feasibility studies and Contractors can be acquainted with financial framework within which contract implementation should take place.

The main constraint of this research is the fact that it was designed for EU co-financed projects in water infrastructure sector in Croatia. In order to broader results, analogous researches can be conducted in different sectors or countries.

The study also identified several key risks that contribute to contract amendments, including regulatory delays, market fluctuations, and supply chain disruptions. These insights offer practical recommendations for project managers and policymakers looking to minimize the impact of contract amendments on project timelines and budgets.

In order to further develop prognostic and project management systems, future research will be focused on determination of predictive/corrective factor values in planning. These factors will be a representation of impact level that most significant risks may make on contracted duration extensions. This specific future research direction will have a goal to simplify time planning in all project phases.

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Industry 5.0: Advancing Sustainability, Human-Centricity, and Resilience through Ethical Project Management

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Abstract:

Industry 5.0 represents a paradigm shift emphasizing the integration of human intelligence with advanced technologies to foster sustainability, human-centricity, and resilience. This paper explores the implications of Industry 5.0 from project management and ethical perspectives. It highlights how sustainable practices can be integrated into industrial processes, reducing environmental impact and promoting resource efficiency. The human-centric approach prioritizes worker well-being, advocating for intelligent systems that enhance human capabilities without displacing the workforce. Resilience is addressed through adaptive project management strategies that anticipate and mitigate risks, ensuring continuity and robustness in operations. Ethical considerations are paramount, underscoring the need for transparency, accountability, and inclusivity in implementing Industry 5.0 technologies. This paper argues that ethical project management frameworks are crucial for balancing technological advancement with social responsibility, ensuring that Industry 5.0 serves not only economic goals but also societal well-being. By examining case studies and best practices, this research provides actionable insights for managers and policymakers aiming to leverage Industry 5.0 for a more sustainable, human-centric, and resilient industrial future.

Keywords: *Industry 5.0, Sustainability, Human-Centric Approach, Resilience, Ethical Project Management*

1. Introduction

As the world grapples with the pressing challenges of sustainability, human-centric development, and supply chain resilience, the emergence of Industry 5.0 offers a promising path forward. Industry 5.0 is a paradigm shift that seeks to harmonize the strengths of advanced technologies, such as artificial intelligence and robotics, with the creativity and problem-solving abilities of human workers (Ahmed, 2023) (Harikannan, 2023). Unlike the previous iteration of Industry 4.0, which prioritized automation and efficiency over human considerations, Industry 5.0 places a strong emphasis on sustainability, ethical practices, and the well-being of individuals (Ahmed, 2023).

At the heart of this new industrial revolution is the recognition that true progress can only be achieved through a delicate balance between technological advancements and human-centric values. By leveraging the power of disruptive technologies, such as the Internet of Things, digital twins, and big data analytics, while also fostering human creativity and collaboration, Industry 5.0 offers a holistic approach to addressing the pressing challenges of our time (Jamwal, 2021) (Ahmed, 2023).

One of the key pillars of Industry 5.0 is the advancement of sustainable practices across the entire value chain. By integrating sustainable technologies and processes, companies can not only reduce their environmental footprint but also contribute to the broader goals of sustainable development (Jamwal, 2021).

The primary objectives of this paper are:

1. To investigate and develop practical frameworks for integrating Industry 5.0 principles into project management methodologies (IPMA, PMI, ISO), with a focus on sustainability, human-centric approaches, and resilience, while addressing the specific ethical considerations arising from the use of advanced technologies.

2. To conduct empirical research that demonstrates successful implementation of sustainable practices, human-centric approaches, and resilience strategies in Industry 5.0.

3. To identify and address research gaps such as the need for practical guidance and detailed case studies, providing actionable insights and best practices for managers and policymakers.

4. By examining the intersection of Industry 5.0 and project management, this paper aims to provide actionable insights for managers and policymakers. It seeks to demonstrate how ethical project management frameworks can balance technological advancement with social responsibility, ensuring that Industry 5.0 serves not only economic goals but also societal well-being. This introduction sets the stage for a comprehensive exploration of Industry 5.0 and its implications for project management, sustainability, human-centricity, and ethics.

2. Understanding Industry 5.0: Definition And Key Concepts

The European Commission introduced its Industry 5.0 agenda in 2021, targeting the development of an industry that is sustainable, human-centric, and resilient (European Commission, 2021).

Sustainability in the context of Industry 5.0 encompasses a holistic approach to manufacturing, where environmental, social, and economic considerations are integrated into business strategies (Jamwal et al., 2021). Human-centricity, on the other hand, refers to the active involvement of human workers in the decision-making and problem-solving processes, leveraging their expertise and creativity to complement the capabilities of intelligent systems (Ahmed, 2023). Finally, resilience in Industry 5.0 is achieved through the integration of advanced technologies, such as artificial intelligence and digital twins, which enable real-time monitoring, analysis, and adaptation of production systems to respond to changing market conditions and unexpected disruptions (Attaran, 2023).

As digitally transformed industries strive to achieve ambitious outcomes, the alignment between legal and ethical imperatives has become increasingly challenging to attain (Dhirani, 2023). In this context, the ethical theories underpinning Industry 5.0 must be thoroughly understood and mapped against the prevailing legal and regulatory landscape (Dhirani, 2023). Only then can the ethical and privacy issues associated with enabling technologies be effectively mitigated (Dhirani, 2023).

The paper “The human-centric Industry 5.0 collaboration architecture” (Attila Tóth, 2023) focuses on the human-centric aspect and indirectly addresses the roles of ethics, sustainability, and resilience in Industry 5.0. The proposed Industry 5.0 collaboration architecture aims to establish a truly integrated human-AI collaboration model, emphasizing the importance of keeping humans empowered and in control within industrial processes. This approach inherently incorporates ethical considerations by ensuring that AI and technological advancements complement human capabilities rather than replace them. The framework's focus on adaptability and knowledge sharing contributes to the resilience of industrial systems, while its potential applicability to broader societal contexts suggests a commitment to sustainable practices that extend beyond mere industrial efficiency (Attila Tóth, 2023).

In conclusion, Industry 5.0 represents a paradigm shift in industrial development, emphasizing sustainability, human-centricity, and resilience while navigating the complex interplay of technological advancement, ethical considerations, and regulatory frameworks to create a more balanced and responsible industrial ecosystem.

3. Industry 5.0 and Project Management

3.1. Industry 5.0 and PM in Academic Publications

In the database of academic publications by Elsevier (Elsevier, 2024), the search for the keywords "Industry 5.0" and "project management" yields 61 results. All keywords from those 61 papers were copied into a table and listed by frequency, if mentioned more than once. The research eliminated those keywords that appeared only once.

Table 1. Keywords "Industry 5.0" and "Project Management" in the Elsevier Database.

Keyword	Frequency
Industry 4.0	14
Industry 5.0	10
Sustainability	5
Digitalization	5
Blockchain	3
Circular economy	3
Internet of things	2
Innovation	2
Big data	2
Engineering Education	2
Interoperability	2
Computer-integrated manufacturing	2
Sustainable manufacturing	2
Cloud-based systems	2
Digitalisation	2
Systematic literature review	2
Manufacturing	2
Industrial internet of things	2
Business model	2
Machine learning	2

Conclusions from the literature analysis:

High Relevance of Industry 4.0 and Industry 5.0: The most frequently mentioned keyword "Industry 4.0" with 14 occurrences indicates its significant relevance in the context of Industry 5.0 and project management. This suggests that Industry 5.0 is often discussed in relation to the advancements and frameworks established by Industry 4.0. With 10 mentions, it is clear that the concept of Industry 5.0 is a central focus of the academic discourse, reflecting a strong interest in the transition or co-evolution from Industry 4.0 to Industry 5.0.

Focus on Sustainability and Digitalization: Sustainability and Digitalization each with 5 mentions, highlight the critical areas of interest. Sustainability's frequent occurrence suggests that integrating sustainable practices within Industry 5.0 is a major concern. Similarly, digitalization indicates the ongoing importance of digitizing processes and the digital transformation in manufacturing and project management.

Emerging Technologies and Concepts: Keywords like Blockchain (3 mentions), Internet of things (2 mentions), and Big data (2 mentions) show the emphasis on integrating advanced technologies in Industry 5.0. These technologies are likely seen as enablers for achieving the goals of Industry 5.0, such as enhanced automation, smarter manufacturing, and improved supply chain management.

Circular Economy and Sustainable Manufacturing: The mentions of Circular economy (3 mentions) and Sustainable manufacturing (2 mentions) underline a growing focus on sustainable industrial practices. This indicates a shift towards more environmentally friendly and resource-efficient manufacturing processes.

Educational and Organizational Adaptations: Engineering Education (2 mentions) and Business model (2 mentions) suggest an interest in the educational and organizational changes necessary to support Industry 5.0. This implies that academic research is also concerned with preparing the future workforce and evolving business strategies to align with Industry 5.0 principles.

Despite the extensive focus on advanced technologies and sustainable practices, a notable gap in the keyword frequency analysis is the lack of emphasis on human-centric and ethical considerations. Key terms such as "human-centric design," "ethics," "social impact," "human factors," and "well-being" are conspicuously absent from the list. This omission suggests several potential implications:

- Technology-Centric Focus: The overwhelming presence of machine- and technology-related keywords indicates that current research is heavily oriented towards the technical and operational aspects of Industry 5.0 and project management. This could imply a prioritization of technological advancements over human-centered approaches.

- Neglect of Human Factors: The absence of human-centric keywords raises concerns about the extent to which human factors are being considered in the development and implementation of Industry 5.0 technologies. Ensuring that these technologies enhance human well-being, job satisfaction, and safety is crucial for their sustainable adoption.

- Ethical Considerations: The lack of ethical keywords suggests that discussions around the ethical implications of Industry 5.0 technologies, such as data privacy, algorithmic fairness, and the socio-economic impact on workers, might be underrepresented. Addressing these ethical concerns is vital to ensure that technological advancements do not lead to unintended negative consequences.

- Holistic Approach: A truly holistic approach to Industry 5.0 should integrate both technological innovations and human-centric considerations. Balancing these aspects can lead to more socially responsible and widely accepted advancements.

The analysis indicates a comprehensive approach to Industry 5.0 and project management, with a strong emphasis on integrating advanced technologies, promoting sustainability, and ensuring interoperability. However, the lack of human-centric and ethical keywords highlights a critical area that needs more attention. Future research and practice should strive to incorporate these dimensions to achieve a balanced and inclusive progression towards Industry 5.0, ensuring that technological advancements are aligned with human values and societal well-being.

3.2. Integration of Industry 5.0 in Project Management Methodologies

The principles of Industry 5.0, which emphasize the integration of human-centric and sustainable approaches, have the potential to revolutionize the field of project management (Morrison, 2004). This chapter explores how the key concepts of Industry 5.0 can be applied to popular project management methodologies, such as the IPMA Standards, the Project Management Institute (PMI), and the International Organization for Standardization (ISO).

One of the key aspects of Industry 5.0 is the recognition of the pivotal role played by human workers in the manufacturing process (Morrison, 2004). Similarly, in project management, the effective management of stakeholders has been identified as a critical factor in project success (Rajablu, 2014). By embracing the stakeholder-centric approach advocated by Industry 5.0, project managers can better align their initiatives with the needs and expectations of all individuals and entities affected by the project (Rajablu, 2014).

Furthermore, the emphasis on sustainability in Industry 5. 0 can be translated to project management through the adoption of more environmentally conscious practices and the consideration of long-term societal and environmental impacts (Muriithi, 2003). This aligns with the growing focus on sustainable project management, which is reflected in the evolving standards and guidelines of organizations such as the IPMA, PMI, and ISO (Muriithi, 2003).

In addition to the human and environmental elements, Industry 5.0 also highlights the importance of technological integration and innovation (Morrison, 2004). This principle can be applied to project management through the leveraging of emerging technologies, such as artificial intelligence and machine learning, to enhance decision-making, optimize resource allocation, and improve overall project performance (Ibbs, 2000).

By incorporating the principles of Industry 5. 0 into their project management practices, organizations can not only enhance the effectiveness of their initiatives but also contribute to the creation of a more sustainable and socially responsible business environment (Muriithi, 2003) (Morrison, 2004) (Harikannan, 2023) (Ahmed, 2023).

The IPMA Standards, PMI, and ISO have already begun to align their frameworks with the evolving needs of the industry, but there is still significant potential for further integration of the Industry 5.0 principles.

IPMA

The International Project Management Association (IPMA) emphasizes competence-based project management. The IPMA Individual Competence Baseline (ICB) (IPMA International Project Management Association, 2015) addresses several key elements of Industry 5.0, including sustainability, resilience, and ethical project management. The ICB emphasizes the importance of sustainability by integrating principles that balance social, environmental, and economic demands. It encourages project managers to assess the impact of their projects on the environment and society, and to apply measures that limit or compensate for negative consequences, aligning project objectives with organizational sustainability strategies. Resilience is addressed through the development of competences that enable individuals to handle uncertainty, problems, and stressful situations effectively. This includes fostering a culture of continuous improvement, learning from past projects, and adapting to changing circumstances. Ethical project management is underscored by the inclusion of codes of ethics, business conduct, and professional standards, ensuring that project managers operate within legal and ethical boundaries and promote integrity and reliability in their actions.

To better align with Industry 5.0, the IPMA could elaborate more on the following areas:

1. The integration of advanced technologies and human-centric approaches, example, leveraging AI and machine learning for project management, enhancing human-machine collaboration, and fostering innovation through digital transformation.

2. The expansion on the role of ethical considerations in the use of emerging technologies and the importance of stakeholder engagement in creating sustainable and resilient project outcomes.

3. IPMA's Code of Ethics and Professional Conduct can be also expanded to include considerations specific to Industry 5.0, such as transparency, accountability, and inclusivity in the implementation of advanced technologies.

PMI

The Project Management Body of Knowledge (PMBOK) (PMI Project Management Institute, 2021) provides a comprehensive framework for project management, encompassing various processes, tools, and techniques that are essential for managing projects effectively. PMBOK addresses key elements of Industry 5.0, such as sustainability, resilience, and ethical project management, through its structured approach to project management. For instance, PMBOK emphasizes the importance of stakeholder engagement, risk management, and continuous improvement, which are crucial for achieving sustainability and resilience in projects. The guide also highlights the need for ethical considerations in project management, ensuring that projects are conducted with integrity and respect for all stakeholders involved.

However, to better align with the principles of Industry 5.0, PMBOK could further elaborate on several areas:

- To provide more detailed guidelines on integrating sustainability into all phases of project management, from initiation to closing, ensuring that environmental and social impacts are considered throughout the project lifecycle.

- To enhance its focus on resilience by offering more robust strategies for managing disruptions and ensuring project continuity in the face of unforeseen challenges.

- To expand on ethical project management by incorporating more comprehensive frameworks for ethical decision-making and promoting a culture of transparency and accountability within project teams.

ISO

ISO standards for project management (ISO: the International Organization for Standardization, 2024), particularly ISO 21500, provide a comprehensive framework for guiding project management practices across various types of organizations. These standards emphasize the importance of structured processes, stakeholder engagement, and the integration of project management with organizational strategy. However, as industries evolve towards Industry 5.0, which emphasizes sustainability, resilience, and human-centric approaches, there are opportunities for ISO standards to further elaborate on these elements:

- Sustainability: ISO 21500 and related standards like ISO 10006 and ISO 31000 touch upon quality and risk management, which are crucial for sustainable practices (ISO: the International Organization for Standardization, 2024). However, they could be expanded to include more explicit guidelines on environmental sustainability, such as incorporating lifecycle assessments and eco-design principles directly into project management processes.

- Resilience: While ISO 21500 provides a solid foundation for risk management (ISO: the International Organization for Standardization, 2024), aligning with ISO 31000, it could benefit from more detailed strategies on building resilience. This includes adaptive project management techniques that can respond to disruptions, such as those caused by geopolitical shifts or pandemics, which are critical in the context of Industry 5.0.

- Ethical Project Management: Ethical considerations are increasingly important in Industry 5.0, particularly with the integration of AI and other advanced technologies. ISO standards could be enhanced by incorporating ethical guidelines for AI usage, data privacy, and human-centric project management practices, ensuring that technology serves to augment human capabilities rather than replace them.

3.3. Framework for Human-Centric and Ethical Project Management

Industry 5.0 places a strong emphasis on the human-centric approach, which prioritizes the well-being and empowerment of workers. Based on the analysis in the previous chapters, the author summarized the recommendations how global project management organizations and methodologies could better address human-centric and ethical project management.

Table 2. Recommendations for the PM organizations.

Recommendation	IPMA	PMI	ISO
Enhanced Integration of Advanced Technologies	Develop comprehensive guidelines on leveraging AI and machine learning for project management. Include strategies for enhancing human-machine collaboration and fostering innovation through digital transformation.	Elaborate on the integration of digital tools and technologies throughout the project lifecycle, providing detailed frameworks for their ethical and effective use.	Introduce specific standards for the ethical use of AI and data privacy within project management, ensuring adherence to ethical guidelines and protection of stakeholder interests.
Strengthened Focus on Sustainability	Expand sections on sustainability to include detailed methodologies for assessing and mitigating environmental impacts. Emphasize the importance of aligning project objectives with organizational sustainability strategies.	Provide more detailed guidelines on integrating sustainability into all phases of project management, ensuring environmental and social impacts are considered throughout the project lifecycle.	Incorporate explicit guidelines on environmental sustainability, such as lifecycle assessments and eco-design principles, directly into project management processes.

Robust Strategies for Resilience	Foster a culture of continuous improvement and learning from past projects. Develop competences that enable project managers to handle uncertainty and adapt to changing circumstances effectively.	Enhance the focus on resilience by offering robust strategies for managing disruptions and ensuring project continuity in the face of unforeseen challenges.	Provide detailed strategies on building resilience, including adaptive project management techniques and the use of digital twins and real-time monitoring to anticipate and respond to disruptions.
Comprehensive Ethical Frameworks	Expand the Code of Ethics and Professional Conduct to include considerations specific to Industry 5.0, such as transparency, accountability, and inclusivity in the implementation of advanced technologies.	Incorporate more comprehensive frameworks for ethical decision-making, promoting a culture of transparency and accountability within project teams.	Enhance ethical guidelines for AI usage and data privacy, ensuring that project management practices are aligned with human-centric principles and ethical standards.
Stakeholder Engagement and Inclusivity	All: Emphasize the importance of stakeholder engagement in creating sustainable and resilient project outcomes. Develop frameworks that ensure inclusivity and address the interests of all stakeholders involved in the project.		

By implementing these recommendations, global project management organizations and methodologies can better address the demands of Industry 5.0, ensuring that projects are not only efficient and effective but also sustainable, resilient, and ethically managed. This holistic approach will foster a more human-centric industrial ecosystem that leverages advanced technologies to enhance human capabilities and improve overall project outcomes.

3.4. Adoption of Industry 5.0 Principles by Leading Global Companies

This chapter explores how top companies are addressing Industry 5.0-related concepts, focusing on keywords such as "Industry 5.0," "project management," "ethics," "sustainability," and "human-centrism."

The analysis involved examining the websites of the selected five S&P 500 companies (Stockanalysis, 2024) and five largest companies headquartered in Europe from the Fortune Global 500 List (Fortune, 2023) for the presence of the specified keywords. The companies were chosen based on their significant weight in the index, ensuring a representative sample of the largest and most influential firms.

Table 3. Research Findings from the S&P 500 List.

Company Name	Website URL	Industry 5.0	Project Management	Ethics	Sustainability	Human Centrism
Microsoft Corporation	https://www.microsoft.com	0	frequently	frequently	frequently	frequently
Apple Inc.	https://www.apple.com	3	frequently	frequently	frequently	0
NVIDIA Corporation	https://www.nvidia.com	frequently	frequently	frequently	frequently	0

Amazon.com, Inc. (except for the products / books)	https://www.amazon.com	0	frequently	frequently	frequently	frequently
Meta Platforms Inc	https://www.meta.com	0	3	frequently	frequently	0

The analysis of Table 3 highlights how different tech giants prioritize various key concepts. Industry 5.0 is a concept that has varying degrees of presence across these companies. NVIDIA Corporation frequently discusses Industry 5.0, indicating a strong focus on advanced manufacturing and integrating human-centric approaches with automation and AI. Apple Inc. also mentions it a few times, reflecting some engagement with the concept. However, Microsoft, Amazon, and Meta do not mention Industry 5.0, suggesting that they may prioritize other technological advancements or industrial strategies.

Ethics and sustainability are universally emphasized, and project management also remains a foundational element across the board, reflecting its importance in successful business operations. Human centrism is particularly emphasized by Microsoft and Amazon, indicating their focus on user-centered design and experiences.

Table 4. Research Findings from the Fortune Global 500 List.

Company Name	Website URL	Industry 5.0	Project Management	Ethics	Sustainability	Human-Centrism
Shell	https://www.shell.com	0	frequently	frequently	frequently	0
Volkswagen	https://www.volkswagen.com	0	frequently	frequently	frequently	0
Uniper	https://www.uniper.energy	0	frequently	frequently	frequently	0
TotalEnergies	https://www.totalenergies.com	0	frequently	frequently	frequently	0
Glencore	https://www.glencore.com	0	frequently	frequently	frequently	0

Based on the analysis of Table 4, none of the companies mention “Industry 5.0” on their websites. This indicates that the concept of Industry 5.0 might not yet be a focal point in their publicly available materials or communications. Companies might still be focusing on Industry 4.0 technologies and innovations.

“Project Management” is frequently mentioned across all companies. This highlights the importance of structured project management practices in ensuring the successful execution and completion of various projects, which is critical in industries such as energy and automotive that involve large-scale and complex projects.

The term “Ethics” is also frequently mentioned by all companies. This emphasizes their commitment to ethical business practices, compliance, and governance. For example, companies like Glencore and TotalEnergies have comprehensive ethics and compliance programs to ensure they operate responsibly and transparently.

Sustainability is a recurring theme on all the analyzed websites. This reflects the companies' dedication to sustainable development and their efforts to reduce environmental impact, promote renewable energy, and implement sustainable practices across their operations.

The specific terms "Human-Centrism" and "Human-Centric Approach" are notably absent. However, these companies focus extensively on human rights, employee welfare, and stakeholder engagement, which could be considered aspects of human-centric approaches. For example, TotalEnergies and Shell both have strong commitments to human rights and community engagement, which indicates a broader, albeit less explicitly named, focus on human-centered values.

In short, the analysis reveals a strong emphasis on project management, ethics, and sustainability across the board, reflecting these companies' strategic priorities in managing large-scale projects, adhering to ethical standards, and promoting sustainable development. Although "Industry 5.0" and "Human-Centrism" are not explicitly mentioned, the companies demonstrate a commitment to human rights and ethical practices, suggesting an indirect alignment with human-centric values.

4. Research Gaps and Recommendations for Further Research

4.1. Research Gaps

The following research gaps were identified:

•Human-Centric and Ethical Considerations: The analysis of keywords on major company websites revealed a significant gap in the emphasis on human-centric and ethical considerations within Industry 5.0. While companies frequently mention project management, ethics, and sustainability, terms explicitly focusing on human-centric design and ethical implications of advanced technologies are conspicuously absent.

•Integration of Advanced Technologies: Although advanced technologies like AI, machine learning, and IoT are often discussed, there is a lack of detailed guidance on how these technologies can be ethically integrated into project management practices. More research is needed on the frameworks and methodologies that can support this integration while maintaining ethical standards.

•Practical Case Studies and Implementation Frameworks:There is a lack of empirical research and detailed case studies demonstrating the successful implementation of Industry 5.0 principles in real-world project management scenarios. This includes examples of how companies can balance technological advancements with sustainability and human-centric approaches.

4.2. Recommendations for Further Research

Proposed recommendations for the further research:

•Developing Ethical Frameworks for Technology Integration: Future research should focus on developing comprehensive ethical frameworks for the integration of advanced technologies in project management. This includes creating guidelines for AI usage, data privacy, and ensuring transparency and accountability in technological implementations.

•Human-Centric Project Management Approaches: Investigate and develop methodologies that prioritize human-centric values in project management. This includes enhancing worker well-being, promoting collaboration between human and machine, and ensuring that technology complements rather than replaces human capabilities.

•Detailed Case Studies: Conduct and publish detailed case studies that showcase successful implementations of Industry 5.0 principles. These should highlight the challenges faced, solutions implemented, and the outcomes achieved, providing actionable insights for other organizations.

1. Conclusions

The primary objectives of this paper were to explore the integration of Industry 5.0 principles into project management methodologies (IPMA, PMI, ISO), conduct empirical research to demonstrate successful implementation, and identify research gaps. The analysis revealed several key insights:

1. Emphasis on Project Management, Ethics, and Sustainability: Companies across various industries frequently mention project management, ethics, and sustainability, reflecting their importance in contemporary business practices. These areas are critical for the successful execution of projects and adherence to ethical standards and sustainable development.

2. Lack of Focus on Industry 5.0: The concept of Industry 5.0 is not prominently featured on most company websites, suggesting that it may not yet be a focal point in their publicly available materials. Companies are likely still focusing on Industry 4.0 technologies and innovations.

3. Human-Centric and Ethical Considerations: There is a notable gap in the emphasis on human-centric and ethical considerations. While companies discuss ethics and human rights broadly, specific terms like "human-centric design" are less frequently mentioned.

4. Need for Comprehensive Frameworks: There is a need for more comprehensive frameworks that integrate advanced technologies ethically and sustainably into project management practices. This includes detailed guidelines and case studies to provide practical insights and best practices.

5. Recommendations for Popular PM Methodologies (IPMA, PMI, ISO) Addressing Industry 5.0: IPMA Standards, PMI, and ISO are aligning their frameworks with industry needs, but more integration of Industry 5.0 principles is needed. The author prepared a list of holistic recommendations to the global project management organizations for adapting their methodologies to better meet Industry 5.0 demands, ensuring projects are efficient, effective, sustainable, resilient, and ethically managed. If implemented, the holistic approach can help create a human-centric industrial ecosystem that uses advanced technologies to enhance human capabilities and improve project outcomes.

By addressing the research gaps and focusing on the recommendations provided, future research can help develop robust methodologies that balance technological advancements with human-centric values and ethical considerations. This will ensure that Industry 5.0 not only drives economic growth but also promotes societal well-being and sustainability.

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Proposal of Mathematical Model for Construction Equipment Deterioration Coefficient Calculation

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Abstract:

The following paper presents the introduction of a new methodological approach aimed at calculating the deterioration coefficient for construction equipment with greater accuracy. A mathematical model specifically designed for construction machinery and equipment engineering is proposed, to enhance the accuracy of practical effects estimation during the computation of construction machinery.

The model incorporates five input parameters identified as having the most significant impact on the deterioration of construction equipment: equipment age, working hours, usage intensity, maintenance protocols, and operator expertise. These parameters are considered for a comprehensive assessment of deterioration.

To validate the effectiveness of the proposed model, a comprehensive empirical analysis is conducted, which encompasses various types of construction equipment and operational scenarios. The results derived from this analysis are expected to demonstrate the model's accuracy in estimating deterioration coefficients and its practical utility in refining engineering calculations for construction machinery. Adjustments to the model will be made if necessary.

In conclusion, the proposed model is recognized as a significant advancement in construction equipment management, providing a systematic framework for utilizing deterioration coefficients to enhance the precision of engineering calculations. Its application is anticipated to streamline maintenance practices, optimize equipment utilization, and ultimately improve operational efficiency in the construction industry.

Keywords: *Deterioration Coefficient; Engineering Calculations; Mathematical Model; Construction Equipment; Maintenance Optimization; Operational Efficiency*

1. Introduction

In today's dynamic construction industry, the effective management of construction machinery is recognized as paramount to project success. However, the accurate assessment of machine deterioration continues to be a persistent challenge, affecting both operational efficiency and financial viability. In response to this challenge, a novel mathematical model for calculating the machine deterioration coefficient is presented in this paper, with the aim of providing construction professionals with a robust tool for optimizing machinery. Through a comprehensive analysis of current methodologies and the development of innovative approaches, this research endeavors to address the complexities of machine deterioration in the modern construction landscape.

1.1 Motivation for the Research

The motivation for this research arises from the recognized need to improve existing methods for assessing the condition of construction machinery, which currently rely heavily on empirical data and experience, often neglecting the dynamic factors that influence the deterioration of equipment performance over time.

The necessity for developing a new model became evident through teaching students and highlighting the shortcomings of the methods currently in use. Traditional methods are often identified as lacking precision and failing to account for the diverse factors that influence machinery deterioration over time. Although the emerging model may not provide an ultimate solution for calculating the deterioration coefficient, it undoubtedly broadens the horizon and lays the foundation for further enhancement. This model is designed to more comprehensively describe the key factors influencing the deterioration coefficient of construction machinery, thereby improving the calculation of the practical performance of construction equipment.

The focus of this research is on deriving the deterioration coefficient with the primary aim of calculating the ***practical performance*** of construction machinery. Unlike other studies in this field (Postiguillo, et al., 2017) , which often concentrate on resolving the economic aspects of the deterioration coefficient, this research prioritizes the organizational and technological implications like suggested in some papers (Galar, et al., 2011).

While economic considerations are acknowledged as important and have been extensively covered in existing literature, they are not always seen as adequately addressing the performance-related challenges faced by construction managers on-site. By emphasizing the practical application of the deterioration coefficient in evaluating machinery performance, this study seeks to provide a more comprehensive tool for improving operational efficiency and decision-making processes regarding equipment management.

Construction projects are heavily reliant on the performance and reliability of machinery, which directly impacts project timelines, costs, and overall success. However, the accurate assessment of the deterioration of these assets is identified as a significant challenge for construction professionals.

Moreover, the high costs associated with equipment maintenance and replacement further underscore the importance of developing a reliable methodology for calculating the deterioration coefficient of construction machinery. By gaining a deeper understanding of the factors contributing to machine deterioration, construction companies can be better equipped to make informed decisions regarding equipment investments, maintenance schedules, and project planning. Ultimately, this research aims to provide industry practitioners with a robust framework for optimizing machinery management strategies and enhancing project outcomes.

1.2. Research Objectives

The primary objective of this research is defined as the development of a comprehensive understanding of the machine deterioration phenomenon in the construction industry and the proposal of a novel mathematical model for more accurately calculating the deterioration coefficient of construction machinery. To achieve this overarching goal, the following specific objectives have been outlined:

- To review and analyze existing approaches and methodologies for calculating the deterioration coefficient of construction machinery.

- To identify the key parameters/variables and factors influencing the deterioration of construction equipment over time.

- To develop a mathematical model that integrates these variables and factors to accurately predict the deterioration of construction machinery.

- To validate the proposed model using real-world data from construction projects and equipment fleets.

- To assess the effectiveness and reliability of the proposed model in comparison to traditional methods and industry standards.

By addressing these research objectives, the advancement of knowledge in the field of construction machinery management is sought, to facilitate more informed decision-making processes within the construction industry.

1.3. Definition of the Machine Deterioration Coefficient

In this section, a clear definition of the machine deterioration coefficient and its significance in the context of construction machinery management will be established. The machine deterioration coefficient is defined as the rate at which a construction machine loses its efficiency over time due to factors such as deterioration and obsolescence. By quantifying this coefficient, construction professionals can gain a better understanding of the economic implications of machinery ownership and make informed decisions regarding equipment acquisition, maintenance, disposal, and, above all, the practical effects of the machinery while in use.

Additionally, the various methodologies and approaches used to calculate the machine deterioration coefficient will be explored, ranging from simple linear deterioration models to more complex dynamic models that account for factors such as usage patterns, environmental conditions, and technological advancements. By synthesizing existing literature and industry practices, a comprehensive understanding of the concept of machine deterioration will be developed, laying the groundwork for the development of the proposed mathematical model.

2. Currently Used Model

In this section, the existing methodologies and models utilized in the construction industry for calculating the deterioration coefficient of machinery will be examined. The strengths and weaknesses of these approaches will be analyzed, and any gaps or deficiencies that may exist will be identified. By understanding the current landscape of deterioration modeling in the construction industry, the need for the proposed model can be better contextualized, and opportunities for improvement can be identified.

2.1 Current Approaches in Calculating Deterioration Coefficient

This subsection will provide an overview of the various approaches and methodologies currently employed to calculate the deterioration coefficient of construction machinery. Traditional models, such as straight-line deterioration and diminishing balance methods, as well as more advanced techniques like regression analysis and machine learning algorithms, will be explored. By examining the advantages and limitations of each approach, insights into the evolving nature of deterioration modeling in the construction sector will be gained.

- Calculation using linear regression function that includes the following parameters: *frequency of machine failures* given through expected time until machine failure, i.e. expected time between failures (average of measured times), *frequency of machine repairs* given through expected time required to repair the machine (average of measured times) (Linarić, 2005.)

- Calculation that uses only the working hours parameter (Vidaković, et al., 2017.)

- Calculation using straight-line method that calculates uniform lowering of value during time. This method is the most common method used in the calculation of expenses of construction machine's work hours (Petronijević, et al., 2012.).When using this method new and very old machines have the same annual depreciation. This method has a focus on the economic aspect of construction machinery depreciation rather than on organizational or technological.

- Calculation using the diminishing balance method, where the depreciation rate is doubled. The depreciation amount of the first year is calculated on the depreciable amount. The depreciation amounts for the second and subsequent years are calculated by deducting the accumulated depreciation amounts from the depreciable amount (Kirli, 2018).

- Calculation using regression analysis with the focus on establishing a correlation between the wear coefficient and the lubricant film parameter, with regression analysis being used to enable more accurate predictions of bearing durability under various operating conditions (Jeon, et al., 2018).

- Calculation where the use of machine learning algorithms for predicting tool wear in industrial milling processes using real sensor data is presented (Van Herreweghe, et al., 2020).

2.2 Current Models Deficiencies

Calculation using the linear regression function served as an inspiration for the development of this model. However, a key deficiency of that approach is that it results in a table with only three numerical values of the deterioration coefficient, similar to the calculation that relies solely on the working hours parameter mentioned earlier. The primary shortcoming in both concepts lies in the area after the coefficient reaches a constant value of ***0.71***. A continuous, fluid model is needed, one that can be calculated for any value of input parameters. The following proposal of a mathematical model aims to address this deficiency.

3. Methodology

The proposed mathematical concept relies upon the interaction of five main input parameters: the age of the machine, the number of working hours, the intensity of use, the degree of maintenance of the machines, and the work experience of the operator. The proposed parameters were selected based on several assessments. The first assessment involved expert evaluation, during which these parameters were identified as having the most significant impact on the operational performance of construction machines. The second assessment involved the analysis of historical data, which demonstrated a substantial influence of these parameters on the working outcomes. The third assessment considered the practical relevance of these parameters in the daily use of construction machines, with the selection reflecting practical aspects of managing construction machines in industrial processes.

3.1. Establishing Control Parameters

Before defining the main input parameters the establishment of control parameters is required. In order to set control parameter for every main input parameter we have to define main categories of input parameters based on experience.

- The machine age – (control parameter s)

This input parameter is categorized into 4 main categories: ***new machines*** *(age 0-5 years)*, ***preserved machines*** *(age 5-10 years)*, ***dilapidated machines*** *(age 10-15 years),* and ***old machines*** *(age over 15 years).* For the control parameter **[*s*]** that will appear in the function that defines the first input parameter, the value ***(s=15)*** was chosen as the limit value of the age of the mchine that still has a sufficiently high working potential on the construction site.

- The number of operating hours – (control parameter b)

This input parameter is also categorized into 4 main categories: ***low number*** (0-2000 wh [1]), ***moderate number*** (2000-4000 wh), ***high number*** (4000-6000 wh) and ***very high number*** (over 6000 wh). For the control parameter **[*b*]** that will appear in the function that defines the second input parameter, the value ***(b=3000)*** was chosen as the mean value of the number of working hours during which the machine still functions under excellent working conditions.

- The usage intensity – (control parameter i)

This input parameter is also categorized into 4 main categories: ***low intensity*** (less than 1500 h/y [2]), ***moderate intensity*** (1500-3000 h/y), ***high intensity*** (3000-6000 h/y) and ***extreme intensity*** (over 6000 h/y). For the control parameter **[*i*]** that will appear in the function that defines the third input parameter, the value ***(i=8760)*** was chosen as the maximum number of working hours per year (theoretical capacity of any machine).

- The maintenance quality degree – (control parameter o)

This input parameter is categorized into 5 main categories: ***regular maintenance*** (after 100 wh), ***preventive maintenance*** (after 500 wh), ***emergency maintenance*** (after 1000 wh), ***inadequate maintenance*** (after 5000 wh), and ***without maintenance*** (after 10000 wh or more). For the control parameter **[*o*]** that will appear in the function that defines the *fourth* input parameter, the value ***(o=1000)*** was chosen as the *maximum value* up to which maintenance can be considered maintenance.

- The operator experience – (control parameter r)

This input parameter is categorized into 4 main categories: ***novice operator*** (0-2 years of experience), ***medium experienced operator*** (3-7 years of experience), ***experienced operator*** (8-15 years of experience), ***expert operator*** (more than 15 years of experience). For the control parameter **[*r*]** that will appear in the function that defines the fifth input parameter, the value ***(r=15)*** was chosen as the maximum value at which the operator has the optimal years of experience.

3.2. Development of the Mathematical Model

1 wh – working hours
2 h/y – hours per year

The mathematical model's development relies on a correlation between the five input parameters mentioned above, which are defined with the assistance of control parameters ***(s, b, i, o, r)*** as outlined in section 3.1. Before defining the final correlation function, the main input parameters need to be determined.

3.3. Defining Main Input Parameters/Variables

In the development of the mathematical model for calculating the deterioration coefficient of construction machinery, the choice of appropriate functions is crucial for accurately describing the dynamics of equipment performance degradation. Sigmoidal and reciprocal functions have been selected due to their specific properties, which facilitate detailed modeling of complex deterioration processes.

Sigmoidal functions have been chosen because they enable a realistic representation of the change in the deterioration coefficient over time. These functions, characterized by an S-shaped curve, are ideal for modeling processes that begin with a gradual increase, then accelerate, and eventually reach a plateau or saturation point. This shape perfectly aligns with the real-world conditions of machinery degradation, where the initial phases of a machine's lifecycle exhibit slow deterioration, which accelerates with increased use, and then slows down as the machine approaches the end of its useful life. Sigmoidal functions, therefore, allow for modeling stages of growth, stabilization, and potential saturation of deterioration, providing an accurate depiction of how the deterioration coefficient evolves.

Reciprocal functions have been selected for their ability to precisely model the inverse relationship between various parameters, such as time or intensity of use, and machine performance. Reciprocal functions allow for the modeling of scenarios where the deterioration coefficient increases rapidly in the early stages and then decreases concerning certain factors, such as proper maintenance or reduced loading on the machine. These functions offer flexibility in modeling to account for different usage and maintenance conditions, thereby providing a more precise estimation of deterioration under varying lifecycle phases of the equipment.

By choosing sigmoidal and reciprocal functions in the model, a comprehensive and dynamic monitoring of machine deterioration is enabled, taking into account both exponential aspects of wear and inverse relationships between key variables. This combination of functions ensures that the model can adequately describe various scenarios and conditions, providing tools for improved planning and management of construction machinery maintenance.

- The machine age (-)

This input parameter is defined with a logistic (sigmoidal) (Kyurkchiev & Markov, 2015) function as follows:

Value ***s*** is a control parameter with a value of ***15***, so the function has a final form:The values of function - for *s*=15 are in the interval (0,1) for any positive value of *x*, as they are and .

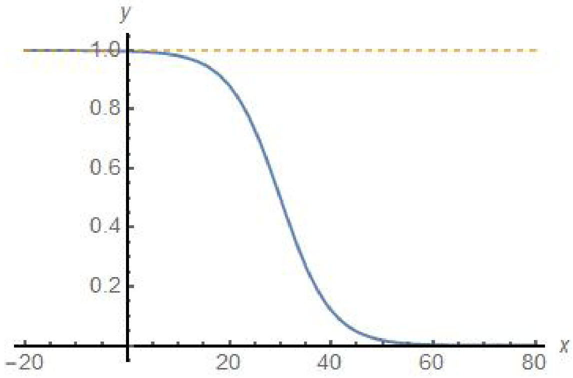

Figure 1. Graph of the function . The line is the horizontal asymptote for and line is the horizontal asymptote for .

- The number of operating hours (-)

This input parameter is defined with a reciprocal (Euler & Foran, 2018) function with a constant as follows:

Value ***b*** is a control parameter with a value of ***3000***, so the function has a final form:

The values of function - for *b*=3000 are in the interval (0,1] for any positive value of *x*, as they are and .

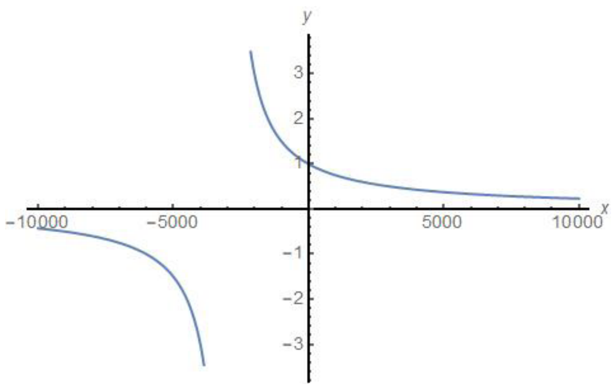

Figure 2. *Graph of the function . The line is the horizontal asymptote for .*

- The usage intensity (-)

This input parameter is defined with a reciprocal (Euler & Foran, 2018) function with a constant as follows:

Value ***i*** is a control parameter with a value of ***8760***, so the function has a final form:

The values of function - for *i*=8760 are in the interval (0,1] for any positive value of *x,* as they are and .

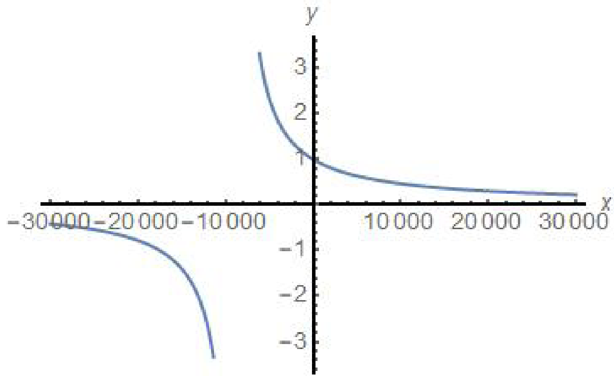

Figure 3. Graph of the function . The line is the horizontal asymptote for .

- The maintenance quality degree

This input parameter is defined with a reciprocal (Euler & Foran, 2018) function with a constant as follows:

Value ***o*** is a control parameter with a value of ***1000***, so the function has a final form:

The values of function - for *o*=1000 are in the interval (0,1] for any positive value of *x,* as they are and .

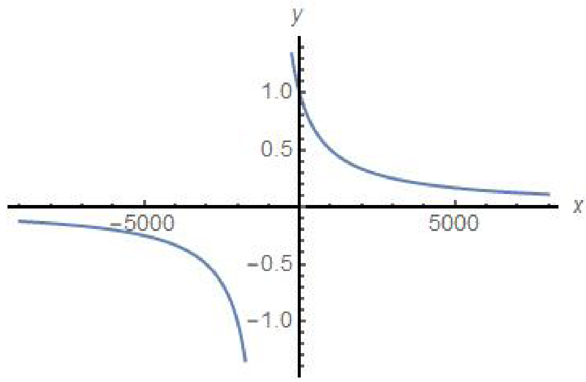

Figure 4. ***Graph of the function . The line is the horizontal asymptote for .***

- The operator experience (-)

This input parameter is defined with a logistic (sigmoidal) (Kyurkchiev & Markov, 2015) function as follows:

Value ***r*** is a control parameter with a value of ***15***, so the function has a final form:

The values of function - for *r*=15 are in the interval (0.5,1) for any positive value of *x*, as they are and .

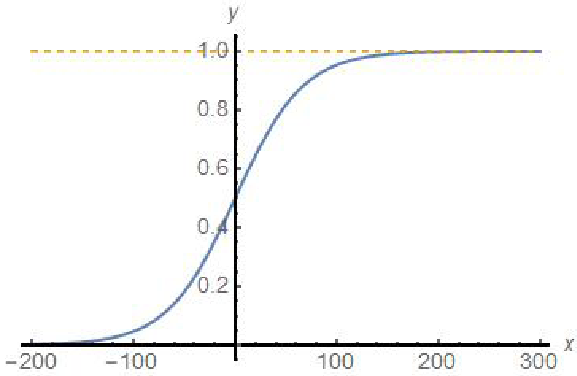

Figure 5. *Graph of the function . The line is the horizontal asymptote for* **.**

3.4. Detailed Description of Modelling Phases

In this section, we will provide a detailed overview of the comprehensive steps involved in the development and implementation of the proposed mathematical model for calculating the machine deterioration coefficient. The modeling process will be broken down into several key phases to ensure a clear and systematic progression from the initial conceptualization stage to its practical application. This paper is focused on first four phases, while the last three phases of the modeling will be covered in the next paper.

3.4.1. Phase 1: Initial Data Collection and Preprocessing

Objective: The objective is to gather pertinent data concerning the ***age of the machinery***, ***its operating hours***, ***usage intensity***, as well as ***maintenance records*** and ***operator experience***.

Activities:

- Identify and select the machinery to be included in the study (Krentz, 2021)
- Collect historical data from maintenance logs, usage reports, and operator records
- Preprocess data to handle missing values, outliers, and inconsistencies
- Standardize data formats and scales for uniformity

3.4.2. Phase 2: Parameter Identification and Selection

Objective: Define and select the critical parameters influencing machine depreciation

Activities:

- Conduct a literature review to identify commonly used parameters in similar studies
- Consult with industry experts to validate the relevance of selected parameters
- Finalize a list of key parameters: machine age (-), operating hours (-), usage intensity (-), maintenance quality degree (-), and operator experience (-)

3.4.3. Phase 3: Development of Input Parameter Functions

Objective: Develop mathematical functions for each input parameter

Activities:

- Create age-based deterioration functions considering exponential decay models
- Develop functions for operating hours using reciprocal models
- Formulate usage intensity functions based on reciprocal models
- Define maintenance quality functions considering frequency and type of maintenance
- Establish operator experience functions, correlating with productivity and error rates

3.4.4. Phase 4: Integration and Model Formulation

Objective: Integrate input parameter functions into a unified mathematical model

Activities:

- Combine individual parameter functions into the overall model equation
- Ensure the model outputs a depreciation coefficient within the range (0, 1]
- Validate the integration through theoretical tests and expert reviews

3.5 The Definition of Construction Equipment Deterioration Coefficient Function

The determination of the construction equipment deterioration coefficient is a critical component of this research, and it involves a rather complex methodology. This process relies on the interaction of five coefficients (- , - , - , - , -) combined within root of the multiplicative function (Sinclair, 2005), which should produce values within the interval (0,1].

The construction equipment deterioration coefficient (C_{ced}) is derived through calculation according to the following formula: The values of function are in the interval (0,1] for any positive value of *x*, as they are and , which was defined as our target range.

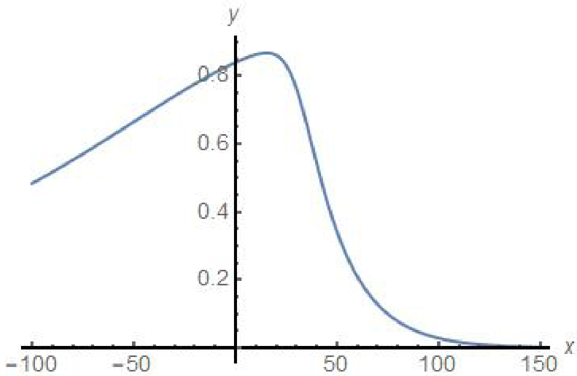

Figure 6. Graph of the function . The line is the horizontal asymptote for .

4. Conclusion

The paper proposed a new mathematical model to calculate the construction machine deterioration coefficient. The critical need for an accurate deterioration model in the construction industry was emphasized. Better efficiency and precision in calculating the practical effect of construction machinery were identified as the primary motivators for the study. The objectives included developing a robust model that integrates multiple parameters influencing machine deterioration, thus offering a more comprehensive and precise approach. It was noted that traditional models often rely on linear deterioration methods that fail to consider the complex interplay of factors such as machine age, operating hours, usage intensity, maintenance quality, and operator experience. These deficiencies highlighted the need for an improved model to adapt to various real scenarios and provide more accurate deterioration estimates.

For a better understanding of the model, it was necessary to analyze and validate the model through its application to a subset of collected data to enable the eventual fine-tuning of the parameters or the descriptive functions themselves. Sensitivity analysis would need to be performed to understand the impact of each parameter, and the entire model would subsequently be tested against independent data sets to assess predictive accuracy. The model would be implemented in a practical setting, and its performance would be evaluated. This model could potentially serve as a valuable framework for future studies.

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Prediction of Buildings' CO_2 Emission by Using Combustion Parameters of Heating Systems

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Abstract:

Reducing energy usage and emissions of gases harmful to the environment, such as CO_2, CO and O_2, is imperative for participants in building projects. Research indicates that poor fuel quality and inadequate maintenance of heating systems lead to increased emissions of harmful gases into the environment and reduced energy utilization. Furthermore, the research indicates an increase in these harmful gases in the future. In that sense, this paper aims to develop a predictive model for forecasting CO_2 emission based on the combustion parameters of heating systems. Data for exhaust gases were collected from 45 buildings of varying ages using a Delta 65 gas analyzers. The Energy Utilization Coefficient (ETA) was also measured. The buildings are located in Primorje-Gorski Kotar County and Istria County, Republic of Croatia. An optimal predictive model based on combustion parameters was developed using the General Regression Neural Network (GRNN). The accuracy of the obtained optimal model is assessed by standard estimators: the mean absolute percentage error is 4.96%, the coefficient of determination is 87.3%, and the correlation coefficient between the actual and the predicted values is 0.935. The general conclusion is that predictive modelling is a valuable tool for accurately predicting CO_2 emissions in buildings and for improving heating system usage and maintenance. Additionally, the software identifies the most important parameters impacting CO_2 emissions. This is useful for reducing CO_2 emission, maintaining the system effectively, and increasing the energy utilization of the heating system.

Keywords: *Building; CO_2; Combustion Parameters; Heating System; Neural Network*

1. Introduction

Humanity today faces challenges such as rising energy costs and environmental pollution caused by the emission of greenhouse gases (GHGs) and other pollutants. These issues threaten environmental quality and contribute to climate change. Many of these gases result from burning fossil fuels in energy systems (Hrvatska enciklopedija, 2024; Moj kvart, n.d.).

Addressing these issues requires a responsible approach. Effective management of all aspects of energy use, production processes, buildings construction, and the operation of residential and business facilities is essential to reduce pollution.

Recent scientific efforts have focused intensively on understanding and mitigating the negative environmental impact. Researchers (Alazwari *et al.,* 2021; Farouk *et al.,* 2022; Valančius *et al.,* 2022; Car-Pušić *et al.*, 2024) highlight two major problems: high energy consumption and carbon dioxide (CO_2) as GHG emission. According to a source Europski parlament (2023), GHG acts like a greenhouse by trapping heat in the troposphere, with increased CO_2 levels significantly contributing to global warming (Hrvatska enciklopedija, 2024).

CO_2 is the most abundant GHG in the atmosphere, with a natural concentration of about 0.03 % (Hrvatska enciklopedija, 2024). According to several sources (Hrvatska enciklopedija, 2024; Europska komisija, n.d.), its share is alarmingly increasing due to human activities, such as industrial processes, transportation and burning fossil fuels in the energy systems. According to Hrvatska enciklopedija (2024), CO_2 levels have increased by over 10 % in the past decade due to fossil fuel combustion, exacerbating the greenhouse effect. On the other hand, the Annual European Union Greenhouse Gas Inventory 1990–2021 and Inventory Report 2023 (European Environment Agency, 2022) indicated that GHG emissions in 2021 were reduced by 30 % compared to 1990 levels. However, comparing 2020 and 2021, the emissions increased by 6.5 % in 2021, attributed to a decreased economic activity in 2020. Regardless, the decreasing trend remains compared to 1990 levels. According to the European Environment Agency (2022), this is partly due to reduced heating fuel consumption and decreased GHG emissions in some industries.

Sources (Moj kvart, n.d.) emphasize that burning fossil fuels – whether in industrial plants, vehicles or homes – releases harmful gases that affect air quality, climate and ecosystem health. Understanding and controlling these emissions is not only a regulatory issue; it is our moral obligation to the planet and future generations.

This research focuses on understanding what happens when burning fossil fuels, specifically extra light (EL) fuel oil, in energy systems, specifically regarding CO_2 emissions in flue gas. The study examines how CO_2 levels are influenced by other exhaust gases, such as oxygen (O_2) and carbon monoxide (CO), as well as the energy utilization coefficient ETA. During combustion of flue gases emission include CO_2, CO, O_2, sulfur dioxide (SO_2), nitrogen oxides (NOx), soot particles and even heavy metals (Hrvatska enciklopedija, 2024; Moj kvart, n.d.).

It is also crucial to differentiate between the problems of old and new energy systems. Old systems have specific issues, such as wear and tear, inadequate maintenance and consequently, unreliability, a lower coefficient of energy utilization ETA, and higher emission of harmful flue gases. Both old and new systems suffer from lower fuel quality. According to Car-Pušić *et al.* (2024), poor maintenance and low-quality fuel often result in reduced levels of energy utilization and increased CO_2 emissions.

Modern technical solutions are being researched to solve the problems of energy consumption and CO_2 emissions. Various solutions, such as the use of clean energy, natural light, phase change materials, heat recovery and insulation, have been proposed to address these two issues (Alazwari *et al*., 2021; Farouk *et al*., 2022; Valančius *et al.,* 2022;). Furthermore, the possibilities of modern solutions to the problem of CO_2 emissions by appropriate use as a working medium in energy systems of the next generation due to its exceptional thermophysical properties are highlighted (Li *et al.,* 2022; Valančius *et al*., 2022). However, it has also been noted that several challenges remain related to the production of components, cost optimization, and system efficiency (Liu *et al*., 2013). With new systems, an important issue is selecting and implementing a technical solution in terms of performance costs, quality, regular control of flue gas emissions and the energy utilization coefficient ETA (Car-Pušić *et al*., 2024).

The problem of harmful gas emissions can be alleviated with modern approaches; that is, it can be solved in new, advanced, modern ways (Li *et al.,* 2022; Valančius *et al.,* 2022; Xue *et al.,* 2022). However, the problem of adequate maintenance of old energy systems remains due to their prevalence. Inadequate maintenance has often been an issue in the Republic of Croatia (Car-Pušić *et al.,* 2024).

2. Research goal

Given the pressing need to address CO_2 emissions, the goal of this research is to develop a model for predicting the CO_2 content in the exhaust gases of the EL fuel oil heating system as a function of the independent variables, O_2 and CO, in the exhaust gases, as well as the characteristics of the system and fuel combustion. The aim is to optimize the system's performance by reducing harmful CO_2 emissions with the ETA – utilization coefficient as the leading indicator of system efficiency. Additionally, the influence (importance) and interdependence of other variables in the system concerning the target variable will be analyzed.

The CO_2 content will be taken as a target variable in the "soft-computing" based model as a function of independent variables and predictors, i.e., the share of O_2 and CO in the exhaust gases and the characteristics of the heating and fuel combustion system. The ETA utilization coefficient, which indicates the degree of utilization of the input energy from the energy source, is particularly important.

For this purpose, a database of 45 measurements from Primorje-Gorski Kotar County and Istria County in the Republic of Croatia was collected.

Measurement was made detecting the proportion of the following exhaust gases:

- Carbon dioxide (CO_2),
- Carbon monoxide (CO),
- Oxygen (O_2).

Some devices detect nitrogen oxides (NOx), which are serious environmental pollutants that cause acid rain and affect human health (Hrvatska enciklopedija, 2024). This is an important topic for further research models.

3. Materials and methods

3.1 Data collection and measurements

The measurement and analysis of exhaust gases in central heating systems using EL fuel oil were carried out in public and private facilities. The study covered the coastal regions of Primorje-Gorski Kotar and Istria counties in the Republic of Croatia. Recordings were made between 2016 and 2023. The coastal area around Rijeka in Primorje-Gorski Kotar County experiences a typical Mediterranean climate, while the city of Pazin in central Istria has a continental climate. The coastal part of Istria also has a Mediterranean climate (Car-Pušić *et al.,* 2024). The measurements were conducted using a Delta 65 exhaust gas analysis device (Ser. Number 026220). The following data were measured:

- T_{dplin} – flue gas temperature in °C,
- O_2 – volume fraction of oxygen in flue gases in %,
- CO – share of carbon monoxide in flue gases in ppm,
- CO_2 – volume fraction of carbon dioxide in dry flue gases in %,
- T_{air} – air temperature in °C,
- Lambda – the ratio of the excess air coefficient (the ratio of the actual amount of air supplied per 1 kg of fuel consumed and the stoichiometric amount of air for burning 1 kg of fuel) to the content of CO_2 max and CO_2 in the flue gases (Struna, 2011; Car-Pušić *et al.*, 2024),
- ETA – utilization coefficient (degree of usefulness) in %,

- Losses – in %.

The energy-generating products is a fuel oil with LU EL 3% and 15.4% (CO_2 max content) characteristics.

3.2. Neural Networks

In this paper, predictive modelling for estimating the target variable CO_2 is conducted using three neural networks: GRNN (General Regression Neural Network), RBF NN (Radial Basis Function Neural Network) and MLP (Multilayer Perceptron) from the predictive modelling software DTREG (Sherrod, 2013). These three NNs were tested, with GRNN providing the most accurate prediction of the target variable.

Neural networks (NNs) are soft computing methods based on the concept of learning from experimental data. They have emerged as attractive alternatives to traditional hard computing models, which have proven inadequate for solving today's multidimensional nonlinear problems (Kecman, 2001). Unlike traditional hard computing methods, which require significant computation time and precisely defined analytical models, NNs learn directly from experimental data and do not require an analytical model of the process being modelled. NNs are of particular interest because they can approximate any multivariant function, modelling unknown, highly nonlinear complex processes.

NNs emulate human cognitive abilities of learning, memorizing, predicting and generalizing. Learning is typically defined as acquiring knowledge about previously unknown system, and algorithms or devices that learn from data are often referred to as intelligent. Today, machine intelligence must handle large amounts of data from multiple sensors simultaneously, manage various tasks at the same time, establish a hierarchy of priorities, and detect or diagnose faults to repair or reconfigure the system. These tasks are integral to the decision-making capabilities of intelligent machines, both now and in the future. NNs are often a key component of such intelligent systems.

Inspired by the structure and functioning of biological neurons, NNs are most used for solving nonlinear regression and classification tasks.

NNs are mathematical models composed of many computing units called neurons. The connections between the neurons are measured by parameters called *weights,* and the values of these weights are adjusted during the learning process. There are many different types of NNs depending on the task they are designed to solve, and the meaning of the weights can vary based on the specific problem.

Neurons are organized in layers, and in most cases, neurons within a layer use the same activation function. The simplest NN architecture includes an input layer, a hidden layer and an output layer. For more complex tasks, NNs may have multiple hidden layers. The neurons in the hidden layers use differentiable nonlinear activation functions, which allow NNs to act as universal approximators. The differentiability of these activation functions enables nonlinear learning. When the activation functions in the hidden layers are not differentiable, optimization algorithms, such as genetic algorithms, are used to learn the weights.

The input layer is typically considered as an input vector, sometimes with added bias terms. The input vector components are passed to the next (hidden) layer. The neurons of the output layer may have different types of activation functions depending on the task being addressed (regression or classification task). A simple NN is presented in Figure 1, which implements the Equation

(1) (Kecman, 2001):

$$o(x, V, w, b) = F(x, V, w, b) = \sum_{j=1}^{J} w_j \sigma_j (v_j^T x + b_j).$$

$$o(x,V,w,b) = F(x,V,w,b) = \sum_{j=1}^{J} w_j \sigma_j \left(v_j{}^T x + b_j\right) \qquad (1)$$

where x is the input vector, b denotes the bias weights vector, V is the matrix of hidden layer weights, w is the output weight vector, and σ_j is the sigmoidal activation function. T denotes the transposed vector, and o is the output (the predicted target) of the NN.

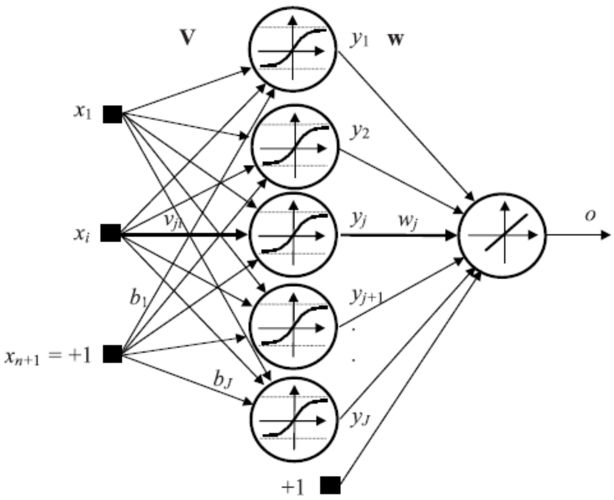

Figure 1. Simple NN which can approximate any nonlinear mapping from R^n to R^1 (R is the set of real numbers)

Input data should consist of a set of variables that are most representative for predicting the output target variable. Using a specific learning rule embedded in its algorithm and architecture, NN will learn the relationship within the input data (between predictors and target) by minimizing the error between the actual and predicted target values, and adjusting the weight values accordingly.

The general characteristics of the NNs used for modelling will be presented below.

3.2.1. General Regression Neural Network

The General Regression Neural Network (GRNN), proposed by Specht (1991), is considered by some authors to be one of the most revolutionary NNs due to its highly desirable characteristics: it is very accurate, can learn from sparse data, and converges to an optimal solution very fast – in just one pass. GRNN has undergone several modifications and has been applied to various research tasks, including mapping, control, prediction, pattern recognition, classification, and time series predictions across various research fields, such as: medicine, geology, chemistry, engineering, civil engineering, and physics. It also handles noise in the input data effectively. However, GRNN requires a large amount of memory, which makes it computationally expensive. The architecture of GRNN is illustrated in Figure 2.

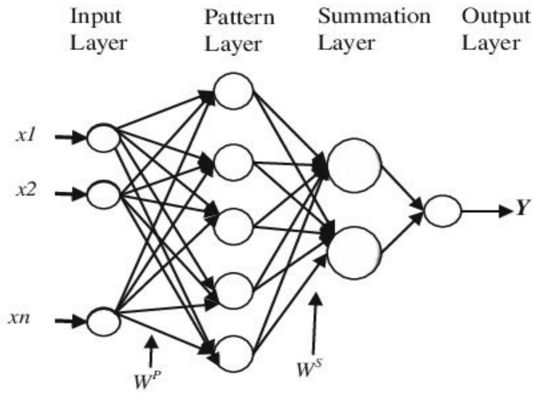

Figure 2. GRNN architecture

GRNN consists of 4 layers: input, pattern, summation and output. The input layer has the same number of neurons as there are predictors (x_1, x_2, ...x_n). The values of the neurons from this layer are passed to the neurons in the next pattern layer, which contains a number of neurons equal to the number of cases in the dataset. W^p and W^s are vectors of weights w_{ij} from the pattern and summation layer, accordingly. In this layer, the Euclidean distance from the center of each neuron is computed for each case, and an activation kernel function is applied. The outputs of the neurons are processed to the next summation layer which has two neurons called denominator and numerator. The denominator sums the weight values from each neuron from the previous pattern layer, while the numerator sums the weight values from the pattern layer multiplied by the actual target values. In the output (decision) layer, the values from the numerator and denominator are divided to obtain the predicted target value (Sherrod, 2013). This architecture implements Equation (2):

$$E[y/X] = \frac{\int_{-\infty}^{+\infty} y f(X,y)\,dy}{\int_{-\infty}^{+\infty} f(X,y)\,dy}$$

where *X* represents the input vector, *y* is the output, and *E[y/X]* denotes the conditional mean of *y* given *X*. Expression *f(X, y)* is not known and can be estimated from observations of *X* and *y*, using the class of Parzen consistent estimators (Car-Pušić *et al.*, 2024).

3.2.2. Radial Basis Function Neural Network

The Radial Basis Function Neural Network (RBF NN) is a type of NN proposed by Broomhead and Lowe (1988). The RBF NN has three layers: input, hidden and output layer. This NN has gained significant attention as an alternative to MLP. Both types of NN feature hidden layers with nonlinear activation function (RBF) and output layers with linear activation function in most cases. For classification tasks, the activation function in the output layer can be of a different type, such as an S-shaped logistic function. An important characteristic of RBF NN is that the input signal *u* to the activation RBF function is the distance between the centre *c* of the activation function and the input vector *x*: $u_j = f(\|x - c_j\|)$. The centers c_j of the neuron's activation function serve as weights of the hidden layer. One of the most significant advantages of RBF NN is its fast and efficient training algorithm, its universal approximation ability and its theoretical foundation, which have been noted by many authors, especially Russian mathematicians (Kecman, 2001).

RBF NN is similar to GRNN, and for problems with small to medium-sized datasets, GRNNs are often more accurate than RBF NN. However, for large training datasets, GRNNs become impractical. The architecture of the RBF NN is illustrated in Figure 3.

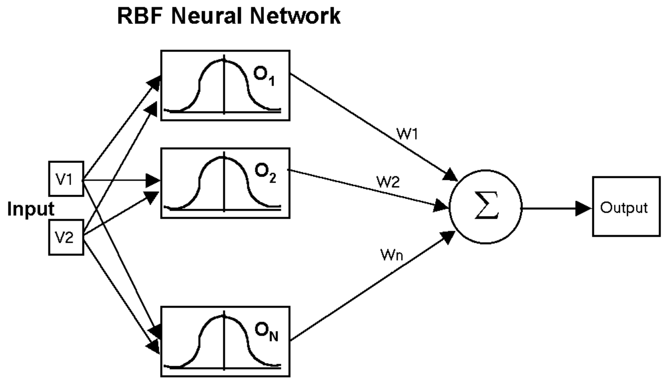

Figure 3. Architecture of RBF NN

3.2.3. Multilayer Perceptron

The input layer of a Multilayer Perceptron (MLP) consists of the input vector with predictor values ($x_1 \dots x_p$), which are distributed to each neuron in the next hidden layer. In the hidden layer, the values from each input neuron are multiplied by the weight w_{ji} and the results are summed to obtain the combined value u_j. Every sum u_j is then processed through the transfer function σ, producing the value h_j, which is transferred to the output layer. In the output layer, the values from each hidden neuron are multiplied by the weight w_{ji}, and the results are summed to obtain the combined value v_j. Each sum v_j is processed through the transfer function σ, producing the output value y_k of the network. When solving a regression task with a numerical target value, the output layer has a single neuron that produces a single y value. For classification problems with N categories, the output layer contains N neurons, each producing a value corresponding to one of the N categories of the target variable. The architecture of the MLP is illustrated in Figure 3.

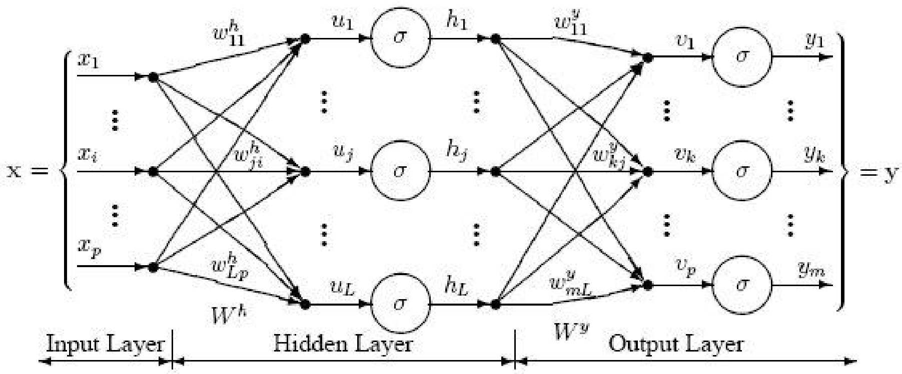

Figure 4. MLP architecture

4. Results and discussion

The predictive modelling software DTREG was used to build the models for predicting the target variable (Sherrod, 2013). The dataset used for model building consists of 45 rows and 8 columns. The target variable is CO_2, while the other 7 variables serve as predictors (as explained in Section 3. “Materials and methods”). Three NNs were tested: GRNN, MLP and RBF NN. The most accurate model was obtained with the GRNN. The accuracy results for all 3 NNs on the validation data are presented in Table 1.

Table 1. Results for the accuracy of the three NNs

Neural network	MAPE (%)(mean absolute percentage error)	R2 (%)(coefficient of determination	Coefficient of correlation between actual and predicted target values
GRNN	4.96	87.301	0.934
MLP	9.39	75.226	0.868
RBF NN	9.10	80.517	0.899

The DTREG software also computes the importance of variables in relation to the quality of the model. Table 2 presents the overall importance of variables for the GRNN model.

Table 2. Overall importance of variables for GRNN

Variable	Importance
O_2 (%)	100.000
T_{air} (^0C)	0.824
Losses (%)	0.027
ETA (%)	0.024
CO (ppm)	0.001
T_{dplin}(^0C)	0.001

AS shown in Table 2, the most important variables impacting the target variable are O_2, T_{air}, Losses, and ETA.

For each model, several parameters in the DTREG software need to be adjusted. For the GRNN model, the most important parameter is sigma, which determines the spread of the kernel function. The initial minimal and maximal values for sigma must be set, and DTREG uses the conjugate gradient algorithm to optimize the sigma values. For our model, the initial sigma value is set to 0.0001, with a maximum value is 3. The DTREG software offers two kernel functions: Gaussian and Reciprocal. We chose the Gaussian function for our model. The software also provides optimization options, the most commonly used one being the removal of unnecessary neurons to achieve more accurate models. For our model, the optimal number of neurons was found to be 33, and the model was reduced to this number when the minimal error was obtained. The validation method selected for the model is LOO (leave one out).

The developed GRNN model has proven to be a reliable and efficient tool for predicting CO_2 emissions from heating systems using data on exhaust gases and system characteristics as predictor variables. Accuracy measures indicate that the model can explain a significant proportion of the variability in actual CO_2 emissions. The research results are significantly valuable in two ways:

they benefit both existing buildings and heating systems, as well as the design of new buildings.

Detecting energy consumption and CO_2 emissions provides useful information for further adjustments, upgrades, replacements and maintenance of heating systems. Additionally, the identified system characteristics (O_2, T_{air}, Losses and ETA) that directly impact CO_2 emissions are crucial for planning and designing new energy-efficient facilities with reduced environmental impact. The application of the model is valuable for optimizing energy consumption in buildings, planning energy efficiency, and reducing operating costs. It can also support decisions regarding investments in modern technologies and heating systems. Forecasting CO_2 emissions enables long-term planning and can provide timely responses to changes in regulations or market conditions. Moreover, by applying the model, users can gain insights into the ecological footprint of their buildings, which can educate and motivate them to modify their behavior and enhance energy consumption management.

Overall, the developed model is a useful tool for facility management. Its use can make buildings more energy-efficient, environmentally friendly, and economically sustainable. The study provides a base for further research and development of new approaches to reduce human negative impact on the environment.

However, the study has certain limitations that should not be overlooked. A primary limitation is that the model was developed using data from only the Primorje-Gorski Kotar and Istria counties, which restricts its applicability to other parts of Croatia or the world. Different regions may have varying climatic conditions, building characteristics, heating systems, and energy usage habits. Additionally, the data were collected from buildings using only EL fuel oil for heating, making the results not applicable to other types of heating such as gas, electricity, solid fuel, etc. Due to these limitations, the model may provide limited insights and restrict its wider application.

Although the accuracy indicators of the obtained model are very high, there is still potential for creating models that provide even more precise results. Expanding the database with additional samples and variables and potentially applying more advanced prediction algorithms could guide further research in this direction.

Given these considerations, it is recommended that the research be expanded to cover the entire territory of the Republic of Croatia (or beyond) and that models be developed to address the needs of different regions with varying climatic, infrastructural, and economic conditions. Additionally, further research should analyze different heating systems and include additional variables that may impact the energy efficiency of the building, such as the building type, size, shape, material and seasonal variations in energy consumption. Expanding and adapting the model could enhance its precision and applicability to other areas and specific heating systems, thereby significantly contributing to energy efficiency and sustainable development. Regarding database expansion, it is crucial to select predictors that are most representative of the target variable and as homogeneous as possible. Several software tools can assist in choosing, analyzing, and preprocessing data. Tools like XGBoost, DataPrep and Scikit-learn can help improve the homogeneity of variables, ensuring similar distributions and enhancing the accuracy and performance of the predictive model. Homogeneous predictors can lead to better generalization and performance on unseen data.

The obtained model demonstrates the connection of CO2 emissions and the level of energy utilization. The importance of utilization levels and their relation to technical indicators of the system, such as maintenance, age, and fuel characteristics, was previously discussed. When designing new buildings, it is essential to consider and test these system aspects during the operational phase. The proposed GRNN model is a powerful tool for this purpose. From the perspective of facility management, this and similar tools should be integrated into the energy management system. It is important to note that there are distinct possibilities for developing models in various directions. By homogenizing and expanding the database, it is possible to create models for different types and purposes of facilities (private, public, manufacturing, residential, etc.) and varying climatic conditions. This suggests a need for continuous measurements, analysis of indicators, creation of more homogeneous databases, and development of models and their integration into the energy management system.

5. Measures to improve the efficiency of the heating system

Heating systems that are not properly maintained often exhibit reduced efficiency, leading to increased fuel consumption and higher emissions of harmful gases. To ensure optimal performance and minimize negative environmental impacts, it is essential to regularly monitor, maintain, and optimize the system's operation. To improve the heating system efficiency, which involves increasing the ETA and consequently reducing gas emissions, the following measures are highly recommended:

1. Regular annual maintenance, burner regulation and flue gas analysis.

2. Additional service in case of increased fuel consumption.

3. Higher fuel quality.

4. Installation of a fuel-saving device in front of the burner (Car-Pušić *et al.*, 2024).

6. Conclusion

The need for rational energy consumption, the consequent reduction of environmental pollution, and improving heating system efficiency through optimizing system parameters is undoubtedly justified. Scientific research, supported by modern devices for measuring and analyzing exhaust gases, as well as the application of contemporary scientific methods, contributes to understanding parameter optimization and the practical application and improvement of measures to enhance efficiency. In this study, the CO_2 share was used as the target variable, modelled as a function of independent variables, including the share of O_2 and CO in the exhaust gases, the temperature of the exhaust gases, the environmental conditions, the Lambda coefficient (the ratio of excess air), the utilization coefficient ETA and losses. The ETA coefficient is particularly significant as it describes energy use efficiency. Three neural networks were tested, and the GRNN model achieved the best accuracy with a mean absolute percentage error (MAPE) = 4.96%, a coefficient of determination R^2 = 87.301% and a coefficient of correlation of 0.934. Neural networks were employed to process measurement data, and the model can be updated with new measurement data for future CO_2 predictions.

Future work should focus on developing the model with an expanded database that includes more representative predictors covering the entire territory of the Republic of Croatia or tailored to the needs of different regions with varying climatic, infrastructural, and economic conditions. Additionally, existing software tools for data preprocessing can be utilized to enhance the model's predictive performance.

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Comparison of Reinforcement Technologies in Construction: Carbon Products vs. Steel Based on a Case Study

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Abstract:

This paper investigates the comparative effectiveness of Carbon Fiber Reinforced Polymers (CFRP) and traditional steel in structural reinforcement, focusing on a case study of a hotel renovation in Rab, Croatia. The study delves into various factors, including mechanical performance, cost-effectiveness, and environmental impact.

CFRP is increasingly recognized for its superior strength-to-weight ratio, corrosion resistance, and long-term durability, making it a strong contender for modern construction projects, especially in seismic retrofitting. However, the initial costs and specialized application techniques associated with CFRP present significant challenges. In contrast, steel remains a robust and reliable material with well-established installation methods, though it requires ongoing maintenance to prevent corrosion, especially in harsh environments. The results of this study suggest that while CFRP offers distinct advantages, particularly in reducing maintenance costs and improving durability, steel continues to be a cost-effective solution for many projects. The paper concludes by highlighting scenarios where the integration of both materials could provide optimal outcomes in construction practices.

Keywords: *Carbon Fiber Reinforced Polymer (CFRP), Steel, Structural Reinforcement, Construction, Case Study;*

1. Introduction

The selection of materials in the construction industry is a critical decision that significantly influences the safety, durability, and cost-effectiveness of structures. Over the decades, steel has become synonymous with structural reinforcement, primarily due to its high strength, durability, and versatility (Androić et al., 1994). However, the rapid advancement of materials science has introduced new alternatives, such as Carbon Fiber Reinforced Polymers (CFRP), which are increasingly being considered for various construction applications (Nechevska-Cvetanovska et al., 2021).

The primary objective of this paper is to provide a detailed comparison between CFRP and steel as reinforcement materials in the construction industry, with a particular focus on their application. By analyzing the mechanical properties, cost-effectiveness, environmental impact, and practical considerations associated with each material, this paper aims to offer insights that can guide engineers, architects, and construction professionals in making informed decisions about material selection in reinforcement projects.

Additionally, this paper seeks to contribute to the ongoing discourse on sustainable construction practices by evaluating the environmental implications of using CFRP versus steel. As the construction industry continues to grapple with the challenges of climate change and resource scarcity, understanding the trade-offs associated with different materials is becoming increasingly important.

1.1. Historical Context and Evolution of Reinforcement Materials

Historically, steel has been the backbone of the construction industry, especially in applications requiring substantial load-bearing capacity (Galić et al., 2020). The material's inherent properties, including its high tensile strength, ductility, and ability to be welded or bolted into complex structures, have made it indispensable in the construction of skyscrapers, bridges, and various infrastructural projects (Androić et al., 1994). Steel's development as a construction material can be traced back to the Industrial Revolution, where advances in metallurgy allowed for the production of stronger and more durable steel at an unprecedented scale (Androić et al., 1994). Its widespread availability and the ability to recycle steel without significant loss of properties have also contributed to its dominance (Španić et al., 2012).

However, steel is not without its drawbacks. One of the most significant challenges associated with steel is its susceptibility to corrosion, especially in environments that are humid, salty, or otherwise aggressive (Španić et al., 2012). Corrosion not only compromises the structural integrity of steel but also necessitates frequent maintenance and protective measures, such as coatings and galvanization, which can add to the overall cost and complexity of construction projects (Galić et al., 2020). Moreover, the weight of steel can be a limitation in applications where reducing the load on foundations is critical (Nechevska-Cvetanovska et al., 2021).

In contrast, the development and adoption of CFRP have been relatively recent, beginning in the late 20th century (MC-Building Chemicals d.o.o., 2024). CFRP materials are composite materials consisting of carbon fibers embedded in a polymer matrix. These fibers provide exceptional tensile strength and stiffness, while the polymer matrix helps to bind the fibers together, protecting them from environmental damage (MC-Building Chemicals d.o.o., 2024). The use of CFRP in construction initially gained traction in specialized applications such as aerospace and automotive industries, where high strength-to-weight ratios are paramount. Over time, as the benefits of CFRP became more evident and the costs associated with its production decreased, its application expanded into the construction industry (MC-Building Chemicals d.o.o., 2024).

1.2. The Growing Importance of CFRP in Modern Construction

CFRP offers several advantages over traditional materials like steel, particularly in terms of its mechanical properties and resistance to environmental degradation (Španić et al., 2012). The strength-to-weight ratio of CFRP is significantly higher than that of steel, which means that it can achieve the same or even greater structural strength with much less material (Nechevska-Cvetanovska et al., 2021). This property is especially beneficial in applications where weight reduction is crucial, such as in retrofitting existing structures where the additional load must be minimized.

Another key advantage of CFRP is its resistance to corrosion. Unlike steel, CFRP does not rust or corrode when exposed to moisture or chemicals, which can significantly reduce the need for maintenance and extend the lifespan of structures reinforced with this material (MC-Building Chemicals d.o.o., 2024). This property makes CFRP an attractive option for structures located in aggressive environments, such as coastal areas or chemical plants, where traditional materials may degrade more rapidly (Španić et al., 2012).

Moreover, CFRP's flexibility in application allows for innovative architectural designs that would be difficult or impossible to achieve with more rigid materials. The ability to mold CFRP into complex shapes and apply it in thin layers means that it can be used to reinforce existing structures without significantly altering their appearance or adding bulk (Galić et al., 2020). This characteristic is particularly useful in the renovation of historical buildings, where maintaining the original aesthetic is often as important as ensuring structural integrity (Španić et al., 2012).

Despite these advantages, CFRP is not without its challenges. One of the primary barriers to its widespread adoption in the construction industry is the cost. CFRP materials are significantly more expensive than steel, both in terms of raw material costs and the specialized labor required for their installation (MC-Building Chemicals d.o.o., 2024). The production of CFRP involves complex processes, such as the alignment and curing of carbon fibers within the polymer matrix, which require specialized equipment and expertise (MC-Building Chemicals d.o.o., 2024). Additionally, the installation of CFRP often involves meticulous surface preparation and the application of adhesives, which can be time-consuming and labor-intensive (Nechevska-Cvetanovska et al., 2021).

Another challenge associated with CFRP is its linear elastic behavior until failure, as opposed to the ductile behavior of steel. Steel structures can undergo significant deformation before failure, providing a warning before collapse and allowing for interventions (Androić et al., 1994). In contrast, CFRP fails in a brittle manner, which means that there is little to no deformation before failure. This characteristic requires careful design and monitoring to ensure that structures reinforced with CFRP are not subjected to loads that exceed their capacity (Galić et al., 2020).

1.3. The Case Study: Application in the Renovation of a Hotel in Rab, Croatia

This paper presents a case study focused on the use of CFRP and steel in the renovation of a hotel in Rab, Croatia, a region that has recently experienced significant seismic activity. The project involved the reinforcement of existing reinforced concrete (RC) slabs to accommodate new mechanical, electrical, and plumbing (MEP) systems, which required the cutting of large openings in the slabs. The key challenge was to ensure that the structural integrity of the building was maintained despite these modifications.

2. Literature review

The mechanical characteristics of steel and carbon reinforcements depend on the specific type of steel and carbon material, as both can vary in properties due to differences in composition, manufacturing processes, and applications. Below is a general comparison:

- **Strength**

Steel is well-known for its high strength and resistance to deformation under load. Various types of steel, such as high-strength low-alloy (HSLA) or carbon steel, exhibit different strengths. Generally, steel is characterized by high tensile strength, which enables it to withstand significant loads without damage. For example, mild steel typically has tensile strengths between 400–550 MPa, while HSLA steels can reach up to 700 MPa (Androić et al., 1994; Ashby & Jones, 2005).

Carbon fiber reinforcements, on the other hand, depend on the properties of their components: fibers, matrix systems, interlayer areas, and fiber orientation. Carbon fiber composites are known for their superior strength-to-weight ratio, and their tensile strength can be higher than steel, particularly in the direction of the fibers, often exceeding 1,000 MPa (Španić et al., 2012; Kaw, 2006).

- **Elasticity**

Steel exhibits elastic behavior, meaning it can deform under load and return to its original shape once the load is removed, up to its elastic limit. This behavior is governed by its modulus of elasticity, typically around 200 GPa for carbon steel (Androić et al., 1994; Callister & Rethwisch, 2020).

In contrast, carbon fiber laminates are highly anisotropic and exhibit linear elastic behavior until failure. While carbon fibers themselves have a high modulus of elasticity (230–600 GPa), the matrix material often limits the elasticity of carbon composites. Additionally, carbon laminates are not ductile, meaning they lack the ability to undergo significant plastic deformation before breaking (Španić et al., 2012; Kaw, 2006).

- **Corrosion sensitivity**

Standard steel is prone to corrosion, particularly in the presence of oxygen and moisture, which can lead to rust and structural weakening. Therefore, steel structures often require protective coatings like galvanization or epoxy coatings to prevent corrosion (Callister & Rethwisch, 2020). In contrast, carbon fiber composites are inherently resistant to corrosion due to the chemical stability of carbon fibers and the inertness of most matrix materials. This makes carbon reinforcements particularly suitable for environments where corrosion resistance is critical (Kaw, 2006).

- **Impact resistance**

Steel generally has good impact resistance, although it can vary depending on the specific alloy and treatment. For example, tempered steels exhibit higher toughness compared to untreated steels, making them better suited to absorbing energy from impacts (Ashby & Jones, 2005).

Carbon fiber composites, however, tend to be more brittle compared to steel. Although they have excellent tensile properties, their ability to resist impacts is limited. Carbon laminates can fracture or delaminate under high-impact conditions, which can compromise their structural integrity (Španić et al., 2012; Kaw, 2006).

Table 1. Comparison of Mechanical Properties of Fiber-Reinforced Polymers (FRP) and Reinforcing Steel (Španić et al., 2012)

Property	Steel reinforced bar	Steel cable	PASV bar	PASV cable	PAUV bar	PAUV cable
TENSILE STRENGTH, MPA (KSI)	483-650 (70-100)	1379-1862 (200-270)	517-1207 (75-175)	1379-1724 (200-250)	165-2410 (240-350)	1200-2068 (170-300)
YIELD STRENGTH, MPA (KSI)	276-414 (40-60)	1034-1396 (150-203)	196-414 (28-60)	1034-1396 (150-203)	276-345 (40-50)	310-414 (45-60)
MODULUS OF ELASTICITY, GPA (KSI)	200 (29.000)	186-200 (27.000-29.000)	41-55 (6000-8000)	48-62 (7000-9000)	152-165 (22.000-24.000)	50-74 (70.000-110.000)
ULTIMATE ELONGATION, MM/MM	> 0.10	> 0.04	0.035-0.05	0.03-0.045	0.01-0.015	0.02-0.026

COMPRESSIVE STRENGTH, MPA (KSI)	276-414 (40-60)	/	310-482 (45-70)	/	/	/
THERMAL EXPANSION COEFFICIENT (10^-6/°C) (10^-6/°F)	11.7 (6.5)	11.7 (6.5)	9.9 (5.5)	9.9 (5.5)	0.0 (0.0)	-1.0 (-0.5)
SPECIFIC GRAVITY	7.9	7.9	1.5-2.0	2.4	1.5-1.6	1.25

2.1. Comparisons of thermal characteristics

Comparison of the thermal characteristics of carbon products and steel used for reinforcing reinforced concrete (RC) structures includes consideration of several key factors: the coefficient of thermal expansion, thermal conductivity, and resistance to high temperatures. Below is a detailed comparison:

- **Thermal expansion**

CFRP materials have a lower coefficient of expansion than concrete and steel, therefore compatibility of materials (concrete to CFRP) to temperature changes is not ensured (Galić et al., 2020). Here the typical CTE: 9.9 x 10^{-6} /°C

Steel has a higher coefficient of thermal expansion compared to CFRP materials. This means that steel expands and contracts more with temperature changes, which can lead to thermal stresses in the structure. For steel, typically: 11.7 x 10^{-6} /°C

- **Thermal conductivity**

CFRP materials are rather thermally inert and are rather good insulators. Typical thermal conductivity factor is between 0,3 to 1,0 W/mK

Steel on the other hand is a good conductor of heat with 45 to 58 W/mK

- **Resistance to high temperatures**

CFRP materials are sensitive to high temperatures. The epoxy resins used as a matrix for CFRP can start to degrade at temperatures above 120-200°C, which can lead to a loss of mechanical properties. Mechanical degradation due to temperatures happens around 120-200°C for epoxy resins.

Steel has high resistance to high temperatures and can maintain its mechanical properties at significantly higher temperatures compared to CFRP materials. However, steel also loses strength at very high temperatures, which is critical in the event of a fire. Steel begins to lose strength significantly above 400-600°C.

In conclusion to the comparison of materials to thermal characteristics carbon products are ideal for situations where minimal thermal stress is required and in situations where no significant exposure to high temperatures is expected. Steel is more suitable for environments with high temperatures or in situations where high fire resistance and mechanical properties at high temperatures are critical. Ultimately, the choice between carbon products and steel depends on the specific requirements of the project, environmental conditions, and the necessary thermal characteristics.

2.2. Technical characteristics of the materials

Table 2 provides a detailed comparison between Carbon Fiber Reinforced Polymer (CFRP) and steel, focusing on key technical attributes essential for their application in reinforcing concrete structures. It outlines differences in tensile strength, weight, modulus of elasticity, and corrosion resistance, offering insights into how each material performs under various conditions. This comparison serves as a valuable reference for engineers and construction professionals when selecting materials based on project-specific requirements, environmental considerations, and long-term durability expectations.

Table 2. Comparison of technical characteristics considering the use of these materials in reinforced concrete structures

Factor	CFRP (Carbon Fiber Reinforced Polymer)	Steel
Strength	Very high tensile strength.	High tensile strength, generally lower than CFRP.
	Typical tensile strength: 1500 to 3000 MPa.	Typical tensile strength: 400 to 800 MPa (standard), 800 to 1200 MPa (high-strength).
Weight	Very light compared to steel.	Significantly heavier than CFRP.
	Typical density: 1.5 to 2.0 g/cm^3.	Typical density: 7.8 g/cm^3.
Elastic Modulus	High modulus of elasticity, but lower than steel.	Very high modulus of elasticity, making it very rigid.
	Typical modulus: 100 to 150 GPa.	Typical modulus: 200 to 210 GPa.
Corrosion Resistance	Highly resistant to corrosion and chemical influences. Does not oxidize or corrode in the presence of moisture or salt.	Prone to corrosion, especially in the presence of moisture, salt, and other corrosive agents. Requires protective coatings or galvanization.
	Corrosion resistance: High.	Corrosion resistance: Low to medium, depending on protection.
Durability	Long-lasting with minimal degradation over time in typical conditions.	Can be durable if protected against corrosion, but has a finite lifespan due to potential corrosion issues.
	Durability: High.	Durability: Variable, depends on environmental exposure and protection measures.

2.3. Economic Considerations

Economic factors play a crucial role in the selection of materials for construction projects. Steel, due to its widespread availability and established production methods, is generally less expensive than CFRP on a per-unit basis (Androić et al., 1994). The lower initial cost of steel makes it the preferred choice for many large-scale projects, particularly when budget constraints are a primary concern. Additionally, the standardization of steel production and fabrication processes has led to efficiencies that further reduce costs (Galić et al., 2020).

However, when considering the total lifecycle cost, CFRP can offer economic advantages despite its higher initial cost. The reduced need for maintenance due to its corrosion resistance and durability can lead to significant savings over the lifespan of a structure (MC-Building Chemicals d.o.o., 2024). Moreover, the lightweight nature of CFRP can reduce transportation costs and lower the load on foundations, potentially reducing overall construction costs in certain applications (Španić et al., 2012). The labor costs associated with CFRP can be higher due to the need for specialized installation techniques, but these can be offset by the material's long-term benefits.

Table 3. Economic considerations on the CFRP and steel

FACTOR	CFRP (CARBON FIBER REINFORCED POLYMER)	STEEL
RAW MATERIAL	Carbon fibers are significantly more expensive than steel. High costs are associated with complex production processes and the price of polymer matrices.	Steel is relatively inexpensive compared to carbon fibers. Raw materials are widely available, and the production process is less complex.
PRICE PER KG:	Approximately €18.00 – €36.00 depending on quality and type.	Approximately €1.35 – €3.45 depending on type and market conditions.
PRODUCTION	Production involves complex processes like weaving or knitting fibers, resin impregnation, molding, and curing. These processes are energy-intensive and require specialized equipment.	Steel production includes melting, casting, rolling, and shaping. While energy-intensive, these processes are highly automated and standardized.
PRODUCTION COSTS	High due to complex processes and expensive equipment.	Lower compared to CFRP due to high automation and simpler processes.
PROCESSING	Processing CFRP requires specialized tools and techniques, like water jet or diamond cutting, to prevent fiber damage.	Steel processing involves standard procedures like cutting, welding, drilling, which are relatively low-cost.
LABOR CONSIDERATIONS	Installation requires precise placement and use of epoxy resins for bonding with concrete. The process is labor-intensive and requires trained workers.	Installation of steel elements involves welding or mechanical fastening on-site, which is faster and requires less specialized labor.
PROCESSING AND INSTALLATION COSTS	High due to specialized equipment and worker training.	Lower compared to CFRP due to standardized processes and skill availability.
LONG-TERM MAINTENANCE COSTS	CFRP materials require minimal maintenance due to high resistance to corrosion and chemical influences. The only significant cost might be UV protection.	Steel is prone to corrosion and requires regular maintenance, including anti-corrosion coatings and repairs to prevent degradation.
LONG-TERM COSTS	Low, due to minimal maintenance needs.	Medium to high, depending on environmental conditions and the need for regular maintenance.

2.4. Environmental Impact

Sustainability and environmental impact are increasingly important considerations in material selection. Steel production is highly energy-intensive and contributes significantly to greenhouse gas emissions, primarily due to the carbon-intensive processes involved in extracting and refining iron ore. The blast furnace process, which is the most common method for producing steel, is a major source of CO_2 emissions, contributing around 7% to global emissions (Nechevska-Cvetanovska et al., 2021; World Steel Association, 2020). Despite advancements in production efficiency, such as electric arc furnaces and carbon capture technologies, the environmental footprint of steel remains a significant concern. Even though steel is 100% recyclable and can be reused indefinitely without losing its structural properties, the initial production still leaves a substantial environmental impact (Španić et al., 2012; Allwood et al., 2012).

Carbon Fiber Reinforced Polymer (CFRP), while also energy-intensive to produce, offers certain environmental advantages, particularly in terms of its longevity and reduced maintenance requirements. The production of CFRP involves carbon fibers that require significant energy to manufacture, particularly during the high-temperature processes necessary to create the fibers. However, the durability and long service life of CFRP can mitigate these initial environmental impacts (MC-Building Chemicals d.o.o., 2024; Galić et al., 2020). The material's resistance to corrosion and environmental degradation reduces the need for frequent repairs or replacement, which can result in overall lifecycle savings in energy and resources.

Furthermore, CFRP's lightweight properties contribute to environmental benefits during transportation and construction. The reduced weight of CFRP-based structures means lower fuel consumption for transportation and handling, and its high strength-to-weight ratio can lead to lighter structures requiring less material, which indirectly reduces the carbon footprint of projects (Galić et al., 2020).

However, the recyclability of CFRP presents a significant challenge. Unlike steel, which can be recycled indefinitely without significant loss of mechanical properties, CFRP composites are difficult to recycle. The complexity of separating the fibers from the polymer matrix makes recycling processes inefficient and often not economically viable (Španić et al., 2012; Pimenta & Pinho, 2011). Current methods, such as pyrolysis or chemical recycling, are being explored but remain limited in application and effectiveness. The end-of-life impact of CFRP is therefore a concern, as landfilling or incineration may be the only options in many cases, contributing to environmental waste. This is an area of active research, with ongoing efforts focused on developing more sustainable production methods and improving recycling technologies for CFRP (MC-Building Chemicals d.o.o., 2024).

Table 4. Environmental impact on the CFRP and steel

Factor	CFRP	Steel
Greenhouse Gas Emissions	20-25 kg CO2/kg	1.8-2.2 kg CO2/kg
Energy Requirements	200-250 MJ/kg	20-30 MJ/kg
Recycling Rate	<10%	>90%
Total Environmental Footprint	High production, lower operational	Moderate production, higher operational, low recycling impact

2.5. Practical Applications in Construction

The practical applications of steel and CFRP in construction vary widely, with each material offering unique benefits depending on the context. Steel's versatility and strength have made it a staple in structural frameworks, bridges, and high-rise buildings, where its load-bearing capacity and ability to form complex shapes are essential (Androić et al., 1994). The ease of joining steel components through welding and bolting, combined with its established supply chains, ensures that steel remains a go-to material for many construction projects (Galić et al., 2020).

In recent years, CFRP has been increasingly used in the retrofitting and strengthening of existing structures, particularly in seismic retrofitting and in areas where corrosion resistance is crucial (Nechevska-Cvetanovska et al., 2021). CFRP's high tensile strength and low weight make it ideal for reinforcing concrete structures without adding significant mass, which is particularly important in the renovation of older buildings that may not be able to support additional load (Španić et al., 2012). Additionally, CFRP's ability to be molded into complex shapes allows for innovative applications in architectural design, where aesthetic and functional requirements intersect (MC-Building Chemicals d.o.o., 2024).

The use of CFRP in bridge strengthening projects has also gained traction due to its ability to extend the lifespan of existing structures without requiring major modifications or the addition of substantial weight. This is particularly valuable in infrastructure projects where downtime must be minimized, and where traditional reinforcement methods may not be feasible due to space or load constraints (Galić et al., 2020). The flexibility in application and the reduced need for future maintenance make CFRP an attractive option for long-term investments in infrastructure.

3. Case study

This case study focuses on a critical construction and reconstruction project within the Suha Punta tourist resort on the island of Rab, Croatia. The project involved the installation of a new vertical utility shaft (150 x 317 cm) designed to accommodate various heating, cooling, and ventilation systems. These systems were intended to run from the roof, where the HVAC units are located, down through the 4th, 3rd, 2nd, and 1st floors, and finally to the ground floor. The complexity of this task was heightened by the requirement to cut through an existing reinforced concrete (RC) slab, necessitating pre-reinforcement to ensure the structural integrity was not compromised during the cutting process.

3.1. Initial Assessment and Load Determination

Before the reinforcement work could begin, a detailed assessment of the existing RC slab was necessary. The slab, with a thickness of 15 cm, was evaluated for its mechanical integrity. Core samples were extracted using diamond cutting technology, which revealed that the slab was in good condition, free from significant mechanical damage, and that the reinforcement within the slab had an adequate protective layer, ensuring its durability. This preliminary analysis was crucial in confirming that the slab could withstand the proposed modifications without compromising safety.

Following the assessment, the next critical step involved determining the loads that the newly created opening would need to bear. This was done in accordance with Croatian standard HRN EN 1991-1-1, which provides guidelines and specifications for loads used in construction projects. The area in question was classified under usage category C, specifically subcategory C3, which includes spaces where people gather, such as museums, exhibition halls, and public access areas in hotels and administrative buildings. The specified load values for this category are a uniformly distributed load (qk) of 30 to 50 kN/m^2 and a concentrated load (Qk) of 40 to 70 kN. These load values were instrumental in guiding the subsequent design and selection of the reinforcement method for the slab. Ensuring that the reinforced slab could handle these loads was essential to maintain the building's functionality and safety.

3.2. Reinforcement Methods Considered

Several reinforcement methods were evaluated for their suitability to meet the project's requirements, particularly in terms of load-bearing capacity, installation time, and long-term maintenance needs. The primary options considered were:

- Steel Reinforcement

Steel has long been the material of choice for structural reinforcement due to its high strength and ductility. The project initially considered using IPE (I-Profile European) steel profiles, which are hot-rolled steel sections commonly used in construction. The IPE profiles, known for their excellent load-bearing capabilities, were considered ideal for this application. However, the use of steel presented several challenges:

Weight Addition: The introduction of steel reinforcement would significantly increase the overall weight of the structure. This additional weight would need to be factored into the existing load-bearing calculations for the building's foundations and other structural elements.

Installation Complexity: Installing steel profiles requires precise measurements, drilling, and anchoring. These tasks are labor-intensive and time-consuming, particularly in confined spaces such as the project site, where access and maneuverability were limited. Additionally, the steel profiles would require welding or bolting, which further complicates the installation process.

Maintenance Requirements: Steel is susceptible to corrosion, especially in environments with high humidity or salt exposure, such as coastal areas. To prevent corrosion, the steel would need to be coated or treated with protective finishes. Regular maintenance would be necessary to ensure the longevity of the reinforcement, adding to the long-term costs of the project.

Despite these challenges, steel remains a viable option for projects where its high load-bearing capacity and well-understood performance characteristics are prioritized. However, for this specific project, the disadvantages outweighed the benefits, leading to the exploration of alternative materials.

- Carbon Fiber Reinforced Polymers (CFRP)

Given the constraints of the project, particularly the need for minimal weight addition and a rapid installation process, Carbon Fiber Reinforced Polymers (CFRP) emerged as a promising alternative. CFRP materials are composed of carbon fibers embedded in a polymer matrix, providing exceptional strength while being lightweight and highly resistant to environmental degradation. Two CFRP systems were considered:

MC-DUR CFK System: This system consists of carbon fiber laminates that can be bonded to the surface of concrete structures or inserted into grooves cut into the concrete. The MC-DUR CFK laminates are particularly effective in handling tensile stresses, making them suitable for reinforcing the RC slab in areas subjected to significant tensile forces. The system includes components such as MC-DUR 1280 adhesive and MC-DUR 1000 Parat 09 leveling mortar, which ensure a strong bond between the laminates and the concrete surface.

MC-DUR CF Sheets: These are unidirectional carbon fiber sheets laminated onto the structural surface to absorb tensile forces. The MC-DUR CF Sheets are flexible and can conform to various shapes and curves, making them ideal for reinforcing complex geometries. The sheets are also compatible with surface protection systems and coatings, which can be applied after installation to enhance durability and aesthetics.

3.3. Cost Analysis

A detailed cost analysis was conducted to compare the expenses associated with steel and CFRP reinforcement methods. Although CFRP materials were more expensive on a per-unit basis, the overall cost of the project favored CFRP due to several factors:

- Labor Savings: The quicker installation process of CFRP materials reduced the labor costs compared to steel, where more extensive installation procedures and longer work hours were required.

- Reduced Maintenance: The corrosion-resistant nature of CFRP eliminates the need for regular maintenance, which is a significant cost-saving factor over the lifespan of the structure.

- Transportation and Handling: The lightweight nature of CFRP made transportation and handling easier and less costly than steel, especially in a project located on an island where logistics can be challenging.

The total cost for reinforcing a single opening with CFRP was calculated at approximately €3.490,81 whereas the total cost of the strengthening using the steel solutions is assessed at €2.264,19. This included the cost of materials, labour, and any additional expenses related to the installation process. Still, when compared to the projected costs of using steel, CFRP offered a more economical solution for this specific project, particularly when considering the long-term savings in maintenance and durability.

3.4. Final Selection and Implementation

After evaluating the advantages and disadvantages of both steel and CFRP, the project team decided to use the MC-DUR CFK system for the reinforcement of the RC slab. This decision was driven by the need to minimize the additional weight on the structure, accelerate the installation process, and reduce long-term maintenance costs.

3.5. Conclusion on the case study

This case study underscores the importance of selecting the appropriate reinforcement method based on the specific requirements of the project. In the Suha Punta project, the choice to use CFRP over traditional steel was driven by the need for a lightweight, durable, and quickly installable solution that would not compromise the structural integrity of the existing building. While steel remains a reliable and widely used material in construction, CFRP offers significant advantages in scenarios where weight, corrosion resistance, and installation speed are critical factors.

The successful application of the MC-DUR CFK system in this project demonstrates the potential of CFRP as a viable alternative to steel, particularly in complex construction environments where traditional methods may not be feasible or cost-effective. As the construction industry continues to evolve, the adoption of advanced materials like CFRP is likely to increase, providing engineers and architects with more options to meet the diverse challenges of modern construction.

This project serves as a valuable example of how innovative materials and techniques can be applied to solve complex structural problems, ensuring the safety, functionality, and longevity of the building while also optimizing costs and efficiency.

4. Conclusion

In comparing Carbon Fiber Reinforced Polymers (CFRP) and traditional steel as reinforcement materials in construction, each material's unique strengths and limitations highlight their distinct applications. CFRP has gained recognition for its superior strength-to-weight ratio, corrosion resistance, and durability, making it a viable alternative to steel, particularly in projects where weight reduction and long-term maintenance are critical.

- **Advantages and Applications of CFRP**

CFRP's high strength-to-weight ratio allows for reinforcement without adding significant weight, making it ideal for retrofitting projects. Its resistance to environmental factors like moisture and chemicals reduces maintenance needs, which is crucial for structures exposed to harsh conditions. Additionally, CFRP's versatility in shaping and application supports innovative architectural designs, especially in preserving historical buildings where maintaining aesthetics is essential.

The case study of the hotel renovation in Rab, Croatia, demonstrates CFRP's practical benefits, particularly in seismic retrofitting. In regions prone to seismic activity, CFRP's ability to reinforce structures without significantly increasing weight is invaluable, reducing strain on foundations and enhancing stability during seismic events.

- **Challenges and Considerations of CFRP**

Despite its advantages, CFRP faces challenges that limit its widespread adoption. The high initial cost of CFRP, due to expensive raw materials and specialized installation, is a significant barrier, particularly in budget-constrained projects. However, CFRP's low maintenance needs and long-term durability can offset these costs over time.

CFRP's brittle nature, exhibiting linear elastic behavior until failure, contrasts with steel's ductility. This characteristic requires careful design and monitoring to prevent overloading, making CFRP less suitable for critical load-bearing elements without additional safety measures.

Recyclability is another concern. Unlike steel, which can be recycled without significant property loss, CFRP composites are difficult and costly to recycle. Current recycling methods for CFRP are limited, raising environmental sustainability issues that require further research and development.

- **Steel's Enduring Relevance**

While CFRP offers compelling advantages, steel remains a robust material, particularly in large-scale projects where cost-effectiveness, ease of use, and well-understood properties are essential. Steel's ductility allows structures to deform significantly before failure, providing a safety margin in dynamic load conditions, such as during earthquakes.

Steel's recyclability enhances its sustainability, but its susceptibility to corrosion requires ongoing maintenance, increasing long-term costs. Despite these challenges, steel's established role in construction ensures its continued relevance, especially where budget and structural safety are primary concerns.

- **The Integration of CFRP and Steel**

An integrated approach combining CFRP and steel can offer optimal solutions for modern construction challenges. Leveraging CFRP's high strength-to-weight ratio and corrosion resistance alongside steel's ductility and cost-effectiveness allows engineers to design structures that capitalize on the strengths of both materials. This hybrid approach is particularly effective in seismic retrofitting and long-term durability projects, where CFRP can reduce weight and maintenance costs, and steel can provide necessary ductility and load-bearing capacity.

- **Future Directions and Sustainability**

The future of construction will likely see increased adoption of advanced materials like CFRP, driven by the need for more sustainable and resilient structures. Ongoing research into CFRP production, application, and recycling is expected to address current challenges, making it more viable across a broader range of projects. As the industry emphasizes sustainability, materials will be chosen not only for performance but also for environmental impact.

In conclusion, the comparison between CFRP and steel highlights the importance of material selection in construction. While CFRP offers significant advantages, its adoption depends on addressing challenges related to cost, brittleness, and recyclability. Integrating the strengths of both CFRP and steel can lead to more resilient, cost-effective, and sustainable construction practices, ensuring that future structures are both innovative and enduring.

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Towards a Digital Ecosystem for Circular Construction

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Abstract:

This paper outlines and presents the extensive research program at the Department of Integrated Planning and Industrial Building, TU Wien, for the creation of a comprehensive digital ecosystem for circular construction. The ecosystem provides comprehensive data on material composition of building stock for urban mining, facilitating reuse and recycling, and the development of new business models for building owners; by coupling various components from ongoing research projects *BIMaterial, SCI_BIM, BIM_stocks, RE:STOCK INDUSTRY, Circular Twin,* and *DiCYCLE*. The key component is the BIM-based Material Passport, enabling semi-automated assessment of material composition of new and existing buildings. Expanding on this concept, and employing innovative assessment techniques like laser scanning for geometry acquisition or Ground Penetrating Radar (GPR) for material assessment, detailed material and even energy-informed BIM models can be generated. The up-scaling of such BIM models of representative buildings in Vienna has enabled the generation of a digital platform for urban mining (*BIM_stocks*) as an additional ecosystem component. *RE:STOCK INDUSTRY* focuses on automation of structural capacity assessment of existing industrial buildings to explore their potential for reuse, renovation, and vertical expansion, while considering circular economy principles. The optimization of new construction and the implementation of the *BIM_stocks* platform as a material cadaster for the purchase of elements for reuse or re-purposing is explored in *Circular Twin*. Finally, business models - for new construction and stock refurbishment - are explored in *DiCYCLE*. Linking the abovementioned components in a holistic digital ecosystem, allows digitally supported and optimized circular design and construction along the lifecycle.

Keywords: *Circularity; Material Passports; Urban Mining; BIM; GIS*

1. Introduction

Settlements and infrastructure constitute the largest material reservoirs in an industrial economy. Research findings in regional material balance indicate that these reservoirs of essential primary materials are already comparable in size to global primary deposits currently economically feasible for mining. Urban mining emerges as a strategic approach to safeguard these urban reservoirs over the long term or to regularly recycle them, aiming to minimize the consumption of primary resources and thereby reduce dependence on imports. It is integral to the pursuit of a circular economy and circular construction, alongside principles such as reduction, refurbishment, reuse, repurposing, and recycling of materials and building elements. To fully leverage urban mining and circular construction, comprehensive data on material composition of the building stock is necessary, along with digital platforms facilitating reuse and recycling, and the development of new business models for building owners.

This paper outlines and presents the extensive research program at the Department of Integrated Planning and Industrial Building, TU Wien, for the creation of a comprehensive digital ecosystem for circular construction, grounded in the coupling of various components from ongoing research projects *BIMaterial, SCI_BIM, BIM_stocks, RE:STOCK INDUSTRY, Circular Twin*, and *DiCYCLE*. The key component of this ecosystem is the BIM-based Material Passport, which enables the semi-automated assessment of material composition of both new and existing buildings. Expanding on the concept of the Material Passports, and employing innovative assessment techniques like laser scanning for geometry or Ground Penetrating Radar (GPR) for material assessment, detailed, material and even energy-informed BIM models can be generated. The up-scaling of such BIM models of representative buildings in Vienna has enabled the generation of a digital platform for urban mining (*BIM_stocks*) as an additional component of the ecosystem. The extension of building use through the assessment of structural capacity of industrial buildings is being explored in *RE:STOCK INDUSTRY.* The optimisation of new construction and the implementation of the *BIM_stocks* platform as a material cadaster for the purchase of elements for reuse or re-purposing is explored in *Circular Twin*. Finally, novel business models for reuse and recycling processes supported through BIM and Blockchain Technology, enabling further new construction and stock refurbishment - are explored in *DiCYCLE.* By linking the mentioned components from *BIMaterial, BIM_stocks, RE:STOCK INDUSTRY, Circular Twin and DiCYCLE* in the presented digital ecosystem, circular design processes and strategies can be digitally supported and optimized along the value chain of circular construction.

In this paper, we hypothesize that a holistic digital ecosystem necessitates the interaction of several components – a digital material passport, a material and circularity informed BIM Model, a comprehensive digital material cadaster, and a business model – to fully enable urban mining and circular construction. This will be elaborated upon in Section 4.

2. Point of departure

The principles of circular economy have been known for the long time, rooting back to the concept of industrial ecology (Lowe and Evans, 1995), which proposes a circular loop system of production instead of linear manufacturing based on extraction of natural resources and moving it to waste.

However, in the context of AEC (architecture, engineering and construction) this is a novel concept, despite the fact that this sector plays a crucial role as the largest consumer in the consumption of raw materials (WEF, 2016) being responsible for 60% of the raw materials extracted from the lithosphere (Bribián *et al*., 2011) and approximately 40% of energy-related CO2 emissions (WGBC, 2016; UN 2020). Extraction of raw materials, and related production of building materials and components, construction process itself, as well as demolition of buildings and infrastructure has large effects on the environment along the lifecycle, through manufacturing energy consumption, environmental emissions and upcoming waste (Treloar *et al*., 2003).

Further on, with the steadily growing population and rapidly increasing urbanization the need for new construction, thus new building materials is also increasing.

The land consumption for residential areas continues to rise much faster than population growth due to the continuously increasing individual demand for living space. In 1971, each person in Austria had just over 20 m^2 of living space. In 2011 it was more than 40 m^2. In 40 years, the living space per person has doubled. (Wiener Zeitung, 2020).

The increase in construction activity resulting from urbanization on the one hand, and the increasing size of living spaces on the other, leads to a steadily increasing consumption of primary resources. With the average lifespan of construction products being 40-50 years, there will be a significant increase in construction waste in the coming decades. This is linked to the problem of landfill space, as the current availability of landfill space is already limited. This ever-increasing consumption of primary resources, but also the need to drastically reduce the generation of waste, can only be reduced by high recycling rates. Accurate knowledge of the material composition of construction waste is needed, but is not currently available. Recyclability is highly variable over time however as it is dependent on technological progress and raw material prices. Further, the design properties, such as accessibility and separability of the components/layers have large impact on both recyclability and reusability.

To minimize the environmental impacts and energy consumption caused by extraction of primary materials, as well as to reduce the upcoming of waste, maximizing the recycling rates is a main strategy, which is also part of the European Union's (EU) action plan for Circular Economy. The objective of Circular Economy is to maintain the value of products, materials and resources in the economy as long as possible in order to reach a low carbon and resource efficient economy (European Commission, 2015). The circulation of resources within the loop consequently reduces the need for virgin materials (Andersen, 2007). However, the uncertainty in predicting the future use of materials and buildings is a challenge in circular economy approaches (De Wolf *et al.*, 2020).

The Circular Economy Action Plan reflected in the EU taxonomy, imposes certain requirements on buildings. For example, at least 90% (by mass in kg) must be reused or recycled in new buildings (at least 70% in existing buildings). Currently, most demolition waste (83%) is used only as concrete rubble, for example in road construction or for backfilling, which reduces its value. Entire building components such as windows, doors, parquet floors or stairs are rarely reused. In the case of wood and plastic waste, thermal utilization (incineration to generate energy) predominates because the contents (wood preservatives, flame retardants, etc.) prevent material recovery (Pamminger and Wimmer, 2023). Further, concrete design requirements in relation to the circular economy are set for "design for adaptability and deconstruction" specifically for each life-cycle phase. The assessment of carbon footprint is also required for buildings for each life cycle phase (Taxonomy, 2024). The aim of the EU taxonomy is to steer capital flows towards sustainable, circular investments. If the requirements are not met and the investment is categorized as unsustainable, the financing costs increase (Pamminger and Wimmer, 2023).

2.1 Material Passports and Circularity assessment

The pursuit of circularity in construction has led to extensive development of methodological and instrumental approaches such as material passports and circularity indicators for assessment of circularity.

Material passports (MP) have been known since the 80's - called "building renovation passport" (Eichstädt, 1982) and can be seen as major tools to facilitate our transition towards a digital circular economy. There are numerous definitions of material passports (Honic *et al.,* 2021a) as well as various terminology such as building material passports, or building circularty passports (Göswein *et al.*, 2022) 'building passports' (Blum, 2009) and 'building material passports" (Munaro *et al.*, 2019).

Madaster defines MPs as live documents that record 'the quality and origins of materials, the disassembling options of the various products and their current location' allowing for the effective 'track and trace' of building elements, facilitating their recycling and reuse (Madaster, 2020).

Material passports can be differentiated into passports for new construction or the passports for existing buildings, generation of which requires precise assessment of geometry and material composition of existing stock, and is thus more challenging task, both in terms of resources and technology (Honic *et al.,* 2023a).

The digital MP can be regarded as an essential part of a broader digital information system—that is, the Digital Product Passport (DPP) envisioned by the EC, as the strategic instrument supporting several Green Deal goals and accelerating the transformation towards a sustainable built environment. The aim of the DPP is to foster sustainability, enable the transition to a circular economy, and support consumers in making responsible purchasing choices through the product-related information recorded along its lifecycle (Panza et al., 2023).

DPP is a key element of the European circular economy strategy and has its origins in the Ecodesign for Sustainable Products Regulation (2024). Initiated by the digital product passport, a basic digital infrastructure for circular economy management is being established. In future, numerous products will be provided with clearly identifiable markers in order to make specific information such as the CO2 footprint, reparability or toxic ingredients available. This is intended to drive the circularity of products, better inform customers in their purchasing decisions and create more transparency along the value chain overall. The first implementations of the Digital Product Passport are planned for the areas of batteries (from 2027), textiles, electronics, plastics and the construction sector. From 2030, regulations are to be introduced for many other product categories. However, as these regulations are still in the development phase, there are still many unanswered questions (Plattformindustrie 4.0, 2024).

Material Passports are considered to be the key instrument for the assessment and achievement of circular construction. There are several concepts currently employed such as the Circularity Indicator by Ellen Mc Arthur, as used by Madaster (2021). Further approaches are introduced by building certificates such as the Circularity Index of DGNB or of the national policy making institutes such as IBO (Austrian Institute for Building Biology) with the EI Disposal indicator (Entsorgungsindikator), created for uniform assessment of the disposal properties of building and construction materials at the building level (IBO, 2024).

3. Research problem

Despite the current European or national policy making for circular economy the realization of circular construction is still facing numerous challenges.

In the particular Austrian AEC context, the construction industry is a major economic sector, creating jobs and local added value, however it accounts for 40-50% of Austria’s total energy and resource consumption and around 72% of total waste generation. Around 10 million tons of construction and demolition waste were generated in Austria in 2015.

90 % of construction and demolition waste is generated during demolition, conversion and refurbishment, only 10 % during construction (BAWPL 2017). The generation and composition of construction waste and the associated measures for recycling and disposal are significantly influenced by decisions made during the lifecycle; in particular in the planning stage. Crucial role plays thereby the choice of materials, connection technology and service life.

For the definition of the research problem, we summarize following particular issues*:*

Firstly, the standardized circularity assessment methodology is lacking, despite the large number of various circular building indicators.

Secondly, the knowledge on the building stock composition is missing, as future secondary material cadaster is lacking, regarding the qualities, quantities as well as the composition of the building stock. While the assessment of the reuse and recycling potential often focuses on documentation methods of materials, building elements or components and chemical constituents, structural behavior or capacities are still largely neglected, thus representing a significant research gap.

In this context strategies for the re-framing of a legal regulative regarding reuse are needed. e.g. standardized methods for assessment of loadbearing capacities and the feasibility for the second-life usage are lacking. These components are still classified as construction rubble or as not satisfactory in terms of technical performance. New policies and building codes are needed in order to enhance the reuse.

Thirdly, new business models are needed for circular construction. The investors still do not see the value or return on investment in circular concepts. There is lack of knowledge on the monetary value or balancing of elements and materials after the deconstruction (second life), as well as the lack of trading platforms where these could be sold or purchased on the broad base.

Finally, the fragmented character of the AEC industry, lacking the integration and collaboration along the value chain hinders the realization of circular economy principles. Design-oriented optimization tools, that could be implemented both in the early-stage design, with highest impact on the life cycle of buildings, as well as along the lifecycle for continuous re-evaluation are still underdeveloped.

4. The digital ecosystem for circular construction

We summarise the discussed challenges into following main objectives for achievement of circularity in AEC:

- Assessment of the material composition and circularity potential of new buildings

- Assessment and modelling of the material composition and circularity potentials of existing buildings

- Gaining thorough knowledge on material composition of existing building stocks for urban mining

- Developing strategies for tracking of elements and materials along the life cycle, determining their monetary value in second life

- Design and decision-making support in early design stages

We address the abovementioned objectives and research questions by creating a comprehensive research platform – a digital ecosystem for circular construction - through coupling of the ongoing research projects *BIMaterial, SCI_BIM, BIM_stocks, RE:STOCK INDUSTRY, Circular Twin*, and *DiCYCLE* (see Figure 1).

The key component provides *BIMaterial*, through the definition of a BIM-based Material Passport, which enables the semi-automated assessment of material composition of both new and existing buildings; as well as providing a framework for circularity assessment and LCA.

We expand the concept of material passports on the existing buildings and building stocks. For modelling and evaluation of a singular building we employ innovative assessment techniques like laser scanning and photogrammetry for geometry acquisition or Ground Penetrating Radar (GPR) for material assessment, thus enabling detailed, material and even energy-informed BIM model generation. To address the building up of a digital cadaster of secondary materials we up-scaled such BIM models of representative buildings in Vienna and embedded these in GIS, which laid a fundament for a digital platform for urban mining (*BIM_stocks*) as an additional component of the ecosystem. A framework for the end-to-end digital recording, modeling, and analysis of the load-bearing stock of industrial buildings for circular reuse and vertical expansion is developed in *RE:STOCK INDUSTRY*. The potential for reuse, modernization and vertical upgrading is determined, and the structure-specific information documented in material passports.

In order to provide novel design-centric tools for optimization of circularity in the conceptual design stage, material informed BIM-objects allow the creation of circular digital twins as well as their evaluation in a VR environment - *Circular Twin* (Providing "Circularity" informed BIM objects for circular digital twins).

Finally, novel business models for reuse and recycling processes supported through BIM and Blockchain are developed in *DiCYCLE*, enabling new construction and stock refurbishment, whereby building elements or materials and their related changes throughout the lifecycle are tracked and certified as products ready for the second-life market.

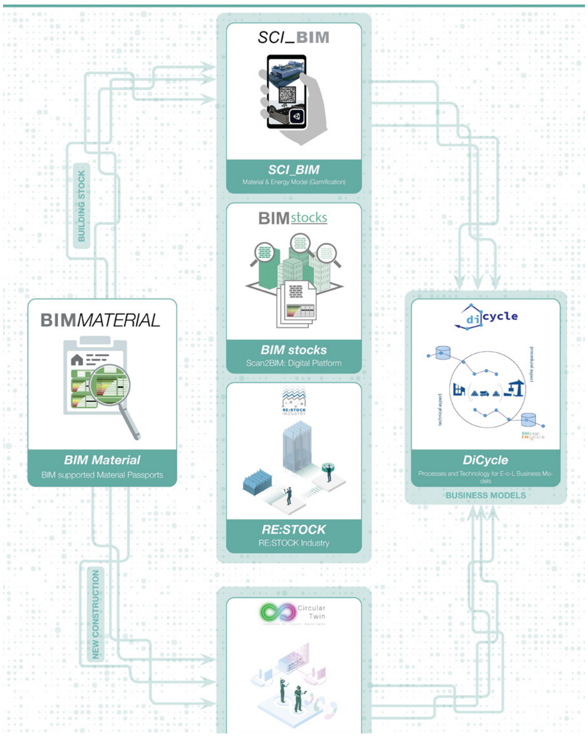

Figure 1. Digital Ecosystem for Urban Mining and Circular Construction

4.1. BIMaterial

The early design stages play a crucial role in the waste reduction, the reusability of the building elements as well as in the increase of the recycling potential. As planners and architects are major decision makers regarding design, materials, construction and the assembly method, they bear large responsibility defining the resources efficiency over the life cycle. In order to optimize the recycling potential and material composition of buildings, new design-centric tools and methods are required as well as tools, which enable a compilation of data repositories on the material composition of buildings. New digital design tools such as BIM enable data management along the life-cycle, thus bearing large potentials for generating a Material Passport (MP).

Within the project *BIMaterial* - Process Design for BIM based Material Passport, a method for a BIM supported semi-automated generation of a Material Passport was developed (Honic *et al.*, 2019). Further on, a concept for parametrization and assessment of a life-cycle-oriented MP was built up. The MP assesses the share of recyclability and waste of a building as well as the LCA. The workflow for a semi-automated generation of the BIM-based MP was defined, based on the coupling of several digital tools, such as BIM, an Analysis Tool (a comprehensive SQLdatabase tool BuildingOne with embedded algorithms) and eco- inventories (Kovacic et al*.,* 2019).

The data-transfer and analysis of the BIM-model in the Analysis Tool allows an extensive assessment and analysis of the material composition of a building, such as an assessment of all material-quantities, of percentages of mineral, metallic or organic materials, of recyclable and waste materials over the buildings' life cycle etc.

The proof of concept was compiled on a use case, in order to examine the usability of the proposed analysis and workflow. Finally, a framework was created, which documents the workflow, data structures and modelling requirements. Further, a framework for a software developer, a modelling guideline for the planners and a roadmap for various stakeholder was generated. The results show that a semi-automated compilation of a MP through coupling of tools and integration of building catalogues is possible.

The proof of concept demonstrated potentials of the MP as instrument along a building's lifecycle – as a design-optimization tool, material-inventory and as a document on material assets of real estates or building stocks, and finally enabling successful implementation of Urban Mining strategies. This project is a central milestone towards standardized, BIM- generated Material Passports.

The conducted research has shown that the developed method, which is based on coupling various digital tools, is appropriate for the compilation of a semi-automated MP. Within the project we focused on the conceptual and the planning stage, where the MP serves as a decision support- and optimization tool for planners. In a further step, the developed MP should be tested in further project stages, as well as in the operation stage. The proof of concept for the generation of the BIM-based MP has demonstrated the potentials for modelling and predicting material flows on urban-level. Coupling of BIM and GIS would make predictive modelling on urban-level possible with one condition: the existence of data about the material composition of buildings.

4.2. SCI_BIM

The aim of *SCI_BIM*: Scanning and Data Capturing for Integrated Resources and Energy Assessment using Building Information Modelling is to enable the increase of resource and energy efficiency by using a gamification concept and coupling different digital technologies and methods for data acquisition (geometry and material composition) and modelling (as-built BIM) of buildings and assets (Honic *et al*., 2021b). Based on a real case study (TU Wien, Aspanggründe) the integrated data acquisition and modelling methods are tested and evaluated in terms of costs and benefits. We use laser scanning for acquisition of geometry and the "Ground Penetrating Radar" (GPR) technology for the material composition. Thereby the suitability of the GPR for the identification of materials coupled with laser scanning technology is tested, to develop the proof of concept for the semi-automated generation of an information-rich as-built-BIM, which enables an efficient generation of models for Material Passports or Building Energy Modelling and Simulation (BEM). Within this project, an innovative gamification concept is developed, in which structural changes and user behavior (such as open windows or lighting) are recorded by user participation (users take photos via smartphones, which are uploaded on the photogrammetric as-built BIM model within the gamification platform). On the one hand, the structural changes will be recorded (static data) and on the other hand, the model for operational building automation will be compiled through the documentation of user behavior (dynamic). Through implementation of user data, the as-built BIM is semi-automatically updated thus generating an information rich digital twin for facility management.

Through application and material modelling by GPR a research gap is closed – the acquisition and modelling of geometry is already well explored, however, the methods and tools for capturing and modelling of the material composition of buildings are missing. The main innovation of this project is the development of the semi-automated recognition of BIM-objects from the point-cloud, as well as the use of gamification for the reduction of energy consumption together with the automated update of as-built-BIM4FM. This approach enables the automated generation of the MP at the end of the lifecycle, and delivery of useful information for the digital material cadaster as well as for the assessment of the material value of a building. The main result is the developed „process design" of *SCI_BIM*, which displays all sub-steps from data collection to the generation and maintenance of the Digital Twin.

The main challenge within the workflow was identified as handling of the discipline-specific models and data. Other challenges, such as the fact that the building was occupied throughout the scanning period which required further scanning tasks, the motivation of the users to participate in the gamification process, as well as the data overload through scanning, and lack of interdisciplinary knowledge were faced. To enable smooth data and information exchange, it is crucial to determine the data exchange formats and their interfaces by conducting team meetings before each step (Honic and Kovacic, 2020).

The results of *SCI_BIM* are the basis for the follow-up project *BIMstocks* in which the technologies "Laser Scanning" and "GPR" are applied on various existing buildings in order to enable upscaling on a city level. In the long term, the digital urban mining platform serves as a basis for increasing recycling and reuse rates at the city level.

4.3. BIMstocks

Due to the global increase in energy and resource consumption and the growing amount of waste (Honic *et al.,* 2021a), the building stock shows great potential to act as a resource reservoir of raw materials and increase the reuse potential of existing materials and elements. Nevertheless, there are obstacles to this process, as current knowledge of actual building structures and material composition is insufficient. The project *BIMstocks*: Digital Urban Mining Platform for Assessing the material composition of building stocks through coupling of BIM to GIS aimed at creation of a digital GIS-based urban mining platform (secondary raw materials cadaster) for city of Vienna, to deliver useful information regarding recycling potential, material flows and waste mas on city level. A Ground-Penetrating Radar and Machine-Learning (ML) Algorithms were employed to compile an BIM-object-catalogue, as well as Material-Passports for upscaling of the material masses via a GIS platform on a city level (Honic *et al.,* 2023b).

To generate the platform two approaches were employed – a top down and bottom up. A top-down approach is used to estimate the material composition in the whole stock, which indicates the materials in use over time. This opens up the possibility of providing data on developments in the overall stock. In contrast, the bottom-up approach carries out detailed studies of representative buildings in order to determine the exact building inventory. The up-scaling of representatives (age and typology) allows modelling of the whole stock.

Ten representative buildings for the city of Vienna were surveyed with the focus on the identification of used materials. On the one hand, invasive methods were applied, i.e. the opening of various building components through drilling or chiseling, and on the other hand, non-invasive methods such as photo documentation, laser scans (mainly for geometric data) and GPR scans. The data was processed in a so-called building- components-layer lists. These lists describe the component layers found in terms of layer thickness, material and material densities and served as a basis for BIM modeling, as well as comparison data for GPR data sets, or training data for a ML algorithm, which should automatically assign the GPR data to these component layers in the future. The BIM models created served as the basis for the material mass evaluation, as each component was recorded in these and assigned to the building-components- layer lists. The evaluated material masses per use case could also be linked to an existing database from the GIS based on information about the building use and the construction period in which the building was built (Honic *et al.,* 2023c). This enabled an upscaling and thus a forecast of the material masses used in the city of Vienna.

4.4. RE:STOCK INDUSTRY

Austria has more than 82,200 industrial and warehouse buildings, with over 1,000 new construction permits issued each year (Statistik Austria, 2022 b,c). Land sealing from horizontal production and storage is a major issue, with around 20.000 hectares of unused industrial and commercial areas and up to 6.000 vacant buildings with reuse potential (Enzinger, 2017; Janitsch, 2022). Companies and municipalities face challenges securing space for expanding or relocating production, warehousing, and logistics (Lasi *et al*., 2014; Vajna, 2014), often neglecting the possibility to settle in existing buildings. Developing cost- and time-efficient concepts for integrating new production and logistics uses into existing structures and solutions for vertical production processes is crucial to bring production back to Europe and minimize new land and soil sealing.

A building's reuse and vertical upgrading potential depends on the condition of its load-bearing structure to support new loads and space requirements. Detailed information on the material and structural composition, condition, pollutant levels, and load-bearing capacity of the stock is often lacking. The challenge is to digitize, model, and analyze existing structures accurately and make them accessible for life cycle-oriented economies. Creating digital as-built models using the finite element method (FEM) for structural analysis is currently a manual, time-consuming, and error-prone process.

The research in *RE:STOCK INDUSTRY* aims to repurpose the existing load-bearing structures of industrial buildings for new developments, expansions, or conversions, avoiding recycling or disposal. The research is developing a computational method based on artificial intelligence (AI) for automated conversion of scan data to FEM models. First, the reconstruction of the parametric FEM model from 3D point clouds is undertaken by heuristic optimization methods. The reconstructed digital model will contain information on the geometry, material and condition of the structure. Second, to interpret the structural joint connections of the stock, a deep neural network (DNN) for automated recognition of the joints degree of freedom from geometric and image data is developed. By integrating an innovative 3D-layout vertical production generator into structural analysis, new approaches for vertical retrofitting and customized production concepts in existing buildings can be explored with the goal to provide a framework which prevents new soil sealing and extends the service life of buildings.

To integrate circular economy aspects into the analysis of existing structures, two methods are being researched: a) Development of a method for evaluating the reuse and retrofitting potential of load-bearing structures, defining clear criteria such as environmental and cost effects, quality, functionality, and technical feasibility. This ecologic and economic assessment model will evaluate the planned retrofitting measures in comparison to demolition and new construction. b) Development of a method to efficiently document the digitized inventory and retrofitting planning in building material passports to record detailed structural information such as material composition, quantity, load-bearing capacity, condition, year of construction, and pollutant content.

Finally, an interactive augmented reality (AR) application will visualize the potential reuse and retrofitting concepts with real-time performance feedback directly on-site, encouraging planners and building owners to upgrade rather than demolish and rebuild.

The data collection and method development focus on steel and reinforced concrete skeleton structures, which make up 80% of the industrial building stock. Ten buildings in Austria are selected as real use cases for framework development and proof-of concept. These buildings are captured using scanning and photogrammetry, on-site inspections by deconstruction and retrofitting experts, and analysis of planning documents. (Reisinger et al. 2024)

4.5. Circular Twin

Optimization of architectural design in terms of circularity and environmental impacts should be conducted in early design stages as this stage bears largest optimization potentials. Conceptual design stage represents a vital phase where materials can enter (or reenter) a new life cycle, and design concepts are still in their initial adjustable stage, thus more flexible to adapt (Gorgolewski, 2018; Honic *et al.,* 2019; Çetin, 2023).

The concept of the project *Circular Twin* therefore addresses architectural design for new circular construction, based on the previous research and developed MPs.

The developed framework is based on a BIM-object catalogue, incorporating material informed objects enriched by eco- and circularity indicators; an End-of-Life-assessment algorithm for attributing and evaluating different building variants in terms of LCA and circularity, and finally a VR platform including a geometric digital twin of design variants and a conversational Virtual Agent for decision support (Wieser *et al*., 2024). The BIM-object catalogue contains data from relevant eco-inventories such as the Austrian database "baubook" which is essential for conducting defined assessments relevant for compliance with the EU Taxonomy classification system (European Commission, 2024).

Circular Twin thus merges early-stage BIM-based architectural design and circularity assessment. The early stage design process is supported by a Virtual Agent in a VR Platform, which enhance the visualization of environmental impacts and enable decision support by suggesting design variants with optimized LCA and circularity. The conversational Virtual Agent represents important step towards achievement of higher usability of digital tools for circular design. - see Figure 2 somewhere?

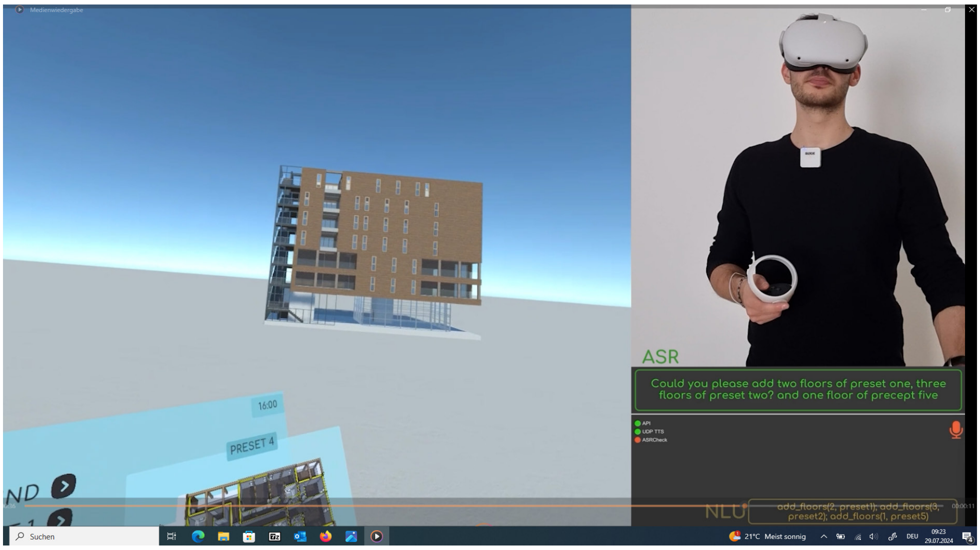

Figure 2. Circular Twin VR Platform with conversational Virtual Agent

4.6. DiCYCLE

A review of existing business models for the built environment, based on literature and industry practice, reveals that few models address the End-of-Life phase comprehensively, with most focusing narrowly on specific activities within the building lifecycle (Srećković and Šibenik, 2023). It is therefore essential to rethink current business models and practices in AEC by viewing waste as a resource and designing buildings as future material reserves (Heisel and Rau-Oberhuber, 2020).

The primary objective of *DiCYCLE* is to develop new business models and foster sustainable digital design, construction, and deconstruction workflows that promote the reuse and recycling of building materials and components throughout their lifecycle. The aim is to identify, analyze, and map current End-of-Life (EoL) processes in the AEC industry. The project seeks to optimize these processes using BIM, Blockchain Technology (BC) and Smart Contracts (SC). Identifying key stakeholders and defining their roles, activities, and responsibilities in developing the underlying BIM model for the EoL phase is essential, as well as understanding the necessary legal framework. *DiCYCLE* focuses on BIM models reflecting the actual state of a building ("as-built") and on workflows that document both data changes and completed construction work. Identifying data structures for EoL-relevant information and integrating this data with BIM is essential. BC will enable the tracking and verification of this EoL data. SC are developed to track the reuse and recycling of building materials and components within an integrated digital building model, allowing for early EoL assessments.

Scenarios for implementing BC and SC across different business models are tested and evaluated using test cases from relevant stakeholders in EoL. Key performance indicators and other relevant data for BIM and SC-supported EoL processes will be linked to the design phase ("as-planned" BIM), enabling EoL predictions early in the design stage. This approach allows the derivation of EoL strategies, serving as design and decision-making tools for building owners and investors, thus promoting circular economy in the construction industry.

Hence, the innovation of *DiCYCLE* lies in: 1) Researching new EoL processes and business models using BIM, BC and SC to develop new digital design, construction, and operation processes for buildings; 2) Integrating various EoL data with BIM to enhance data interoperability, focusing on open data storage for broader application. 3) Creating a feedback loop from BIM "as-built" or "as-is" to BIM "as-planned," providing decision support in early design phases for assessing EoL value chains in the building lifecycle and ensuring reliable life cycle calculations and sustainability assessments; 4) Establishing a lifecycle-wide framework solution by coupling the *DiCYCLE* framework with ongoing projects (BIMd.sign, FMChain), ensuring a continuous digital data chain through dynamic BIM models that combine static building models with processes and assessing project participants' responsibilities and roles; 5) Developing innovative BIM-based approaches, processes, interfaces, and tools to enable digital working methods for EoL; 6) Striving for open solutions and documentation of existing processes to create new opportunities for SMEs and support standardization for digital procedures such as digital approvals, material passports, tendering, contracts, and billing procedures. (Sreckovic *et al.*, 2022)

5. Discussion and Conclusion

With the developed Ecosystem for Circular Construction, we have embedded the semi-automated BIM-based MPs in a larger system – for building up of a digital cadastre for urban mining. Further we have shown the potential of MPs to act as an instrument for assessment of circularity as well as an instrument for optimisation of new construction.

However, it must be noted that the unique, standardized methodology for circularity indices in construction is still lacking. Thus the compilation of MPs as circularity instruments is facing challenges such as: the issues of life duration of the construction-layers in composite materials or building elements, where the shortest living defines the life of the whole building element, the evaluation of the way how the components are held together (e.g. glued or screwed) which significantly impact the separability, thus reusability and recyclability of the building elements or materials (products).

The generation of the digital secondary resources' platform *BIMstocks* demonstrated that the material assessment is particularly time and resources consuming, whereas the assessment of geometry less so. The GPR technology used for material assessment bears numerous potentials in particular in the bottom up approach, but it needs further testing to a) apply it to different building structures and b) build-up a material database, which would significantly increase the efficiency of material determination, in particular when coupled to AI algorithms.

At the same time, *BIMstocks* proposed an evaluation methodology allowing the classification of the reuse and recycling potential or conventional disposal paths of materials, considering contaminants, pollutants and hazardous substances in existing buildings.

The presented methods in *RE:STOCK INDUSTRY* enable sustainable reuse and retrofitting, extend building service life, prevent soil sealing, and enhance economic value, social structures, and workplace conditions. Digitally capturing and analyzing the structural stock and visualizing retrofit potentials with AR can motivate stakeholders to reuse and enhance buildings through vertical retrofits. Automating and standardizing data gathering and storing for building structures is crucial for optimizing and monitoring building waste management, with centralized geometric, structural and material data being the key. Integral analysis and evaluation at early design stage can lower barriers for stakeholders to invest in building and production facility modernization and upgrading.

Simultaneously, current business models for architectural design and construction must be restructured to integrate reusable and recyclable building components and materials along the lifecycle. This shift necessitates significant changes within the AEC industry. The ultimate aim is to facilitate transparent, recycling-friendly collection and tracking of building materials and components, minimizing waste during renovation, deconstruction, and demolition. This involves exploring potential synergies among digital technologies, when developing novel business models that integrate e.g. BIM, Blockchain and Smart Contracts, as it is the case in *DiCYCLE*, with the aim of element and material provenance tracking and certification, such as is relevant for MPs.

Concludingly, new digital workflows for capturing of material and geometry, as well as algorithms for a semi-automated BIM model generation and assessment of circularity (reuse and recycling potentials) are needed. Such generated created material documentations can be integrated in GIS in order to serve as a secondary raw materials cadaster.

In addition, reform of building codes and waste regulations is urgently needed to improve and successfully transition to circular construction. The waste management regulation in Central Europe urgently needs updating, as currently all reused elements are classified as construction waste and cannot be reused as such. The building code and permitting process needs to be more flexible in dealing with the potential, future implementation of reused elements, as these are rarely known or available on the market at the time of issuing a building permit.

With enhancement of circular economy in the built environment novel business models will be needed – e.g. already available are renting of flooring, carpets, furniture and more. Manufacturers will want to build a longer-term business and get their materials back one day. Investors and developers can save costs because they do not have to tear everything out by themselves after a few years of use or wear and tear, but can get new solutions from the supplier at a calculable cost. In this way, the building owner secures its value, but does not have to worry about what happens to the materials after 40 or 50 years, and the supplier receives secondary raw materials.

However, the key to a sustainable, circular built environment does not primarily lie in the digital technologies or construction methods itself, but rather in regional and spatial planning – which is a political as well as a societal challenge.

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eGovernment Projects in Czech and Slovak Republic

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Abstract:

The digitization of public services is a critical component of digital transformation in the Czech Republic and Slovakia, both of which started from a common point after the split of Czechoslovakia. While Slovakia has made significant strides in establishing a formal framework for IT project management, the Czech Republic lags behind, facing challenges related to institutional support, statutory frameworks, and project standards. This study compares the digital progress of both countries using publicly available information, such as the Digital Economy and Society Index (DESI), and identifies best practices that can be adopted by the Czech Republic to improve its IT project management.

The research highlights key areas for improvement, including the need to accelerate the development of statutory frameworks, establish unified project management standards, and adopt Agile and iterative approaches. By synthesizing methodologies such as PRINCE2, IPMA, and ITIL, the study proposes a national framework that can increase the efficiency, transparency, and quality of IT projects in the public sector. The findings contribute to the ongoing digital transformation efforts in the Czech Republic, providing recommendations for policymakers and public sector managers to improve eGovernment services.

This study underscores the importance of addressing the current gaps in IT governance and project management to enhance the country's digital competitiveness and achieve better project outcomes.

Keywords: *Agile; Digital transformation; eGovernment; projects; public administration.*

1. Introduction

The digitization of public services is an integral part of the digital transformation that our world is currently undergoing. The Czech Republic and Slovakia had the same starting position after the split of Czechoslovakia. The Czech Republic allocates billions of crowns for digitalization through subsidy titles (IROP and NPO), especially for e-government and cybersecurity to ensure these services for citizens. Digital transformation brings along a great deal of change. Regardless of sector, public or commercial, it is necessary to manage these changes, to treat the risks and threats associated with the implementation of tools and rules that bring a higher level of digitalization. However, more complex changes cannot be addressed within the BAU (Business As Usual), especially in public organizations with a high degree of governance. A project-based approach is then a logical way to introduce change into the organization. The introduction of project management in the public sector is often based on already established or newly introduced processes (Takagi, 2024). This has been directly linked to the success of projects in the public sector (Meyerhoff Nielsen and Mahmoud Ali, 2021). Digitization is based on the foundations of IT, "Public service delivery is closely dependent on the quality IT services that can be acquired through ITSM." (Sarwar, 2023). Functional IT based on ITSM is one of the critical factors for the success and implementation of changes in the digital transformation. "Most public sector organizations are within the ad-hoc and fragmented maturity levels of IT Governance" (Mathase, 2019). Project management is then the right connection between existing processes, ITSM, new processes and the desired target state through the delivery of successful projects.

The Czech Republic is making significant efforts in digitizing services for citizens. In 2022, the Czech Republic ranked 20th in Europe. "Important strategic area, for every country, is the functioning of its public administration. Public administration utilizes appropriate results the increased efficiency and effectiveness in both public sector and private sector" (Glavas, 2021). Efforts to improve both the quality of services and the position in comparison with other countries are being implemented through projects that increase the level of digitisation of public services. The quality of these public services is highly dependent on the quality of the projects that deliver these services." The research findings reflect the challenges in implementing IT governance in most public sector organizations because of factors ranging from weak corporate governance, financial constraints, lack of interest and innovation, large size of most of the public sector organizations, making the control structure too broad for the Boards, and political reasons." (Mathase, 2019). Public projects in the Czech Republic are often faced with problems that put them at risk in terms of time, costs and quality. Even in the case of projects funded by EU structural funds, which have a predetermined course, rules and conditions from the provider of the subsidy. The question is, therefore, what are the success factors for projects in the public sector. The key is to identify hard, soft and regional factors leading to project success, which will give guidance on how to adjust and set up the whole system leading to improved quality of eGovernment in the Czech Republic.

2. Materials and methods

2.1. The Digital Economy and Society Index (DESI)

The European Commission has been monitoring Member States' digital progress through the Digital Economy and Society Index (DESI) reports since 2014. DESI provides a comprehensive assessment of digital performance and tracks the evolution of EU countries in digital competitiveness. As of 2023, DESI has been integrated into the State of the Digital Decade report, in line with the Digital Decade Policy Programme 2030. This integration aims to monitor progress towards the EU's digital targets, ensuring that member states are advancing in areas such as connectivity, digital skills, digital public services, and the integration of digital technology by businesses (The European Commission, 2022).

2.2. Quality Assurance (QA)

Quality assurance is a critical component in the management and implementation of IT projects. For detailed information on quality assurance practices, one can refer to the guidelines provided by the Ministry of Investment, Regional Development and Informatization of the Slovak Republic (MIRRI SR). These guidelines are accessible on the MIRI website: https://mirri.gov.sk/sekcie/informatizacia/riadenie-kvality-qa/ (in Slovak). The QA framework ensures that IT projects meet predefined standards and deliver desired outcomes efficiently and effectively.

2.3. Key Performance Indicators (KPI)

The success of IT projects is significantly influenced by the establishment and measurement of Key Performance Indicators (KPIs). KPIs are essential metrics that help in tracking project performance and outcomes. However, as highlighted by Hochstetter (2022), the complexity of managing projects increases with the number of KPIs monitored. This increased complexity can make project management more challenging, as it requires balancing multiple performance indicators while ensuring that project goals are met. It is crucial to select relevant KPIs that provide valuable insights without overwhelming the project management process.

2.4. Procedure Used in Analysis and Goal Design

Data Collection:

Source: Publicly available information, DESI reports, and legislative documents from the Czech Republic and Slovakia.

Process: Relevant data were collected and critically analyzed.

Comparative Analysis:

Methodology: The institutional, legislative, and methodological frameworks of the Czech Republic and Slovakia were compared.

Output: Key differences and areas where the Czech Republic lags were identified.

Identification of Best Practices:

Methodologies: Best practices from PRINCE2, IPMA, and ITIL methodologies were analysed.

Output: Key elements of these methodologies that can be integrated into new national standards were synthesized.

Goal Design:

Process: Based on the gathered data and best practices, specific goals for improving IT project management in the Czech Republic were proposed.

Goals: The proposed goals included accelerating the development of the legislative framework, establishing unified project management standards, enhancing institutional support, developing training programs, implementing a centralized Project Management Office (PMO), promoting transparency and accountability, encouraging public-private partnerships, adopting Agile and iterative approaches, and measuring and evaluating project outcomes.

This structured approach ensured that the proposed goals are based on solid foundations and relevant data, contributing to more effective IT project management in the Czech Republic.

3. Results

3.1. Comparison of the Czech Republic and the Slovak Republic

The comparison of the two entities, the Czech Republic and the Slovak Republic, is based on publicly available information. It compares the degree of formalization of the approach to IT projects, highlighting the institutional, statutory, and methodological frameworks that guide these initiatives in each country.

Institutional Framework

In the Czech Republic, the institutional framework for IT projects is provided by the Digital Information Agency (DIA). DIA is responsible for overseeing the development and implementation of digital projects and strategies aimed at improving public administration services. In contrast, Slovakia has established the Ministry of Investment, Regional Development and Informatization (MIRRI), which plays a similar role. MIRI's responsibilities include investment oversight, regional development, and the informatization of public administration, ensuring that IT projects align with national development goals.

Statutory Framework

Statutory framework governing IT project management is currently under development in the Czech Republic. This indicates an ongoing effort to establish comprehensive guidelines and regulations that will standardize how IT projects are managed across the public sector. Meanwhile, Slovakia has already defined its statutory framework through Decree No. 401/2023 Z.z. on project management and change requirements in the operation of public administration information technologies. This decree provides a clear legislative basis for project management, outlining the necessary procedures and requirements for effective IT project governance.

Project Standards

Project standards in the Czech Republic are also in the preparation phase. These standards are expected to unify various project management practices, ensuring consistency and quality across IT initiatives. On the other hand, Slovakia has made significant progress in this area with the establishment of the Quality Assurance (QA) standards by MIRI. These standards provide a structured framework for assessing and ensuring the quality of IT projects, helping to maintain high standards of performance and delivery.

Methodological Framework

The methodological approach to IT project management in both countries varies by organization. In Slovakia, organizations can base their methodologies on the existing legislative framework and standards, providing a robust foundation for project management practices. This legislative support facilitates a more consistent and structured approach to managing IT projects. In contrast, organizations in the Czech Republic currently rely on their internal methodologies, which can lead to variations in practice. The ongoing development of national project standards and statutory frameworks will address these inconsistencies, promoting a more unified approach.

Comparative Analysis

A comparison of approaches to IT projects between the Czech Republic and Slovakia, based on publicly available information and relevant projects from MZČR (Ministry of Health of the Czech Republic), and MIRI (Ministry of Investment, Regional Development and Informatics of the Slovak Republic) reveals that Slovakia has a more established and formalized framework. Slovakia's statutory and project standards provide a clear and structured approach to IT project management, which organizations can readily adopt. In contrast, the Czech Republic is in the developmental phase, working towards creating similar frameworks and standards. Once these are established, they are expected to bring about significant improvements in the consistency and quality of IT project management in the Czech Republic.

In summary, while Slovakia currently demonstrates a more mature and formalized approach to IT project management, the Czech Republic is actively working towards developing similar frameworks. These efforts indicate a commitment to enhance the management and implementation of IT projects, ultimately aiming to achieve a higher level of standardization and quality in the public sector.

3.2. Goals for Improving IT Project Management in the Czech Republic

Based on previous comparative analysis, the following areas for improvement in IT projects emerge for the Czech Republic. In this document we continue to focus on selected areas: Establish Unified Project Management Standards, Adopt Agile and Iterative Project Management Approaches and Measure and Evaluate Project Outcomes.

- Accelerate the Development of Statutory Framework
- Establish Unified Project Management Standards
- Enhance Institutional Support
- Develop Comprehensive Training Programs
- Implement a Centralized Project Management Office (PMO)
- Promote Transparency and Accountability
- Encourage Public-Private Partnerships
- Adopt Agile and Iterative Project Management Approaches
- Focus on Cybersecurity and Data Protection
- Measure and Evaluate Project Outcomes

3.3. Establish Unified Project Management Standards

Goal: To create and implement a unified national framework for IT project management that utilizes proven methodologies such as PRINCE2, IPMA, and ITIL as the foundation.

Actions:

Analysis of Existing Methodologies

Description: Examine and analyze existing methodologies PRINCE2, IPMA, and ITIL to identify key elements that should be integrated into the new national standard.

Output: A comprehensive report on the suitability and comparative analysis of these methodologies in the context of the Czech public sector.

Development of the National Framework

Description: Based on the analysis, develop a unified framework for IT project management that includes:

- PRINCE2: Focus on process and organizational structures, defining roles, responsibilities, and control mechanisms.

- IPMA: Integration of a competency model that assesses the skills and abilities of project managers and focuses on project cycle management.

- ITIL: Implementation of best practices in IT service management and IT operations support, ensuring that IT projects align with business needs and deliver value.

Creation of Comprehensive Documentation

Description: Develop detailed guidelines, manuals, and templates for project management, which will include:

- Standardized processes and procedures.
- Templates for planning, risk management, communication, and project documentation.
- Tools for tracking and reporting project progress.

Training and Certification

Description: Develop and implement training programs for public employees, which will include:

- Courses and workshops on PRINCE2, IPMA, and ITIL.
- Certification programs to ensure that project managers have necessary knowledge and skills.

Output: Certified project managers capable of effectively managing IT projects according to the new standards.

Pilot Projects and Iterative Improvement

Description: Implement pilot projects to test the new framework and gather feedback for iterative improvement.

Output: Validated and refined standards based on practical experiences from pilot projects.

Implementation and Monitoring

Description: Roll out the new framework across all government institutions and ensure continuous monitoring and evaluation of its effectiveness.

Output: Regular reports and performance analyses to ensure that the standards are adhered to, and desired outcomes are achieved.

Benefits:

- Consistency and Quality: Ensuring consistency and quality in IT project management across the entire public sector.
- Efficiency and Transparency: Increasing efficiency and transparency in project management, leading to better outcomes and higher public trust.
- Competency Development: Enhancing the professional level of project managers and their ability to effectively manage projects.

Implementing these steps will help create a robust and unified framework for IT project management in the Czech Republic, thereby increasing the success and benefits of these projects for the public sector.

3.4. Adopt Agile and Iterative Project Management Approaches

Goal: To increase the flexibility and responsiveness of IT projects by adopting Agile methodologies and iterative development processes.

Actions:

Introduction to Agile Methodologies

Description: Provide a comprehensive overview and training on Agile methodologies such as Scrum, Kanban, and Lean.

Output: Training materials and workshops that explain the principles, practices, and benefits of Agile project management.

Pilot Agile Projects

Description: Select a few IT projects to implement as Agile pilot projects to demonstrate the effectiveness of Agile methodologies.

Output: Case studies and reports on the outcomes of the pilot projects, highlighting successes and areas for improvement.

Develop Agile Framework for Public Sector

Description: Create a tailored Agile framework suitable for the public sector, integrating key principles from Scrum, Kanban, and Lean.

Output: A public sector-specific Agile framework document that includes guidelines, processes, and best practices.

Training and Certification

Description: Develop and deliver training programs and certification for Agile project management to public sector employees.

Output: Certified Agile practitioners within the public sector who can lead and manage Agile projects effectively.

Iterative Development Cycles

Description: Implement iterative development cycles (sprints) to allow for continuous feedback and adaptation during the project lifecycle.

Output: A schedule and process for regular sprint planning, review, and retrospectives.

Establish Agile Teams

Description: Form cross-functional Agile teams that can collaborate closely and quickly adapt to changing requirements.

Output: Agile teams with clearly defined roles, responsibilities, and workflows.

Agile Tools and Software

Description: Introduce and utilize Agile project management tools and software to facilitate planning, tracking, and collaboration.

Output: A suite of recommended Agile tools (e.g., Jira, Trello) and guidelines for their use in the public sector.

Continuous Improvement Process

Description: Implement a continuous improvement process where teams regularly review and refine their workflows and practices.

Output: Regular retrospective meetings and action plans for ongoing improvement.

Stakeholder Engagement

Description: Engage stakeholders throughout the project lifecycle to ensure their needs and feedback are integrated into the development process.

Output: Structured stakeholder meetings and feedback loops to maintain alignment and support.

Performance Metrics and KPIs

Description: Define and monitor key performance indicators (KPIs) and metrics to measure the success and efficiency of Agile projects.

Output: A set of KPIs and a monitoring framework to track project performance and outcomes.

Benefits:

- Increased Flexibility: Agile methodologies allow for rapid adaptation to changes and new requirements.
- Enhanced Collaboration: Cross-functional teams work closely together, improving communication and collaboration.
- Improved Stakeholder Satisfaction: Continuous feedback loops ensure that stakeholder needs are met throughout the project.
- Higher Quality Deliverables: Iterative development and regular reviews lead to higher quality and more reliable project outcomes.

Implementing these steps will foster a more flexible and responsive approach to IT project management in the Czech Republic, leading to better project outcomes and increased efficiency in the public sector.

3.5. Measure and Evaluate Project Outcomes

The key to the success of projects is the established and measured level of KPIs (Key Performance Indicator). However, as the number of KPIs monitored increases, so does the complexity of projects, i.e. the difficulty of managing them (Hochstetter, 2022).

Goal: To continuously assess the effectiveness and impact of IT projects by defining and monitoring key performance indicators (KPIs) and utilizing systematic evaluation processes.

Actions:

Define Key Performance Indicators (KPIs)

Description: Identify and establish KPIs that align with project goals and objectives. These should cover various aspects such as time, cost, quality, stakeholder satisfaction, and business impact.

Output: A comprehensive list of KPIs for IT projects, with clear definitions and measurement criteria.

Develop Evaluation Framework

Description: Create a standardized framework for evaluating project outcomes based on the defined KPIs. This should include methodologies for data collection, analysis, and reporting.

Output: An evaluation framework document outlining procedures, tools, and templates for assessing project performance.

Implement Monitoring Tools

Description: Introduce and utilize software tools and technologies for real-time monitoring and tracking of project metrics.

Output: A suite of recommended monitoring tools (e.g., dashboards, analytics platforms) and guidelines for their use in the public sector.

Regular Performance Reviews

Description: Conduct regular performance reviews and audits at key project milestones and after project completion to assess outcomes against the KPIs.

Output: A schedule for performance reviews and a template for performance audit reports.

Stakeholder Feedback Mechanism

Description: Establish a structured mechanism for collecting and analyzing feedback from stakeholders, including project team members, end-users, and other relevant parties.

Output: Surveys, feedback forms, and structured interview guidelines to gather comprehensive stakeholder input.

Post-Implementation Reviews

Description: Perform thorough post-implementation reviews (PIR) to evaluate the overall success and impact of completed projects, identifying lessons learned and areas for improvement.

Output: A PIR report template and guidelines for conducting these reviews systematically.

Continuous Improvement Loop

Description: Implement a continuous improvement process where insights from evaluations are used to refine project management practices and frameworks.

Output: Action plans based on evaluation findings to enhance future project performance and methodologies.

Training and Capacity Building

Description: Provide training for project managers and teams on the importance of measurement and evaluation, including how to effectively use KPIs and evaluation frameworks.

Output: Training programs and workshops focused on measurement and evaluation best practices.

Benchmarking and Comparative Analysis

Description: Conduct benchmarking studies to compare project outcomes with industry standards and best practices, both locally and internationally.

Output: Benchmarking reports that highlight areas of excellence and opportunities for improvement.

Transparent Reporting

Description: Ensure that evaluation results and performance reports are transparently communicated to all stakeholders, promoting accountability and trust.

Output: Publicly accessible performance reports and dashboards that provide a clear view of project outcomes.

Benefits:

- Objective Assessment: Provides an objective basis for assessing the success and impact of IT projects.
- Informed Decision-Making: Facilitates data-driven decision-making for future projects and resource allocation.
- Continuous Improvement: Supports a culture of continuous improvement by identifying strengths and areas for enhancement.
- Stakeholder Confidence: Increases transparency and builds confidence among stakeholders by demonstrating accountability and effectiveness.

3.6. Rich Picture

The analysis indicates that a critical issue in the Czech Republic's public sector IT project management is the lack of clarity in roles, responsibilities, and competencies. While many institutions in the country predominantly follow the PRINCE2 methodology, integrating the IPMA (International Project Management Association) standards, particularly within the IT Service Management (ITSM) environment, could enhance the effectiveness of project execution. By combining the structured, process-driven approach of PRINCE2 with the competency-based framework of IPMA, public institutions could achieve more clearly defined roles, better accountability, and stronger leadership in IT projects.

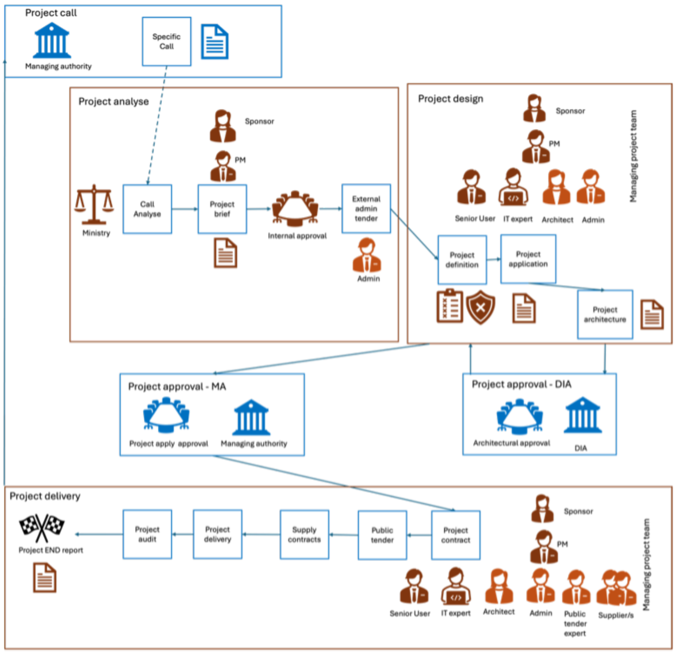

Figure 1: The Rich picture of gov IT project (source: own)

The application of SSM (Soft System *Engineering*) and its tools for further research and implementation of future solutions is proposed. SSM is a way of thinking that focuses on soft systems. Soft systems are systems that are not easily quantifiable and include soft, human elements such as social interaction and multiple individual perspectives (Checkland and Poulter, 2007). SSM emerged from the broader general systems theory. General systems theory proposes holistic approach and views the world and everything in it as a part of interconnected system (Bertalanffy, 1950). SSM is an action-oriented process of inquiry and insight into problematic situations through the concept of worldview1 and use of systems ideas. A worldview is a tendency of a concrete person to see the world in a particular way. All problematic situations contain people that try to act on purpose, with intentions aligned to their worldviews. Systems ideas deal with interactions between parts that make up a whole system that can survive by adapting to changes in its environment (Checkland and Poulter, 2007).

3.7. Possible research approach

The possible research on the topic of project management methodology in public administration will follow a structured sequence of phases, beginning with a systematic literature review. This review will explore existing studies and theories related to project management within the context of public administration.

Following the literature review, an in-depth analysis of current literature and documents specific to state administration will be conducted. The next phase involves structured quantitative research, aimed at gathering and analysing numerical data to support the study's objectives.

After completing the quantitative research, a gap analysis will be performed to identify areas where the current research and practice do not align, highlighting opportunities for further investigation or improvement. The findings from these earlier phases will then be compiled and prepared for publication.

In parallel, structured qualitative research will be conducted, focusing on gathering in-depth insights from experts or case studies. The results of this qualitative research will also be prepared for publication, along with a preliminary outline of the proposed methodology.

A pilot project will then be launched to test the practical application of the proposed methodology. Following the pilot, an evaluation will be carried out to assess its effectiveness and gather feedback for refinement.

Based on the evaluation results, the methodology will be finalized, incorporating any necessary adjustments. Finally, the completed research and refined methodology will be published, marking the conclusion of the project.

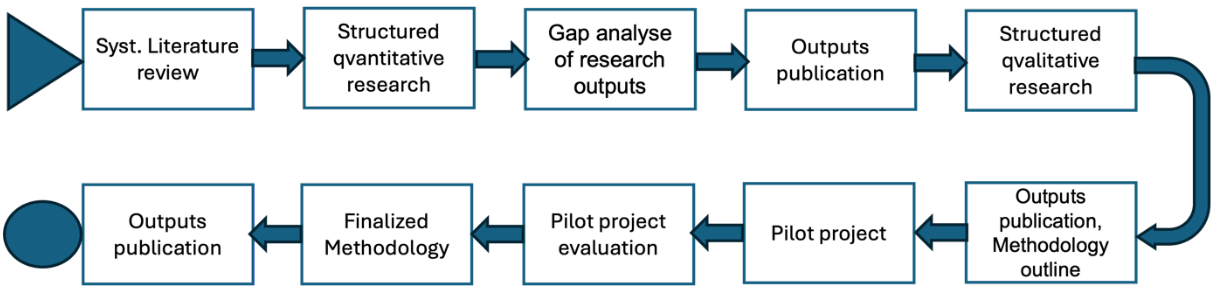

Figure 2: The possible Research approach (source: own)

Each case study should have own specific environment, but common approach (Fig 2.). That approach brings comparative outputs important for research questions. Each analysed case study will be a focus on competencies and roles of all stakeholders (Fig.1.). For research in each case studies should be used the SSM mentioned techniques (3.6).

4. Discussion

4.1 Practical and Theoretical Contributions

This article highlights the current state and challenges of IT project management in the public sector of the Czech Republic, drawing comparisons with Slovakia. This article examines the state of IT project management in the Czech Republic, identifying significant gaps compared to Slovakia. “Important strategic area, for every country, is the functioning of its public administration. Public administration utilizes appropriate results the increased efficiency and effectiveness in both public sector and private sector” (Glavas, 2021).

The study emphasizes the need for a unified project management framework and the adoption of Agile methodologies to address these gaps. The findings underscore the importance of developing a legislative framework, enhancing institutional support, and implementing comprehensive training programs to improve the quality and effectiveness of eGovernment projects. "Agile methods are increasingly finding their way into public administrations, especially in IT projects"(Dietel, 2020).

Practically, it identifies key areas for improvement, such as the development of a unified legislative framework, the establishment of standardized project management practices, and the adoption of Agile methodologies. These recommendations aim to enhance the efficiency, transparency, and quality of eGovernment services. Theoretically, the study contributes to the literature by providing a comparative analysis of IT governance frameworks and methodologies in the public sector, emphasizing the importance of integrating best practices like PRINCE2, IPMA, and ITIL. "Information technology (IT) provides ease, convenience, and efficiency to run some errands. IT is not only facilitating services to customers, but also as the main backbone to drive business and management in an organization. A lot of IT projects were established to solve problems or improve business problems with IT. "(DwiHarfianto, 2022).

4.2 Implications for Policy and Practice

The findings suggest that policymakers and public sector managers in the Czech Republic should prioritize the acceleration of legislative developments and the implementation of comprehensive training programs for IT project managers. Adopting a structured approach to project management will likely improve the consistency and success rates of IT projects. Additionally, fostering public-private partnerships and engaging stakeholders throughout the project lifecycle can further enhance project outcomes.

5. Conclusion

5.1 Summary of Key Findings

This article examines the state of IT project management in the Czech Republic, identifying significant gaps compared to Slovakia. The study emphasizes the need for a unified project management framework and the adoption of Agile methodologies to address these gaps. The findings underscore the importance of developing a legislative framework, enhancing institutional support, and implementing comprehensive training programs to improve the quality and effectiveness of eGovernment projects.

5.2 Recommendations and Future Directions

Based on the analysis, the study recommends accelerating the development of statutory frameworks, establishing unified project management standards, and adopting Agile and iterative approaches. Future research could explore the impact of these improvements on the overall digital transformation of the Czech public sector and investigate additional factors that contribute to successful IT project management in various regional contexts.

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KEY SUCCESS DRIVER FOR THE PUBLIC SECTOR: CHARACTER - COMPETENCE MODEL

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Abstract:

Project managers' competences are defined in various frameworks used for assessment, training, and role requirements. While these frameworks emphasize the importance of competence development for project success, recent research suggests that competence alone is insufficient for an organization to achieve its goals because our ability to develop and employ our competences is directly connected to our strength of character.

Public sector projects are inherently complex, often involving hierarchical structures and bureaucratic constraints that project managers must navigate. Furthermore, these managers deliver critical outcomes for society and must work effectively with various stakeholders, all of which demand high performance. This complexity underscores the need for a comprehensive approach to project management.

The research purpose is to compare the different project management competence frameworks by grouping their elements into characters and competences to create a character-competence model.

Design / Methodology / Approach. This study used a qualitative approach. The content analysis was performed on five selected project management competence frameworks/standards: IPMA Individual Competence Baseline for Project Managers 4.1, PMI Project Manager Competency Development Framework, APM Competence Framework, AIPM Professional Competency Standards for Project Management and UK Government Project Delivery Capability Framework.

Findings. Our study reveals three of the analyzed PM competence frameworks encompass character and competence elements. According to the 11 dimensions of the Leader Character Framework, six were identified in PM competence frameworks, while five dimensions are not mentioned, but are still crucial for powerful project managers.

Keywords: project manager, competence, competency, public sector, character

1. Introduction

Various organizations, including those in the public sector, have developed project management competence frameworks/standards. These models have been researched, enhanced, and revised over several years to align with current trends and address the evolving demands of project management.

A competence framework is essential in the public sector for project management as it helps define the skills, knowledge, and behaviours required for effective project delivery, ensuring that project managers can meet organizational goals and adapt to the complex, dynamic nature of public sector projects. (Skorkova, 2016) The development of competences can lead to better budgeting, scheduling, productivity, and stakeholder relationships, which are essential for the successful delivery of public sector projects. (Rwelamila, 2007)

However, the latest research reveals that competence alone is insufficient for an organization to achieve its goals because our ability to develop and employ our competences is directly connected to our strength of character. (Crossan, et al., 2024)

The research purpose is to compare the different project management competence frameworks by grouping their elements into characters and competences to create a character-competence model.

The character of project managers influences how they perceive and interpret situations, as well as how they respond to various challenges. In the public sector, developing character is crucial for efficiently meeting the diverse needs of stakeholders. While competence is also important, it is incomplete without strong character. Distinguishing between the development of character and competence is essential for clarifying the further development of public sector project managers.

2. Literature review

2.1. Specifics of Public Sector Project Management

Public sector projects tend to be more complex than private sector projects (Wirick, 2009). An evaluation of 34 public projects in Norway showed that, although projects often succeed in some areas, they may fail in others. Despite some cost overruns, many projects achieved their strategic goals, such as user benefits and alignment with long-term strategies, reflecting the complex nature of public project success. (Volden & Welde, 2022)

It highlights the necessity for clear and open processes within public sector projects. It also emphasises the importance of providing evidence to various stakeholders, such as the public, media, and political entities, to ensure that all actions and decisions are traceable and justified. (Crawford & Helm, 2009; Obradovic, 2018) Due to the involvement of a greater number of stakeholders, defining the scope of public sector projects is more complex than in the private sector. Therefore, project management processes should be more precisely defined. (Gasik, 2018) The need to adhere to strict procurement procedures, comply with government policies, and ensure transparency and accountability can introduce additional layers of complexity that are not as prevalent in private sector projects.

A key organizational structure used in the public sector is the matrix. This structure involves integrating employees from different functional areas to work on specific projects. The matrix organization helps facilitate better coordination and resource allocation, enabling a more flexible response to project needs and changes, as well as includes potential conflicts between functional and project managers over resource allocation, unclear authority lines, and communication difficulties. (Patanakul, 2014)

At the same time, while standardising project processes is seen as necessary for consistency and quality assurance, there is a concern that it might prioritize bureaucratic procedures over the professional development and empowerment of project managers. (Obradovic, 2018) Projects must be implemented under bureaucratic conditions, where existing processes can significantly hinder the achievement of project goals. (Wirick, 2009). Public sector organisations prioritize accountability, lawfulness, incorruptibility, and reliability over profitability and efficiency. (Jalocha, et al., 2014)

Public sector organizations are constantly scrutinized and need to demonstrate control over their projects (Crawford & Helm, 2009). Since the public sector is funded by taxpayer money, they are controlled by various other institutions (Wirick, 2009), so project managers must focus more often on proving the correctness of their work and providing answers and additional information than on achieving project goals.

Projects must fulfil political interests (Wirick, 2011) which might be completely opposite. The progress of the project is changed by frequent changes in management decisions, including the change of political leaders. (Pulmanis, 2015) Public projects often pursue various objectives beyond financial gains (Volden & Welde, 2022) because they operate in an environment with conflicting goals and outcomes (Wirick, 2009)

Public sector projects often involve various stakeholders, such as government agencies, political representatives, and the general public. (Crawford & Helm, 2009) Public sector projects focus on delivering public value. This includes the protection of public interest, values, and ethics. Therefore, project managers must manage stakeholders to meet project objectives, align with the public service philosophy, and maintain public trust. (Blixt & Kirytopoulos, 2017) Failures or perceived mismanagement can damage the reputation of the public agencies involved and affect public trust. (Aritua, et al., 2011) Public sector institutions are under constant scrutiny by the media, which is a highly significant stakeholder that must be considered. (Wirick, 2009)

2.2. Competence, Competency and Character

The public sector often faces criticism for its bureaucracy and slowness, but its unpredictable and innovative nature requires flexibility and responsiveness to changing goals and conditions (Altukhova, et al., 2016). In order to be more flexible, project managers must have a clear understanding of their work framework, which can be defined by their competences. According to Sampson (1998), “competence represents the first stage of performance”.

The terms ‘competence’ and ‘competency’ are widely used in the field of human resources and management, sometimes interchangeably. In the PRIMO system, which ensures the availability of scientific articles from various citation databases, selected relevant articles by the author describe and explain both the keywords ‘competence’ and ‘competency’ in the context of education and pedagogy, as competence frameworks are used for the training, evaluation, and development of project managers.

Table 1. Definitions of term ‘competence’ and ‘competency’

Competence	Competency	Author
The ability to meet the performance criteria	A set of knowledge, skills, abilities, attitude, and behaviours	(Arifin, 2021)
Basic demonstration of an activity which is assessed with a “yes” or “no”. Competences can be grouped to create a checklist, whose successful demonstration allows to carry out particular tasks	Competency is generally used as more detailed behavioural statements	(Sampson, 1998)

Competence ability to perform skill and the attribute of performer	Competency is a skill	(Khan & Ramachandran, 2012)
Conception that underpins the whole framework	Denoting the exercise of autonomy and responsibility	(Brookman, Clarke, & Winch, 2009)
Typically refers to the measurable performance or outcome of an individual	Often associated with the underlying characteristics such as knowledge, skills, and attitudes that lead to effective performance	(Salman, Ganie, & Saleem, 2020)
Skilled – based	Behaviour-based	
Standard – attained	Manner of behavior	(Rowe, 1995)
What is measured	How the standard is achieved	

According to the definitions provided in Table 1, the main difference between 'competence' and 'competency' lies in their focus. Competence refers to the ability to perform a task and meet the required performance criteria - essentially, the measurable outcome or the "what" of performance. On the other hand, competency is about the underlying characteristics, such as skills, knowledge, and behaviors, that enable someone to achieve and focus on the "how" of behavior and actions that lead to effective performance.

Competence refers to the ability to perform a task to a basic, measurable standard, often assessed as a binary outcome (competent or not). At the same time, competency encompasses a broader range of behaviors and qualities, often described with varying degrees of proficiency, making it more complex to define and evaluate. (Sampson, 1998) Competence focuses on what is done (the task itself), while competency emphasizes how it is done (the behavior and approach), making competence easier to assess in educational contexts. (Holmes, et al., 2021)

Using Sampson's (1998) example to explain the difference between the two terms, 'competence' for a project manager would be creating a Gantt chart, while 'competency' would refer to the attitude, responsibility, and courage with which this task is performed.

Salman et.al (2020) research identified that competence has both visible and invisible dimensions. Visible aspects relate to performance that can be directly measured, while invisible aspects refer to personal attributes that influence performance but are more difficult to quantify. A project manager's job is inherently task-orientated, requiring the ability to break down complex undertakings into manageable and delegable portions (Holzbaur Aalen University, 2010) that must be measured.

Project management frameworks/standards use both the terms 'competence' and 'competency'. The author indicates that the original titles of the competence frameworks/standards will be retained despite the explained difference between the term's 'competence' and 'competency'.

The International Project Management Association (IPMA), the Association for Project Management (APM), and the Australian Institute of Project Management (AIPM) use the term 'competence'. IPMA defines competence as the "application of knowledge, skills, and abilities to achieve the desired results". (IPMA, 2023). AIPM define and uses both terms: competence is the "ability to perform tasks and duties is assessed to the standard", while competency is "knowledge an individual brings to the application of those skills (AIPM, 2023). APM Competence Framework doesn't explain the term competence but illustrates that the framework is a tool for assessing and improving performance. (APM, 2023) These definitions support the previously mentioned theoretical distinctions between terms, indicating that the competence framework/standard must be designed to measure competence. The IPMA Competence Baseline describes competence indicators and their measures that lead to high performance. AIPM only provides supporting evidence. The APM Competence Framework defines them as the applications required to fulfil each competence.

The Project Management Institute (PMI) and the UK government use the term ‘competency’. PMI states: “Competency is the demonstrated ability to perform activities within a project environment that lead to expected outcomes based on defined and accepted standards”. (PMI, 2017) The author emphasizes that the term “competence” is commonly used in the USA and essentially corresponds to the definition of term ‘competence’, as it aims to achieve the outcomes specified in the standard. In Europe, the term ‘competence’ is more widely used and usually refers to the ability to perform tasks to a standard, focusing on the outcome or result of the performance. Le Deist and Winterton (2005) explain that the difference reflects regional focuses: behavioral in the USA, functional in the UK, and holistic in Europe.

The UK Government defines competency as the skills, knowledge, behaviors, and experience needed to successfully perform a task (UK Government, 2021). The document outlines competencies for Project Delivery and provides competence profiles for each role. Although both terms are used, the document does not clearly state the difference between them.

The relationship between character and competences has recently been studied frequently. It is essential to understand that these are two distinct concepts.

Sejits (2014) argues that ‘character can be expressed as a set of traits, values, and virtues’. The character of leadership determines what they will do in different situations, in contrast to competence, which determines what a person is capable of doing (Sejits, 2014). Becoming a better leader requires both character and competence. Character is necessary to influence positively, while competence is necessary to influence effectively. (Clark, 2016) Higher character ratings enhance the positive impact of competencies on trust. (Zeng, et al., 2023)

Character is the core; competence is the crust. The core of character is not related to technical and professional knowledge, skills, and experience, as it is competence. (Clark, 2016)

The Leader Character Framework identifies 11 dimensions of leadership character: accountability, collaboration, courage, drive, humanity, humility, integrity, judgment, justice, temperance, and transcendence. (Crossan, et al., 2024), See Figure 1.

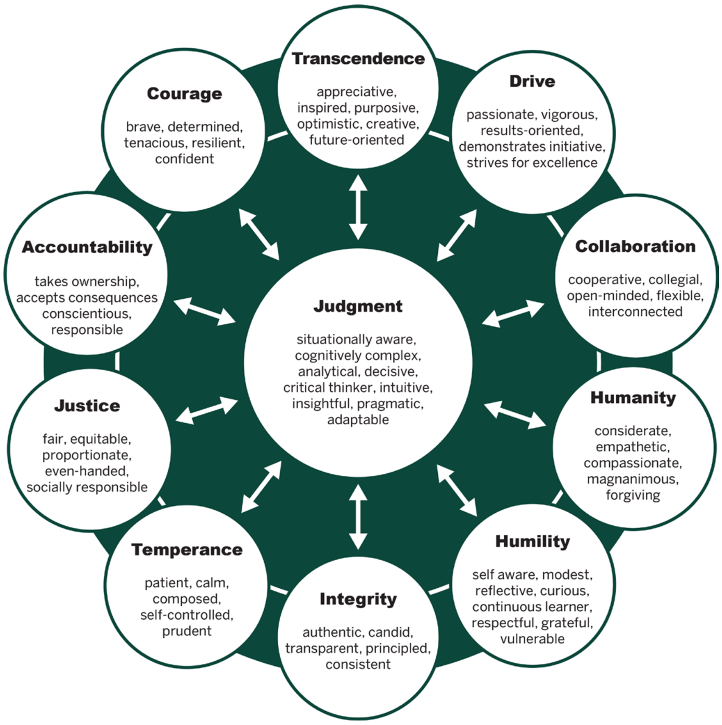

Figure 1. Leader Character Framework (Crossan et al., 2024)

The authors addressed the gap between knowledge of what constitutes good leadership and its actual practice. This framework emerged as part of a broader shift toward understanding leadership beyond skills and competences, instead focusing on its moral and ethical dimensions. For a brief definition of character, see Table 2.

The framework has been validated with 188 leaders. The study shows that drive and judgment are critical connectors between leader character and positive follower outcomes, highlighting the importance of a holistic approach to understanding and developing leader character to improve workplace practices. (Monzani, et al., 2021)

The Leader Character Framework is dedicated to leadership; therefore, to use it in project management, it is essential to distinguish whether a project manager is a manager or a leader.

This distinction is critical because leadership involves motivating and guiding people, creating a vision, and fostering a positive work environment. These are essential for managing projects' complexities, uncertainties, and interdisciplinary nature (Anantatmula, 2010). Research on core competences for project management success confirms that leadership variance indicates its critical role in project outcomes. (Alvarenga, et al., 2019) The essence of leadership is influence. It must aim for something good, something noble, something that builds, lifts, and makes better. (Clark, 2016)

3. Research background and methodology

The five project management competence frameworks/standards briefly described below were selected for the research. The selection criteria for the frameworks are: 1) the framework is open for everyone; 2) it has been developed by a project management association or similar organisation, or a public sector institution.

- *IPMA Individual Competence Baseline for Project Managers (ICB), version 4*.1 (IPMA, 2023). The IPMA Individual Competence Baseline is the global standard for individual competence in project management. It contains three areas of competence: people competences (10 elements), practice competences (13 elements), and perspective competences (5 elements). Key indicators and measures are defined for each competence that describe highly detailed performance.

- *PMI Project Manager Competency Development Framework (PMCDF) 3rd Edition* (PMI, 2017). The purpose of PMCDF is to provide a framework for defining, assessing, and developing the competence of project managers. The PMCDF consists of three dimensions: knowledge competence, performance competence (10 elements), and personal competence (6 elements). Knowledge competence content is not defined in the framework and can be confirmed by passing an appropriate accreditation certificate. Each competence element is defined in terms of performance criteria, expectations, sources of evidence, and examples.

- *APM Competence Framework (CF), Third Edition* (APM, 2023). The framework aims to reflect current good practices and the profession's future needs and provides a benchmark for all those engaged in change initiatives. It consists of 29 competences, divided into four groups: setting up for success (6 competences), preparing for change (6 competences), people and behaviours (6 competences) and planning and managing deployment (11 competences). The APM competency framework also includes a simple five-point rating system to assess the level of performance against knowledge and application criteria.

- *AIPM Professional Competency Standards for Project Management (PCSPM) 3rd version* (AIPM, 2023). The AIPM Competency Standard provides the basis for the development, assessment, and certification of project managers. This standard is arranged in four generic, chronological modules within a lifecycle context: Aligning and Initiating (4 competences), Planning and Development (10 competences), Governing and Delivering (13 competences), Evaluation and Closing (3 competences). The Standard explains the supporting evidence and minimum requirements.

- *Project Delivery Capability Framework (PDCF),* 3rd version (UK Government, 2021). The Project Delivery Capability Framework describes the job roles, capabilities, and learning for Project Delivery Professionals across the government. It is structured into 19 technical competences and 10 behavioural competences. Each job role lists the required capabilities and four levels of capabilities for the role.

The project management competence framework used the qualitative content analysis method to identify and interpret the meaning of each competence. An example of the competence related to risk and opportunity management is presented in Table 2. All competences from the frameworks were grouped and analyzed in this manner.

Table 2. An example of the competence "risks and opportunities" for the content analysis.

Competence framework/standard	RISK AND OPPORTUNITY	Description or definition of competence
IPMA ICB	Risk and opportunity	Risk and opportunity management is a process of identification, assessment, response planning, implementation and control of risks related to projects. It enables decision - makers to make informed choices, prioritise actions and distinguish between alternatives, all taking place over the entire project lifecycle.

PMI PMCDF	Project Risk Management	Conducting risk management planning, identification, analysis, response planning, and controlling risk on a project.
APM CF	Risk and issue management	The ability to identify and monitor risks (threats and opportunities); to plan and implement responses to those risks, and respond to issues that affect a change initiative
AIPM PCSPM	Identify and analyse risks	Risks are 'uncertainty factors' that might affect project outcomes, either positively or negatively. The way that risk is managed on projects should reflect the organisation's Risk Management Framework (if there is one); otherwise, risk management should align to the ISO31000 Standard for Risk Management. Risk management within this phase is characterised through the conduct of meetings, reviewing the project plan for this project and for relevant past projects, developing a plan to manage risks on this project, and identifying and analysing any perceived project risks.
UK PDCF	Risk and issue management	Risk and issue management is the ability to systematically identify and monitor risks and issues, planning how to mitigate / respond to those risks and issues and implementing the responses.

Competences were categorized into professional competences and character-oriented based on qualitative content analysis. Competences aligning with the definition of character were segregated and then classified according to the dimensions of the Leader Character Framework.

4. Research results

All competence frameworks/standards differ as they are developed using various approaches; however, they share a commonality in the competences required for a project manager. Content analysis has resulted in a summary of professional competences for project managers, presented in the Table 3. A detailed summary is available in for the request.

Table 3. Summary of competences included in PM competence frameworks/standards

Competence	ICB	PMCDF	CF	PCSPM	PDCF
Scope, Benefits and Requirements	x	x	x	x	x
Time	x	x	x	x	x
Quality	x	x	x	x	x
Finance	x	x	x	x	x
Procurement and contract management	x	x	x	-	x
Risk and opportunity	x	x	x	x	x
Stakeholders and communication	x	x	x	x	x
Organisational structure and information	x	x	-	x	-
Teamwork	x	x	x	x	x
Life cycle and integration	x	x	x	x	x
Strategy	x	-	x	-	x
Governance and processes	x	-	x	x	x
Compliance, standards and regulations	x	-	x	-	x
Change and transformation	x	-	x	-	x

Culture	x	-	x	-	x
Leadership	x	x	x	-	x
Conflict and crisis	x	-	x	-	x
Resources	x	-	x	-	x
Power and interest	x	-	-	-	-
Personal communication	x	-	-	-	-

Project scope, benefits, and requirements are one of the core competences for future project planning. The most crucial element is the breakdown structure of the work, a technique for dividing and dividing the scope. (Hermarij, 2016) It is necessary to clarify the requirements and define the project's benefits. Agreement on the benefits and how they will be measured, monitored, and managed should be determined until they are realized (APM, 2023); therefore, it must be included in the project's scope. Requirements management justifying stakeholder needs (UK Government, 2021), which should be considered during the project scope design.

Time, Quality, and Finance. These competences are mentioned in all PM competence frameworks/standards. This is a "triple constraint" in managing competing project requirements. While managing public funds responsibly, the emphasis is on delivering public value rather than merely reducing costs (Crawford & Helm, 2009), which means that the primary focus is quality. Little tolerance for failure is allowed in public sector projects. (Wirick, 2011)

Procurement and contract management in the public sector are inseparable because any good or service needs to be procured. Procurement processes in the public sector are complex, especially under integrated procurement routes. (Bernard, et al., 2011)Public procurement processes are highly regulated and require contracts to ensure transparency, accountability, and compliance with legal standards (Zuberi, 1987).

Risk and opportunity. Managing risks in the public sector is crucial, especially in preventing media exposure and political embarrassment. The goal is to minimize risks while ensuring that projects meet public needs efficiently. (Crawford & Helm, 2009) Risks and opportunities must always be considered together, as in the public sector, effort will be required to mitigate risks and seize opportunities.

Stakeholders and communication competences are primarily separated in the PM competence frameworks/standards. Communication starts with a person, but the project manager professionally creates the project communication plan based on the stakeholders' register. PCSPM (AIPM, 2023) certifies that project communications comprise activities that provide a critical link between stakeholders, their ideas and information at all stages of the project life cycle. Effective communication is crucial in the public sector to navigate the complex stakeholder environment and ensure project goals are clearly understood and met. (Dias, et al., 2023)

To separate professional stakeholder-based communication competence from personal competence, the recommendation would be to include personal communication competence in the competence model, i.e. ways of exchanging accurate and consistent information with all relevant parties.

Organizational structure and information. Public institutions usually have a matrix structure. In a matrix organization, employees with similar expertise are grouped in the same department, but can be assigned to multiple projects simultaneously, resulting in them reporting to more than one manager (Hermarij, 2016). Information flow and exchange are challenging.

Teamwork. A multi-disciplinary team consists of individuals with diverse expertise and varied personalities who must work together. Effective teamwork facilitates selecting the right people and ensuring that they can cooperate productively. (Hermarij, 2016) One of the biggest challenges in the public sector is that the project manager has to work with the employees available within the institutions.

Life cycle and integration. Project integration management begins when a project is conceived and continues throughout the project lifecycle's planning, developing, delivering, and closure phases. (AIPM, 2023)

Strategy. This competence highlights the necessity of aligning every initiative, project, or program with the organization's strategy before deciding. It will help to avoid projects that seem straightforward and originate from personal motivations or ambitions rather than logical reasoning. (Hermarij, 2016)

Governance and processes. The more projects organizations have, the more structure is needed in how management controls them (Hermarij, 2016). The public sector is process-orientated, with various procedures, documents, and regulations that a project manager must know to manage a project successfully. Having a strategy alone is not su- cient.

Compliance, standards, and regulations. Effective project managers must be well versed in international laws and standards such as ISO, which are increasingly relevant in the interconnected world today. (Yasin, et al., 2009) Projects are concerned with legislation, codes of conduct, and professional standards. You must consider laws and regulations, especially in the public sector.

Change management. A critical aspect of governance is the consistent implementation of policies and the effective management of changes. (Crawford & Helm, 2009)

Culture. One of the strongest and often unnoticed factors that shape behavior is culture. (Hermarij, 2016) Culture competence in the public sector is critical to creating relationships with stakeholders. (Carriazales, 2019)

Leadership. Although technical knowledge and skills specific to project management are crucial, they must be complemented by a solid understanding of organizational dynamics, leadership skills, and the ability to work effectively in diverse and international settings. (Yasin, et al., 2009)

The competences included in the fewest frameworks are not explained, but this does not conflict with their application. Table 4 includes descriptions of the dimensions of the leader character framework and the competences that inherently correspond to specific characters.

Table 4. Competences corresponding to the Character (Character and source: (Crossan, et al., 2024))

Character	Short definition of character (Crossan, et al., 2024)	Competence
Drive	Strives for excellence, strongly desires to succeed, tackles problems with a sense of urgency, and approaches challenges with energy and passion.	x
Collaboration	Values and actively supports the development and maintenance of positive relationships among people. Encourages open dialogue and does not react defensively when challenged. Is able to connect with others at a fundamental level in a way that fosters the productive sharing of ideas. Recognizes that what happens to someone, somewhere, can affect all.	ICB Relationships and Engagement PMCDF Collaboration

Humanity	Demonstrates genuine concern and care for others and can appreciate and identify with others' values, feelings, and beliefs. Has a capacity to forgive and not hold grudges. Understands that people are fallible and offers opportunities for individuals to learn from their mistakes	x
Humility	Let accomplishments speak for themselves, acknowledge limitations, understand the importance of thoughtful examination of one's opinions and ideas and embrace opportunities for personal growth and development. Does not consider oneself more important or special than others, is respectful of others, and understands and appreciates others' strengths and contributions.	ICB Self-reflection and self-management
Integrity	Holds oneself to a high moral standard and behaves consistently with ethical standards, even in difficult situations. Others see them behaving in a way consistent with their values and beliefs. Behaves consistently with organisational policies and practices.	ICB Personal integrity and reliability PMCDF Professionalism PDCF Credible action
Temperance	Conduct oneself calmly and composedly. Maintain the ability to think clearly and respond reasonably in tense situations. Complete work and solve problems thoughtfully and carefully. Resist excesses and stay grounded.	x
Justice	Strives to ensure that individuals are treated fairly and that consequences (positive or negative) are commensurate with Contributions. Remains objective and keeps personal biases to a minimum when making decisions. Provides others with the opportunity to voice their opinions on processes and procedures. Provides timely, specific, and candid explanations for decisions. Seeks to redress wrongdoings inside and outside the organisation.	x
Accountability	Willingly accepts responsibility for decisions and actions. Is willing to step up and take ownership of challenging issues. Reliably delivers on expectations. You can be counted on in tough situations.	x
Courage	Does the right thing even though it may be unpopular, actively discouraged, and result in a negative outcome for them. Shows unrelenting determination, confidence, and perseverance in confronting difficult situations. Rebounds quickly from setbacks.	ICB Results Orientation PMCDF Resilience
Transcendence	Draws inspiration from excellence or appreciation of beauty in sports, music, arts, and design. Sees possibility where others cannot. Considering the long-term and broad factors, it has a very expansive view of things. Demonstrates a sense of purpose in life.	PMCDF Innovation
Judgment	Makes sound decisions on time based on relevant information and critical analysis of facts. Appreciates the broader context when reaching decisions. Shows flexibility when confronted with new information or situations. Has an implicit sense of the best way to proceed. Can see into the heart of challenging issues. Can reason effectively in uncertain or ambiguous situations.	PMCDF Cognitive Ability PMCDF Working with ambiguity

The two competence models did not identify the competences that correspond to characters, whereas the three models did. As shown in Table 4, 6 of the 11 characters' elements have identifiable correspondences with competences.

Collaboration requires cooperation, collegiality, openness, flexibility, and interconnectedness (SIGMA Assessment Systems, 2013). Encouragement of open dialogue and connecting with others is fundamental to foster positive interactions and open communication in projects, but it always starts with each person individually. Communication is one of the key competences in project management. However, it will be challenging for a project manager to implement the activities outlined in the communication plan if they are not open, collaborative and collegial. Work performance is unattainable without the presence of character elements.

Humility is essential for leaders because it contributes to favorable workplace outcomes. Humility requires self-awareness, modesty, reflection, curiosity, continuous learning, respect, gratitude, and vulnerability (SIGMA Assessment Systems, 2022a). ICB Self-reflection and self-management emphasize humility, respect for others, and an appreciation of others' strengths, highlighting the importance of personal development and effective, respectful interactions.

Integrity encompasses authenticity, candidness, transparency, principledness, and consistency. (SIGMA Assessment Systems, 2013) Personal integrity, reliability, professionalism, and credible action align closely with maintaining high moral standards and consistent ethical behavior. This character ensures project managers follow their values and principles, demonstrating dependability and promoting the public good. By following ethical behavior and challenging unacceptable actions, project managers consistently adhere to organizational policies and practices, even in difficult situations.

What separates courageous leaders is that they do the right thing even when it is unpopular, actively discouraged, or has a negative consequence for them. Courage is about bravery, determination, tenacity, resilience, and confidence. (SIGMA Assessment Systems, 2022b) It involves doing the right thing despite unpopularity, showing determination and perseverance in difficult situations, and quickly rebounding from setbacks.

Transcendence can encourage you to find a more significant sense of purpose in life. It includes being appreciative, inspired, purposive, future-oriented, optimistic, and creative. (SIGMA Assessment Systems, 2013) Innovation corresponds to transcendence in that both involve seeing beyond the present and conventional approaches; innovation requires thinking creatively and implementing new ideas, while transcendence consists of drawing inspiration from excellence and beauty, seeing possibilities where others cannot, and maintaining a broad, long-term perspective.

Judgment is about being situationally aware, cognitively complex, analytical, decisive, critical thinker, intuitive, insightful, pragmatic and adaptable. (SIGMA Assessment Systems, 2013) The ability to make sound decisions in uncertain and changing environments, appreciate the broader context, show flexibility with new information, and apply critical judgment aligns with effectively directing a project by reducing ambiguity and discerning the best course of action amid evolving details.

Does the project manager need other characters? Definitely! A project manager needs a drive character to set high standards, maintain timelines, inspire the team, and proactively address challenges, ensuring successful project completion. Humanity's character is necessary to build trust, understand and support team members, maintain a positive atmosphere, and encourage continuous improvement by recognizing and learning from mistakes. Maintaining a calm and composed demeanor to ensure clear thinking, reasonable responses, and thoughtful problem-solving in tense situations helps resist excesses and stay grounded. Justice character ensures fair treatment, makes unbiased decisions, allows team input, provides transparent explanations, and upholds ethical standards. A project manager needs an accountability character to ensure responsibility for decisions and actions, reliably deliver on expectations, take ownership of challenging issues, and be dependable in tough situations.

5. Conclusion

Project manager's competence frameworks/standards help to better understand the essence of a project manager's professional activities. However, several frameworks/standards mix the concepts of competence and character. The author suggests separating character dimensions and competences in the competence frameworks/standards.

The proposed character-competence model consists of 11-character dimensions and competences, which each institution can determine according to its field of activity from the list of competences provided in this article. Character is relevant to any leadership and manager's role; therefore, the author doesn't recommend including it in the project manager's competence framework/standard but using it in the combined model.

In the context of public sector project manager competences, author suggests to define measures at multiple levels to allow for adaptation to specific country contexts. Currently, no competence framework/standard offer both measures and levels.

This study was conducted in the public sector, where project manager performance is extremely critical considering bureaucratic processes, the structure of government institutions, and the importance of projects to various stakeholders. Merely developing competence-based training program will not suffice to expect an honest, passionate, inspired and creative project manager.

6. Limitations and future research

Five project manager competence frameworks/standards were compared within the scope of this study, which is a limitation of this research. Public sector institutions develop competence frameworks in the national language, which makes them less accessible. However, this study can be used as a basis for creating competence frameworks in countries where they do not yet exist.

The study uses the term 'competence' however, the author would like to note that the term 'competency' as indicated in the original titles, has not been altered.

Future research could focus on the correlations between character and competence and their impact on performance. This would help identify the most essential competences and character traits for a public sector project manager.

In this study, the competences are structured, but measures in the public sector are not defined. This could be research for future research or an activity for one of the project management associations.

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Real-Time Collaboration in Construction Projects as a Pathway Towards Sustainability

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Abstract:

Sustainability push is setting various growing requirements and whole industrial transitions can be expected. The growing requirements are creating even more complex construction projects. Collaboration is widely acknowledged as a necessity to successfully manage all the time growing complexity and demands of construction. This is also required for creating new solutions and practices for sustainability. However, the overall understanding of collaboration in construction is still deficient. This paper presents research results addressing logic of collaboration in operational level: Collaboration indicator model and Structured model of real-time collaboration (RTC). The paper aims to unpack the logic of collaboration in operational level. Second aim is to open the discussion concerning collaboration happening in real-time or near-real time manner in construction projects. The presented results are based on further development of earlier research results and literature study.

Keywords: *Collaboration; Sustainability; Construction projects; Management*

1. Introduction

Construction projects can be conceived as a complex system of systems (SoS) where, figuratively speaking, everything interacts with everything. Financing opportunities together with cost estimating and pricing practices are forming first steppingstones. Markets of products and technologies are expected to be utilized along the principles of industry standards and qualifications. Sustainability push is setting various growing requirements and whole industrial transitions. Different construction stakeholders form a manifold huge group that is a source for dynamic and often conflicting requirements. The interplay between operative actors such as architects, engineers, consultants, contractors, subcontractors, special contractors, and suppliers is a complicated managerial challenge. It is widely acknowledged that wide-range and profound collaboration is essential for long-term success in this modern construction business environment. Thus, key points for our departure towards higher collaboration are 1) all the time growing complexity of construction operations, 2) multi-dimensional and often conflicting requirements, 3) understanding collaboration as working together for the good of project in question.

To address the complexities and demands of collaborative environments, several construction project delivery models have emerged that promote structured partnerships and interaction. The most well-known are Project partnering (PP), Project Alliance (PA) and the integrated project delivery (IPD). PP delivery model aiming to improve cooperation within existing frameworks has its roots in the United States in large military projects in the 1980s, and more recently it has seen as a response to the high levels of conflict typically present in the construction industry (Eriksson, 2008). After originating in UK, PA delivery model became successful in Australian oil, gas, and mining projects (Ross, 2009). The IPD model from the United States has close links to the Lean Construction's principles practices (Viana, 2020). Now we can see a range of solutions that can provide basis for multi-trade teamwork from design to construction operations and information sharing. Those solutions can bind different project players together in a manner where clear benefits can be reached compared with traditional project operations. Inside PP, PA, IPD and other relational delivery models we can recognize a common target for establishing "integrated project team" for the benefits of project in question. An integrated project team is composed of key partners, such as contractors and consultancies, and their continuous working together i.e. collaboration is facilitated systematically e.g. with jointly developed project goals, joint risk-sharing and financial incentives, and joint decision-making.

Next, we will explore practical appearances of collaborative construction. Construction projects with special delivery arrangements for enabling high level of cooperation and collaboration between project partners are gaining growing popularity. At the same time those are also objects for research-based evidence and conclusions over the project models in questions, human aspects, and cultural challenges just to mention here some current topics of interest among scholars (Tadayon, 2018; Asmar et al, 2013; Franz et al, 2017). Apparently, our knowledge base over the collaborative construction projects is now growing strongly.

Not just limited to relational delivery models and major complex construction projects the solutions for collaboration have been creeping into the world of traditional construction deliveries (DBB, DBCM, CM). For example, last planner system as it promotes conversations between different project partners for improving flow of work and for identifying issues of disruptions is a practical instrument for collaboration (Ballard, 2020). It has gained popularity in different types of construction projects.

Traditionally, the collaboration between different project partners has taken place in joint gatherings such as design management meetings arranged e.g. every second week which is then defining the frequency of collaboration. Co-location arrangements (big rooms or technology enabled location independent collaboration with a virtual workspace) and new building model data sharing possibilities are showing the way ahead and changing the overall picture of collaboration. It looks obvious that the operational logic of collaboration in construction projects is developing towards constant collaboration where collaborative activities are taking place in real-time or near-real time manner. This trend is changing the collaboration phenomenon with new requirements for needed technology and organizations with their professionals who are involved. Research, development, and innovations are needed for realizing the potential benefits of real-time collaboration in construction.

The objective of this paper is to open conceptual, operational, and human aspects towards RTC in construction projects. First key features of sustainability, and particularly circularity in construction operation is to be addressed for seeing the needs for RTC between key project partners. After that, the RTC concept is opened and a structural view over RTC technologies is presented. Next, human aspects that have explanatory capability regarding the needs of RTC and can enlighten the barriers of RTC implementations are disclosed. Finally, a discussion and conclusions are presented for summing up various viewpoints and results of the paper. The paper is based on exploration and further development of the authors' most recent outputs.

2. Sustainability and circularity as problematising factors

Modern construction operations have many dimensions: at least technical, social, human, ecological, political and financial. The complexity of construction is thus plain, and this complexity is evidently continuously growing. The built environment sector, with its building and renovation projects, can be understood as a highly complex system of systems (SoS). This SoS is composed of numerous different systems (and their sub-systems), which all together are interdependent and continuously interacting with each other in dynamic manner. Sustainability can be seen as a new sphere in the built environment SoS (Figure 1). Sustainability can be seen as a significant joint motive or goal to collaborate. The EU The Taxonomy Regulation is setting high level requirements that are gradually impacting different operations such as design and site operations in a profound manner. This is likely to create tensions between different players in construction projects and it calls for collaborative procedures and practices.

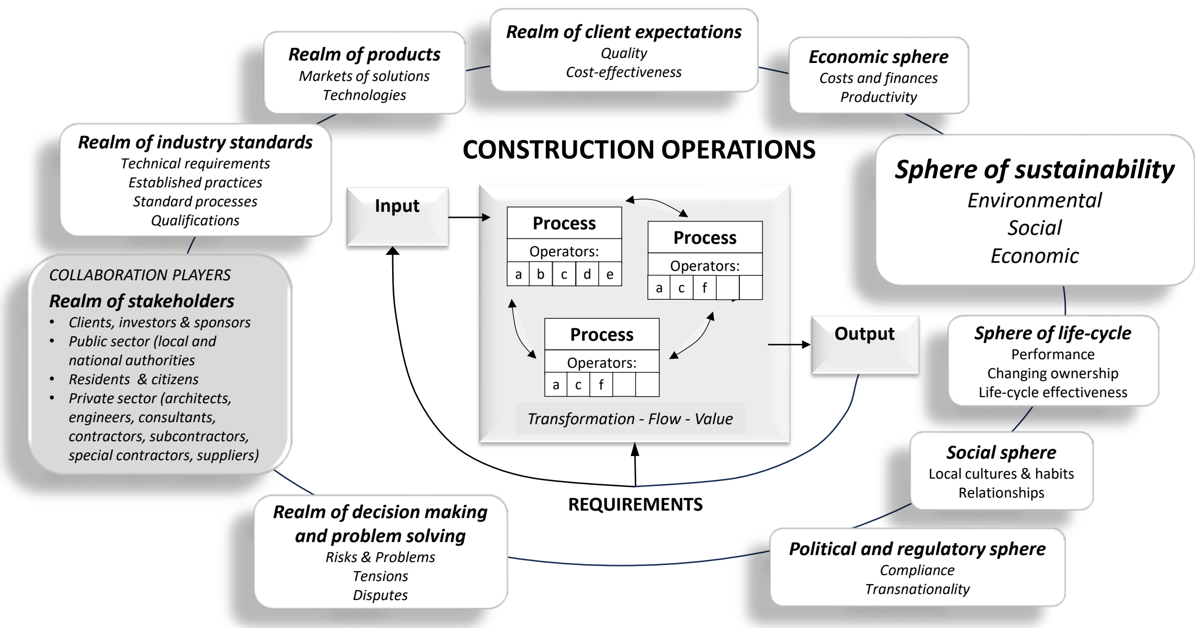

Figure 1. Sphere of sustainability as a factor within SoS of construction operations (modified from Moradi et al, 2024).

Circularity is a key systemic thanking model for advancing sustainability and it is dramatically challenging real estate and construction sector. Rather than limiting thinking on waste management the attention needs to be in growing manner on infrastructures and built environment systems that are designed, built, serviced and connected to reverse its negative impact on nature (World Economic Forum, 2020). Our recent research on 2022 (47 interviews of company people and municipal office holders) addressed present circularity practices in construction. As one main result several operational bottlenecks were recognised that are hindering are totally preventing circularity advancements in construction projects. Those are: attitudes, lack of skills, economics of recycling, what-where-and-when, collaboration, legislation, interim storage, incentives, sorting, dismantling mapping. In general, it was stated in the interviews that availability and access to timely information does not work well enough. The flow of information between municipal office holders, the flow of information between municipal office holders and municipal subsidiaries, and the general flow of information between parties operating in the field were found to be deficient. The flow of information related to the circular economy and the circulation of materials was said to be based on radios, experience or individual personal contacts. The projects that have succeeded in using recycled materials have been more lucky coincidences than planned: the right people meet by chance at the right time. Circularity in construction is in its infancy.

3. Collaboration indicators

Collaboration can be recognised as an embedded operational practice inside several process development patterns and models, e.g. concurrent engineering, lean construction, participatory design and technology enabled integrated design. Additionally, certain procurement models, such as project alliance, integrated project delivery (IPD) and project partnering, are directly setting path for collaboration between different project players. For explaining this further, researchers have recognised the need for indicators that could be used for assessing and developing practices. For example, The RElational CAPability assessment tool (RECAP) includes six criteria, seventeen sub criteria and seventy-two indicators for capturing and understanding collaborative relationships (Suprapto, 2016). As action research experiments inter-organizational collaboration in construction projects have been particularly carried out regarding project partnering, integrated project deliveries and project alliancing (Lahdenperä 2012, Walker and Walker 2015). Inter-organizational collaboration and integration in practice is still an area where additional research-based knowledge and understanding is needed (Saukko et al. 2022).

Savolainen et al (2018) have presented collaboration indicators model that is primarily focusing on nature of observable aspects, managerial practices and operational outputs. The model is purposefully and in a simplified manner presenting "Status of beneficial collaboration" as script and main indicator for assessment and actions. In connection to the main indicator four sub-indicators were defined that each are equipped with observable aspects, management procedures and metrics. The model is based on research data obtained from case studies. Recently, the model was developed further into the version presented in Figure 2. The model provides goal-oriented viewing of collaboration and thus it can have managerial implications in construction projects.

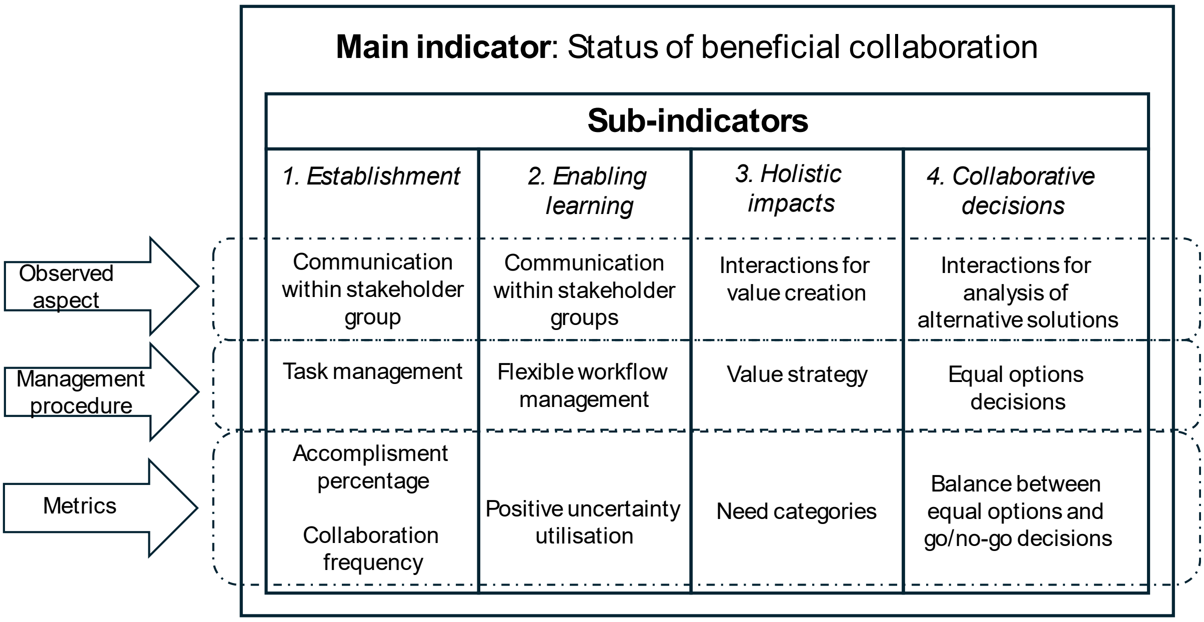

Figure 2. Indicators of beneficial collaboration.

4. Real-time collaboration concept

Presently, collaboration in construction projects is more often and purposefully targeted. It is also gradually entering the world of traditional construction delivery models, modifying those and their practices. The modern collaboration in construction projects is a combination of contractual arrangements, organizational and individual abilities, and technological solutions. As a rule, this is resulting in a constant working together mode where different project partners are together developing design solutions, planning project realization, and solving problems. Nearby concepts, but not to be understood as instances of collaboration, are interoperability and co-operation which are more limited to the information and knowledge sharing (Ren & Zhang, 2021; Moradi et al, 2022). Additionally, the concept coordination is also frequently used to explain activities that bringing together different project partners for aligning their efforts (Elsayegh & El-Adaway, 2021).

Compared with the previous the concept collaboration in construction projects is addressing primarily working together where project partners join their effort for engineering, planning, site operations and project management. The collaboration makes the interpersonal processes imperative and reflects the level of trust, team maturity and the overall commitment between people (Koolwijk et al, 2018). With an optimal collaboration all needed knowledge and abilities are available for further development of project in question, its problem solving and it overall performance without any delays. This can be reached in a co-location, e.g. big room, where project key-people work together constantly or according to pre-defined periods. Co-locations are fostering collaboration, but advances technologies are providing possibilities that go beyond this.

The real-time collaboration (RTC) concept has emerged first with the real-time communication solutions such as online documents and later based on immersive collaborative environments (VR/AR/XR) (Riemer & Frößler, 2007; Oprean et al, 2018). Based on literature and their own work Riemer and Wulf (2010) have defined that RTC technologies consist of four interconnected building blocks:

1. Provision and integration of data sharing and communication media

2. Presence awareness capability

3. Contextualization towards business systems and processes

4. Collaboration support, e.g. co-editing, co-design

Real-time collaboration entails people working together at the same time regardless of their location. It’s particularly applicable to remote and hybrid teams that have employees working from office or home while being miles away. The main aim is sharing of status and results of activities, such as design and planning, towards partners who would benefit from this information, or whose knowledge and competence can help to reach next level with the design and planning solutions in question. The implications of real-time collaboration in each company are diverse.

5. Elements of RTC

Structured view of RTC can be opened with its technologies, organizational and human aspects. Enabling technologies are essential for RTC although research findings are showing that technology and human systems require balanced attention and investments for successful collaboration (Swanson et al, 2017). Although this is reflecting general working together solutions rather than pure RTC it is considered that such results are valid with RTC which is seen as a stage of ultimate collaboration. The overall picture of RTC is to be portrayed based on i) specific RTC oriented knowledge together with ii) generic characteristic and nature of collaboration.

5.1. Technological possibilities and elements

Advanced technological infrastructure for managing and accessing model-based data is basically providing various solutions applicable to RTC. Apparently, specific RTC technologies are needed for coping with the complexity of construction projects with its all partners from different professional businesses. The following presents the identified key technologies for RTC.

<u>Real-time information sharing</u>

Sharing technologies play a critical role in enabling collaboration by facilitating communication, coordination, and data sharing between parties regardless of their location or time zone. The following three topics have been identified as important ones for RTC in construction:

- Federated modelling environment
- Adaptive dynamic data sharing
- Cloud-based live modelling

Federated modelling technology enables independent design systems to work together in a coordinated manner without sharing the native design data. Through this mechanism design applications will be able to adapt to changes made in other design models.

The adaptive dynamic data sharing is a technology defined and developed for detecting automatically the data to be shared by an author and/or received by a consumer. The core of the system is a linking system that can dynamically identify both the parties and data model contents necessary for communication and information sharing in different situations. The need will be detected based on the customizable context-based dependencies.

Cloud-based live modelling technology is being defined and developed to integrate annotation modelling tools and other 3D content that is not the actual BIM content but can be used for communication and coordination purposes as well as for modelling and sharing requirements. The interface used for integrating the annotation modelling tools shall make it possible to use also 3rd party modelling tools compatible with the interface.

<u>Real-time communication</u>

The core solution is a real-time communication platform that can connect communication threads to the content of released BIM models and live models as well as connect people with communication threads. The platform can be used to connect conversations using commercial communication applications (e.g. Microsoft Teams and WhatsApp) to data model content. The linking mechanism can be used to identify the parties involved in the discussion and connect them to the discussion. In addition, the possibility of having a conversation between different commercial applications via the platform is to be investigated.

Data governance and management

Digital collaboration in a construction project produces data both in a form of non-personal data (e.g. BIM data, event data) and personal data (e.g. collaborators' personal information or data linked to the identities). The needed solutions need to comply with regulatory aspects, requirements and methods relating to construction collaboration, e.g. processing of personal data under GDPR and data sharing and transactions from the point of view of the Data Governance Act, Data Act and/or AI Act. It needs to be defined how the collaboration data shall be virtualized and anonymized to use data for machine learning purposes and study the implications it has on implementing data sharing. Additionally, this task will validate the applicability of different data sharing initiatives (e.g. iShare framework). Research and definition work is needed for creating data structures, formats, and ontologies for managing and storing the event data created through real-time communication. The purpose of this information is to understand the chain of events and their consequences. The collected information is intended to be used in the future, e.g. to analyses and recommendation systems based on machine learning.

Digital involvement

The digital involvement for RTC is apparently challenging the existing practices and obligates renewing the construction industry and its operating methods. Acceptability of technology is an essential factor in the desired transformation. The user experience provided by digital collaboration tools plays a key role in the adoption of digital technology and collaboration methods. The work consists of implementation of integrations of selected communication tools with design models and data of those. The technological basis is likely to be on certain well-established ones (e.g. Microsoft Teams) as well as solutions such as Metaverse. The goal is to test how users can interact in real time with each other and with digital objects in a 3D virtual world using avatars or other digital representations of themselves. Mobile solutions can have here role of importance.

5.2. Organizational aspects of RTC

Even with limited and small-scale trials of RTC need to be planned carefully. Understanding of structures and contents of processes forms basis for planning operations, their implementations, control and management. Presently we have considerable amount of research-based knowledge about BIM based construction projects and collaboration in those. These results can be used as starting points for shaping RTC solutions. The following presents list of fields that have been recognised as potential starting points for clarifying the RTC dynamics for its implementations:

- Processes and flows of modelling along the construction project life cycle have proved to be useful building blocks for managing BIM operations. Harnessing RTC within those in a smart manner can be advantageous.

- Lessons from BIM based collaboration in BIM-based construction networks (BbCNs) are pointing out the importance of roles, relating responsibilities and processes (Oraee et al, 2019). These human centric softer issues need to be recognised for effective and successful collaboration [16].

- Professional roles. BIM operations have been sources new professional roles that are clarifying responsibilities inside various teams of project partners e.g. BIM coordinator, BIM manager, BIM lead modeler (different design professions). The organizational models are not well-established, and practices are uneven (Kouider et al, 2019). With RTC the dynamics of design operations increase, and the clarified roles of designers and others involved can be very helpful.

- LOIN, LOD and relating solutions. Level of information need (LOIN) presented by the EN ISO 19650 standard is showing path towards modelling and its logic in a broad manner by attempting to capture the information content of the entire construction project. Consequently, a specific standard ISO/FDIS 7817-1 for level of information need and information deliveries is under development and scheduled to be released in 2025. The concept Levels of Development (LOD) refer to a standardized framework for defining the amount of detail and accuracy. LOD can be seen to refer to the status of design that is of importance with the RTC operations when collaborative on-line design operations are under way or when designers are sharing their work to others.

5.3 Human aspects of RTC

Needs of RTC

Design changes and needs for those are usually unwelcome issues in construction projects. But they are inevitable due to the uniqueness and complexity of construction maneuvers. Consequently, the research on changes in construction and development of change management have created interest in academia and industry (Motawa, 2005; CIRIA, 2001; Hao et al, 2008).

For understanding the interplay of design changes between construction project partners a workshop was arranged for capturing views of construction professionals. The workshop was attended by ten people representing clients, architectural design, engineering, BIM coordination, technology providers, and researchers. A rather open tasks was presented to the participants "Identify the causes behind design changes in different phases of building construction projects." The results were captured with the Miro communication platform. This produced 102 data points each of which represents a specific cause for design change. The data analysis has provided numerous insights, and it has clarified the overall picture of dynamics of design changes in construction projects. For example, it appeared that the design management is receiving the biggest share of requests for design changes (Figure 3). Additionally, it is worth noticing how different design consultants are directly also receiving requests for design changes from different other partners.

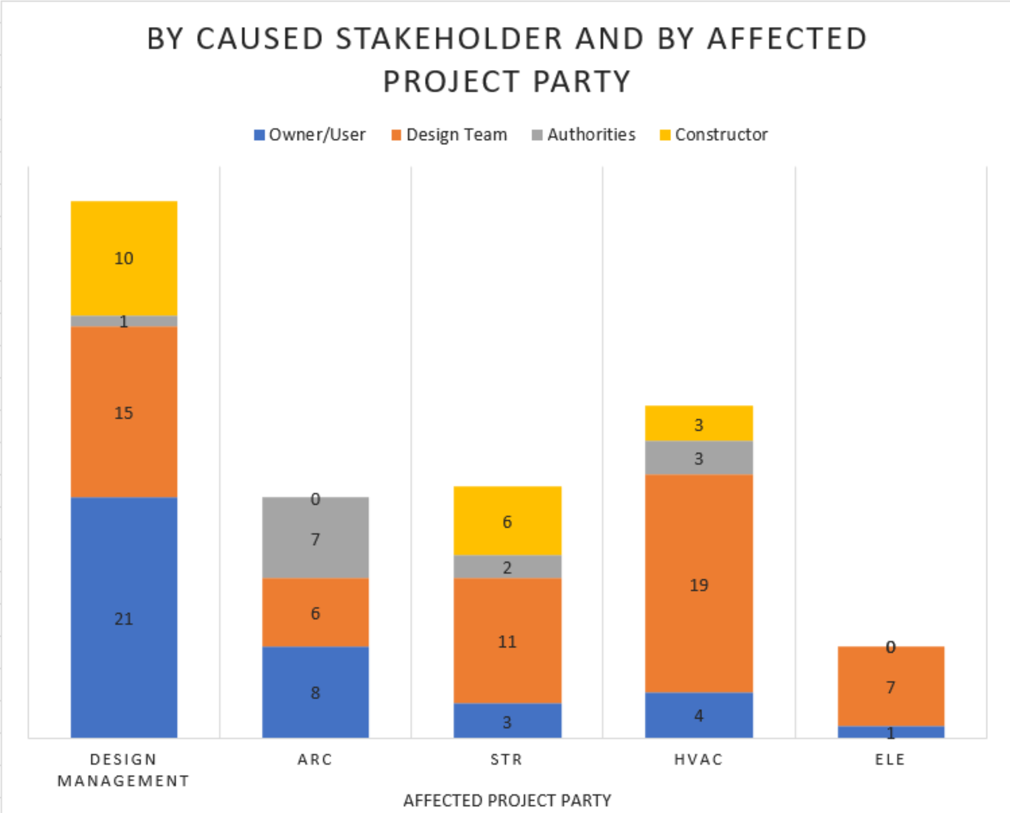

Figure 3. Interplay of design changes between construction project partners based on a workshop where views of construction professionals were captured.

Barriers of RTC

Barriers of collaboration in general business operations, in construction and in BIM-based construction projects have been studied actively during last two decades. These results can form useful stepping stones when we are planning RTC implementations. Oraee et al (2019) have carried out an extensive literature study which included 163 journal articles and 76 of those were used for identifying 89 barriers. Finally, those were placed in five categories that are also forming the main structure of the proposed conceptual model: context, process, team, task, and actor.

For the need of first practical trials of RTC for building design, designers' collaboration with construction site and RTC management The Figure 4 was developed to point out possible RTC barriers. The listed barriers aim to address causes or event root causes of relevance rather than naming higher abstraction level contents such as fragmentation or trust. The conceptual model by Oraee et al (2019) was used as a starting point and the RTC concept, the applicable main technologies (5.1) and possible implementations were used as a filter for reshaping barriers of relevance that have been mentioned in the literature or identified by industrial partners who have been involved in our research activities (Riemer & Frößler, 2007; Oraee et al, 2019; Shelbourn et al, 2007; Galaz-Delgado et al, 2021; Kelly, 2005; Lines et al, 2015; Siemieniuch & Sinclair, 1999; Sclater et al, 2001; Alreshidi et al, 2018). The barriers of RTC (Figure 4) present an early understanding of main barriers that need attention when first RTC implementations are planned. This list is to be developed further and validated in the following research efforts.

The identified barriers of RTC are pointing out the wide spectrum of challenges that are technical, organizational, and social. Compared with the collaboration that means mostly working together in face-to-face or along digitally supported sequences RTC is more demanding with its dynamic nature.

Figure 4. Barriers of RTC in construction projects. The identified barriers represent particularly those which are relevant to designers' collaboration.

6. Discussion

RTC looks a potential avenue for developments and for important benefits in the construction sector. Trials of RTC for design engineering in automotive industry are showing evidence for benefits such as having more effective discussions between distributed project teams, less opportunity for misunderstandings, and an ability to react more quickly to arising problems (Siemieniuch & Sinclair, 1999). On the other hand, the gained results are pointing out kind of implementation challenges that have been discussed earlier in this paper.

Our understanding of RTC in construction is still very limited as we are moving ahead with technology development and planning of first pilots. However, we need to look at sector-wide possibilities and how to scale up RTC solutions for reshaping practices in different types of construction projects. From practical BIM implementations we have recognized the pivotal role of lead contractors. The lead contractors are setting rules for operations and with their PDCA managements establishing the way how construction project is moving ahead and how different project partners are working together. Project BIM guidelines or full-scale BIM Project Execution Plan (BEP) are used for directing the of project partners. These plans and guidelines can be elaborated for the inclusions of RTC process and principles. Real-time collaboration as a transformation is possible in certain regional construction cultures or in certain types of delivery models easier than more generally outreaching towards sectoral implications.

An optimally functioning RTC environment is an arena where plenty of signals are all the time flowing between project partners. Those signals can carry e.g. feedback, alerts, comments, change requests, update info, approvals and status notifications about digitals models and surrounding live project environment. Additionally, virtual presence enables communication, dialogues, and meetings with short notice. This is reflecting dynamic nature of RTC. It is a RDI challenge how the dynamics of RTC in construction projects can be modelled and explained for the purpose of its acceptance and implementations.

7. Conclusions

Real-time collaboration (RTC) entails people working together at the same time regardless of their location. It is concluded that the frequency of collaboration in construction projects can be considerable improved using RTC which can result in extensive benefits. We are in an early stage of RDI activities for understanding RTC in construction projects. Building blocks for RTC solutions and research challenges of importance have been identified and those are requiring further RDI attention.

Circularity and its goals are challenging real estate and construction sector for the reuse of building materials and components. With the existing building stock some limited reuse results can be achieved but this requires timely collaboration and information exchange between various project partners. Fundamental transitional changes for circularity require design and construction of buildings for disassembly and reuse.

Regarding both RTC and circularity the following research directions are seen as highly relevant ones:

- Enabling technologies for RTC
- Dynamics and processes of RTC in construction projects
- Trials of RTC in live construction projects along the principles of action research
- Collaborative solutions for enabling the reuse of materials and components from existing buildings
- Building design solutions for circularity

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Investigation of critical resources effect on a large-scale construction project through entropy-based scheduling

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Abstract:

A critical parameter of the achievability for every time schedule and construction budget is the number and availability of critical project resources. As such, in contemporary project management the time schedule is not only comprised of activity precedence relationships and duration assignments but provides a clear picture of the utilized resources and respective costs. The present research adopts the entropy-based scheduling technique. The main rationale is to minimize the total entropy of the project, so as to come up with a schedule that is stable and, hence, more manageable. A methodological approach is presented to associate the project duration, project cost and entropy, while applying the developed concepts on an actual large-scale construction project as a case study. The innovative characteristics of this research relate to the fact that the entropy-based scheduling technique is applied in a sufficiently complex case study for the construction of a new airport terminal hub, whose time schedule does not only include numerous precedence relations, but also reflects a total project duration of more than four calendar years. The increase of the deployed resources, for a specific activity, results in the reduction of the activity's duration and, hence, leads to a shorter project duration under the condition that the affected activity belongs to the critical path. The analysis evidently proved that entropy is a critical project metric and there is a plateau beyond which any further increase of the activities' resources does not lead to a reduction in the project duration.

Keywords: *case study; entropy; productivity; resources; scheduling;*

1. Introduction

In the initial project planning phase, each estimator creates a baseline time schedule which reflects the main assumptions of the methodological and constructability approach in terms of construction techniques, and the deployed resources (Panas and Pantouvakis, 2010). However, as the dynamically changing project conditions evolve, the initial time schedule is regularly reviewed and updated, in order to accommodate the actual on-site setting (Panas and Pantouvakis, 2015). A critical parameter of the achievability for every time schedule and construction budget is the number and availability of critical project resources. As such, in contemporary project management each time schedule is not only comprised of activity precedence relationships and duration assignments but provides a clear picture of the utilized resources and respective costs. In that sense, a valid baseline time schedule should be resource-loaded and cost-loaded, in order to ensure a timely project completion (Ding et al., 2023).

However, in real-life situations, a project manager almost never has the luxury of being able to deploy as many resources as required on a given time for a construction project (Spyropoulou et al., 2021). In other words, the norm is that project resources are always of limited capacity and availability which leads the project activities to compete for ensuring their unobstructed realization. Therefore, there are two main approaches for managing resources in a construction project: (i) the resource usage profile is smoothed by moving the non-critical activities within their float, in order to minimize resource usage (Ponz-Tienda et al., 2013) and (ii) resources are utilized without breaching their constraints and the aim is to cause the minimum possible delay (if any) to the project duration. The former is characterized as a Resource Leveling Problem (RLP), while the latter is known as the Resource-Constrained Scheduling Problem (RCSP) (Christodoulou et al., 2009; Qiao and Li, 2018).

This research is focused on investigating the RCSP issue with the objective of completing all necessary tasks in the minimum total finish time. Such problems, are traditionally solved through a burdensome computational process and several analytical methods, as will be described in the next section. Within this framework, the present research adopts the entropy-based scheduling technique, as proposed by Christodoulou et al. (2009). The main rationale is to minimize the total entropy of the project schedule, in an attempt to come up with a project schedule that is stable and, hence, more manageable. More details on the concept of entropy in relation to project scheduling are provided in the following section. A real, large-scale construction project in Greece serves as a testbed for the practical evaluation of the developed concepts. The innovative characteristics of this research relate to the fact that the entropy-based scheduling technique is applied in a sufficiently complex case study for the construction of a new airport terminal hub, whose time schedule does not only include numerous precedence relations, but also reflects a total project duration of more than four calendar years. The latter is a critical parameter, since entropy has two principal properties (Christodoulou et al., 2010): subaddivity and maximality, which means that the longer the duration of the project, the greater the maximization of the entropy. Therefore, it is rather challenging to minimize the project duration under that conflicting condition.

In addition, the research is focused on labour resources since construction workforce is traditionally more sensitive to fluctuations during the project execution. Hence, the main research question is formulated as follows: "*how does the fluctuation of labour resources affect the project's entropy and how is that related to the project time schedule and budget*?"

The remainder of the paper is structured as follows: first, a literature review of pertinent research is presented, in order to establish the theoretical framework of the research scope. Then, the research methodology is delineated with a subsequent analysis of the selected case study. A discussion of the inferences emerging from the study along with the main conclusions conclude the present paper.

2. Literature Review

The literature review focuses on presenting two main concepts that actually affect the study: (i) Resource-Constrained Project Scheduling and (ii) entropy in relation to the execution of a construction project.

2.1 Resource-Constrained Project Scheduling

Any given time schedule is a fusion of two main scheduling approaches: (a) serial scheduling and (b) parallel scheduling. In real-life construction project time schedules, the planner who develops the schedule network tries to insert as many parallel activities as possible, since their presence expedites the project execution time. On the other hand, parallel activities compete, in order to secure the necessary resources required for their timely completion.

Therefore, in the case of parallel resource-constrained scheduling, the defining parameter is which activity will be the first to receive the required resources for its execution. On an experiential basis, this would mean the activity that minimizes the overall project duration. However, in complex networks – such as the one corresponding to the real-life project scrutinized as the research case study – the use of scheduling software is recommended.

The most commonly used software is the Primavera Project Planner (P6) (Primavera Project Planner, 2024) and the Microsoft Project (MSP) (Microsoft Project, 2024). The resource-constrained scheduling issue is addressed as a resource leveling issue within the operations of a commercial software (Christodoulou et al., 2009). As stated in the introductory section, the resource leveling essentially represents a smoothing of the resource profile by shifting non-critical activities within their float, in order to minimize resource usage. It has been found that resource leveling does not always optimize resource allocation, since there are cases where automated resource leveling may leave the project time duration unchanged although there could be a shortening of the project duration (Christodoulou et al., 2009). The reason of this finding is partly based on the fact that the resource leveling is executed through heuristic methods which evaluate a series of prioritization criteria: resource sufficiency, task interdependencies, constraints and priorities (Microsoft Project, 2024; Primavera Project Planner, 2024).

2.2 Entropy for a construction project

Resource entropy departs from the previously mentioned heuristic approach and associates the project scheduling function with the resource utilization. In essence, the supporting theory is explained in much detail by Christodoulou et al. (2009). However, the main concepts are repeated in this section, for reasons of research robustness which are to the benefit of the reader. In essence, the concept of entropy stems from the statistical mechanics area, where entropy is a measure of the disorder of a system. Since the higher the entropy, the higher the disorder, the entropy is expressed as being proportional to the natural logarithm of the number of possible microscopic configurations of the system (microstates) (Qiao and Li, 2018). In that sense, the entropy $H_{i,j}$ of an activity *i* produced by a resource *j* is defined in Equation 1 (Christodoulou et al., 2009). (1)

Where: $p_{i,j}$ represents the ratio of the required (R) over the assigned resource (R') units for activity *i*.

The rationale for the definition of $p_{i,j}$ is based on the assumption that as-built (as represented by R') versus as-planned (as represented by R) resource assignments are a good indication of a project's expected progress. In that sense, the ratio R/R' reflects the project's tendency to fall into disorder and, hence, is deemed as a good metric of entropy for construction projects. If it is assumed that the project entails n_a activities and n_y resource types, then all resource types *j* ($j \in [1, n_y]$) can be summed in terms of their entropy to a total resource-based activity entropy (H_{ACT}) as defined in Equation 2. (2)

The total resource-based project entropy (H_T) is derived as the sum of all resource entropies of all activities *i* ($i \in [1, n_a]$) according to Equation 3. (3)

The main rationale is that the lower the entropy values, the less chaotic an activity and the project, in general, may be. Of course, it is important to keep certain constraints valid in Equations 1-3 such as (a) resource assignments should take only positive, integer values which cannot be fractional, since the latter has no physical meaning and (b) no change is allowed in the scheduling network logic (i.e. predecessor and successor relationships remain constant).

3 Research Methodology

The current research investigates the relation between the duration, the cost and the entropy for a real-life construction project. First, the baseline time schedule is drafted based on the available project data. Cost data are retrieved from national databases which are publicly available and describe the average daily wage of personnel, equipment operators, technicians etc. The project start date and completion date are pre-specified, while for analysis facilitation purposes, it is assumed that there is no restriction on the availability of project resources. Taking into account all of the aforementioned conditions, the adopted solution opts to satisfy all cost, time and entropy criteria. In other words, the objective is to conclude the project in the shortest time possible, with the minimum construction cost and with the project entropy ranging, ideally, in the area of zero. An iterative simulation process is implemented, by changing different parameters, such as the number of resources, the activities' duration etc. The next paragraphs describe analytically the methodological steps that have to be followed, in order to conduct the research.

3.1 Methodological steps

The research methodology comprises of the next steps:

Step 1 – Initial project time schedule: The first step is the compilation of the baseline time schedule by selecting the activities that are going to be executed along with their resources. The time schedule also depicts the dependencies between the different activities according to the functionalities of the selected software. This research adopts the Microsoft Project (MSP) (Microsoft Project, 2024) software platform, due to its user-friendly interface and extended familiarity with the project personnel.

Step 2 – Data preparation for analytical processing: The next step would be the transfer of the data from the software to an interim spreadsheet database (e.g. Microsoft Excel, 2024). The transmitted data indicatively comprise of early start and early end dates, activity duration, resources type etc. The database feeds all transmitted data to the Crystal Ball software (Crystal Ball, 2024), in order to conduct iterative simulations along specific project parameters. There has been a provision to secure the interoperability of the transmitted data between the interim database and the simulation software. In every scenario, the project duration is calculated via the application productivity estimation algorithms and their respective mathematical formulae (Panas et al., 2023). In a similar fashion, the estimation of Early Finish (EF) and Late Finish (LF) durations for each activity along with the project's critical path follows.

Step 4 – Combinatory application of project data: The three aforementioned software platforms (Microsoft Excel, Microsoft Project and Crystal Ball) are interfacing in the following manner: the activities' resources are modified (either increased or decreased) in every scenario, which leads to the respective alteration of the activities' duration in the Crystal Ball model. The same modifications are being transferred to the Microsoft Project models and the respective spreadsheet database. The latter facilitates the estimation of the critical path, the total duration, the cost and the project's entropy. The application of the iterative simulation process aids in finding the optimum solution.

4. 4. Case Study presentation

The practical implementation of the entropy concepts are tested against a real-life construction project that represents a sufficiently complex setting and respective resource allocation complexities. The airport “Macedonia” (SKG) is located around 13km south of the city of Thessaloniki, in Northern Greece. The airport is the second largest in Greece and includes also a commercial terminal hub. Due to the projections of passengers’ increase for the next ten years, the airport’s infrastructure was upgraded by reconfiguring the existing installations in the period 2016 to 2021 (see Figure 1 below). More specifically, a new building structure was erected and connected to the existing departures terminal. The main objective of the interventions was the renovation of the existing building surfaces with a total area of 26.606,27m^2 and their extension to a total area of 34.033,30m^2 on all levels, thus resulting in a total area for the whole terminal equal to 60.639,57m^2.

Figure 1. SKG Airport extension (source: INTRAKAT, 2024)

4.1 Technical description of the project

The new terminal has been designed as a linear continuation of the existing building. The control tower does not fall within the scope of the intended works. The two buildings (old and new) are interconnected through two corridors. From a functionality point of view, the new building operates mainly on two levels (departures and arrivals), while it also includes lounges, restaurants, administration offices and E/M infrastructure.

An excerpt of the time schedule is presented in Table 1 below and it shows that the resource-unconstrained schedule has a total duration of 1578,50days.

Table 1. Project baseline reference time schedule (source: own study)

Activity	Duration	Early Start (ES)	Early Finish (EF)	ES	EF	LS	LF
PROJECT DURATION	1578,5	17/10/2016	21/07/2021	0	1714	0	1714
Project Start	387,5	17/10/2016	08/11/2017	0	381	0	1714
Contract signing date	0	01/12/2016	01/12/2016	43	43	43	43
Master Plan	121	01/12/2016	31/03/2017	43	163	43	212
Preparation of renovation works	60	01/12/2016	22/02/2017	43	124	43	125
Approval of renovation plan	30	23/02/2017	05/04/2017	124	166	125	166
Preparation of design analysis	92	01/11/2016	08/03/2017	13	140	13	141
Approval of design analysis	28	09/03/2017	17/04/2017	140	178	141	181
Preparation and submission of environmental planning	34,5	17/10/2016	02/12/2016	0	45	0	45
Approval of environmental planning	243	02/12/2016	08/11/2017	45	381	45	381
Construction Phase	1533,5	01/12/2016	21/07/2021	43	1713	43	1526
Contractor mobilization	30	06/04/2017	17/05/2017	166	207	166	207

4.2. Technical description of the project

The execution of the present research is based on the following assumptions:

- The average values of the wages for all technical personnel as well as the cost for equipment lease have been derived from the official databases of the Greek State (Hellenic Statistical Authority, 2024).

- The need for additional work is covered by additional personnel and not by overtime of the existing workforce.

- The total project cost is essentially reflected by the direct cost, since the indirect cost has not been incorporated in the analysis.

- It is assumed that all project resources are available for the execution of the project in relation to the baseline time schedule.

- The resources' productivity (labourers, equipment etc.) is considered to be constant.

4.3 Resource utilization framework

The research investigates the variation of (a) the total construction cost, (b) the entropy and (c) the achieved productivity due to the respective variation of resources associated both with critical, as well as non-critical activities. More specifically, the resources that have been selected (either to be increased or decreased) are: (a) Architect Engineer, (b) Skilled Labourer (e.g. technician) and (c) Unskilled labourer.

The selection of these resources is directly linked mainly to critical activities, since they represent resources broadly utilized throughout the project. Besides, it is expected that the increase of resources and the subsequent decrease of the duration for critical activities will result in the following:

- The duration of the project is determined by the duration of the longest path in the time schedule.
- The acceleration of the project's duration relies on the decrease of its longest path. The latter is directly dependent on the duration decrease for at least one critical activity.
- The decrease of the duration for the critical activities diminishes the float of the respective non-critical activities. In fact, if their float is entirely consumed, then these activities become critical as well.

It should be noted that in case there are more than one critical paths in the time schedule, then a respective decrease of all critical paths will result in an accelerated time schedule. Furthermore, in case the entropy values take up negative values, then the absolute values are tabulated in the respective results for presentation purposes. The next paragraphs describe the resource variation scenarios which present the following logic: first an investigation of the effect of resource increase will be conducted, in order to explore the limits of the entropy's variation. The main issue to be tested is to which extent an increase in activity resources has a positive impact on the project's time schedule. Christodoulou et al. (2009) have clearly stated that there is a limit on the number of assigned resource units beyond which any further increase of resources does not bring any additional benefit to the project duration and the project in general. In a proportionate manner, the selected resources are decreased, in order to explore the resource-constrained scheduling problem. A probability histogram is going to be produced, so as to illustrate the effect of resource scarcity on entropy, cost and project delay.

The resource "Architect Engineer" is increased by one unit in the following activities:

- Preparation and submission of environmental planning
- Approval of environmental planning

The environmental planning and approval phase is of paramount importance since it defines the framework, within which the project is going to be executed. The increase of the specific resource by one unit in those two activities, results in a reduction of the total project duration from 1.578,50 days to 1.506 days and a respective increase of the entropy's total value from zero to 1,25 (see Table 2 below).

In other words, it seems that the entropy takes values close to zero, when the project's duration lies within a reasonable margin of the initial (baseline) duration of 1.578,50 days. In addition, the decrease of the project's duration results also in a reduction of the construction cost from 9.603.071,86€ to 9.576.471,86€ (cost saving equal to 26.600€). The physical meaning of the increase for this specific resource is the acceleration of the project permitting process, which is critical for the enabling of the construction works' commencement.

Table 2. Results on project variables for the case of increasing the "Architect Engineer" resource by one unit (source: own study)

Statistics	Total revisedcost (€)	Total entropy	Total Duration (days)	Total Delay (days)	Resource "Architect Engineer" utilization (days)
Trials	1.000,00	1.000,00	1.000,00	1.000,00	1.000,00
Base Case	9.603.071,86	0,00382	1.578,50	0,00	2.627,50
Mean	9.576.471,86	1,25000	1.506,00	-72,50	2.095,50
Median	9.576.453,86	1,23307	1.500,19	-72,56	2.098,38
St. Deviation	260.745,40	0,48684	143,76	7,29	209,73
Variance	88.165.390,44	0,23701	20.665,76	53,08	43.986,97
Skewness	0,15	0,84426	-0,01	0,03	-0,05
Kurtosis	2,93	4,16810	2,95	2,86	3,09
Coefficient of Variability	0,03	0,37562	0,10	-0,10	0,10
Minimum	8.946.293,53	3,42977	1.008,62	-94,41	1.408,47
Maximum	10.419.882,32	0,00379	1.914,94	0,00	2.767,55
Range Width	1.473.588,79	0,00	3,39	3,43	906,33
Mean Std. Error	8.245,49	0,01540	4,55	0,23	6,63

4.3.1 Increase of the resources "Architect Engineer" and "Skilled Labourer" by one unit

This case represents the combinatory increase of the "Architect Engineer" and "Skilled Labourer" resource by one unit in the following activities:

- Preparation and submission of environmental planning (Architect Engineer)
- Approval of environmental planning (Architect Engineer)
- Construction of piles (Skilled Labourer)
- Insulation works (Skilled Labourer)

The increase of the specific resources by one unit in the aforementioned activities results in a decrease of the project duration from 1.578,5 days to 1.473 days and an increase of the entropy's absolute values from zero to 2,04 (see Table 3 below). The equivalent decrease in the project cost is 31.175,72€ (namely from 9.603.071,86€ to 9.571.896,14€).

Table 3. Results on project variables for the case of increasing the "Architect Engineer" and "Skilled Labourer" resource by one unit (source: own study)

Statistics	**Total Entropy**	**Total Revised Cost (€)**	**TotalDelay (days)**	**Total Revised Duration (days)**	**Resource "Architect Engineer" utilization (days)**	**Resource "Skilled Labourer" utilization (days)**
Trials	1.000,00	1.000,00	1.000,00	1.000,00	1.000,00	1.000,00
Base Case	0,0035	9.603.071,86	0,00	1.578,50	2.627,50	6.808,00
Mean	2,0425	9.571.896,14	-105,50	1.473,00	2.095,50	6.744,00
Median	1,9861	9.565.160,53	-105,59	1.467,32	2.099,63	6.730,52
Standard Deviation	0,5465	272.935,76	10,60	140,61	209,34	666,69

Variance	0,2986	93.929.451,32	112,40	19.770,01	43.823,57	444.481,72
Skewness	0,6965	0,02	0,03	-0,01	-0,07	0,12
Kurtosis	4,0968	3,13	2,86	2,95	3,01	2,86
Coeff. of Variability	0,2675	0,03	-0,10	0,10	0,10	0,10
Minimum	4,7479	8.669.554,04	-137,39	986,51	1.400,36	4.903,85
Maximum	0,0035	10.504.080,87	0,00	1.872,98	2.808,87	8.721,30
RangeWidth	4,7444	1.834.526,83	137,39	886,47	1.408,51	3.817,45
Mean Std. Error	0,0173	8.630,99	0,34	4,45	6,62	21,08

Increase of the resources "Architect Engineer" and "Skilled Labourer" by two units

This test is a direct application of the previous trial, with the only difference being the fact that the resources are increased by two units instead of one. All other parameters (e.g. affected activities) remain the same. The results show that the project duration is decreased by ten days more (1.578,5 days to 1.463) and the entropy is increased even further to 3,25 (see Table 4 below). The equivalent saving in the project cost is 36.776,44€ (namely from 9.603.071,86€ to 9.566.295,42€).

Table 4. Results on project variables for the case of increasing the "Architect Engineer" and "Skilled Labourer" resource by one unit (source: own study)

Statistics	Total Entropy	Total Revised Cost (€)	Total Delay (days)	Total Revised Duration (days)	Resource "Architect Engineer" utilization (days)	Resource "Skilled Labourer" utilization (days)
Trials	1000	1000	1000	1000	1000	1000
Base Case	0,0031	9.603.071,86	0,00	1.578,50	2.627,50	6.808,00
Mean	3,2490	9.566.295,42	-115,50	1.463,00	2.041,50	6.730,00
Median	3,1945	9.559.499,61	-115,60	1.457,36	2.045,52	6.716,55
Standard Deviation	0,6381	272.889,02	11,61	139,65	203,95	665,31
Variance	0,4072	8.417.312,63	134,72	19.502,49	41.594,05	442.638,22
Skewness	0,6058	0,02	0,03	-0,01	-0,07	0,12
Kurtosis	3,8229	3,13	2,86	2,95	3,01	2,86
Coeff. of Variability	0,1964	0,03	-0,10	0,10	0,10	0,10
Minimum	6,0687	8.664.220,31	-150,41	979,82	1.364,27	4.893,67
Maximum	0,0023	10.498.164,31	0,00	1.860,27	2.736,49	8.703,20
Range Width	6,0665	1.833.944,00	150,41	880,45	1.372,21	3.809,53
Mean Std. Error	0,0202	8.629,51	0,37	4,42	6,45	21,04

Further increase of the resources "Architect Engineer" and "Skilled Labourer"

In case of a further increase in the resources amount for "Architect Engineer" and "Skilled Labourer" (e.g. equal to three, four etc.) there is no alteration in the project's duration, i.e. it remains constant to 1.463 days. In a similar fashion, the entropy, as well as the project cost, keeps increasing. Therefore, there is no essential meaning in pursuing a further investigation in that respect.

Decrease of the resources “Architect Engineer” and “Unskilled Labourer” by one unit

Subsequently, we decrease the resources amount for “Architect Engineer” and “Unskilled Labourer” by one unit in the following activities:

- Preparation and submission of environmental planning (Architect Engineer)
- Approval of environmental planning (Architect Engineer)
- Execution of architectural works for the extension of the existing terminal building (Unskilled Labourer)

As a result, the project duration increased to 1840 days from 1.578,5 days, while the respective entropy reached the value 0,2588 (see Table 5 below). The reduction of the resources results in the increase of the project duration and the increase of entropy. Entropy is positively correlated with the project duration. In addition, the increase of project duration results in the increase of the project cost (from 9.603.071,86€ to 9.671.228,62€). The resulted project delay falls within the area of 281,50 days and the cost overrun is equal to 68.156,76€.

Table 5. Results on project variables for the case of decreasing the “Architect Engineer” and “Unskilled Labourer” resource by one unit (source: own study)

Statistics	Total Entropy	Total Revised Cost (€)	Total Delay (days)	Total Revised Duration (days)	Resource “Architect Engineer” utilization (days)	Resource “Skilled Labourer” utilization (days)
Trials	1000	1000	1000	1000	1000	1000
Base Case	0,2588	9.603.071,86	281,50	1.587,50	2.627,50	19.869,00
Mean	0,2588	9.671.228,62	281,50	1.860,00	3.737,50	20.093,00
Median	0,2423	9.662.308,88	281,26	1.852,83	3.744,86	19.963,17
Standard Deviation	0,1529	274.040,80	28,29	177,55	373,38	1.878,65
Variance	0,0234	98.359.473,89	800,27	31.522,98	139.410,28	3.529.335,21
Skewness	-0,7954	0,02	0,03	-0,01	-0,07	0,06
Kurtosis	4,1319	3,13	2,86	2,95	3,01	3,08
Coeff. of Variability	0,6818	0,03	0,10	0,10	0,10	0,09
Minimum	-0,4301	8.767.103,56	196,42	1.245,70	2.497,66	13.794,21
Maximum	0,5618	10.616.902,96	372,38	2.365,07	5.009,86	26.542,27
Range Width	0,9919	1.849.799,40	175,96	1.119,37	2.512,20	12.748,06
Mean Std. Error	0,0048	8.665,93	0,89	5,61	11,81	59,41

4. Discussion

This section presents the main inferences emerging from the study. First, the incremental enhancement of the project resources results in a proportionate increase in entropy values and respective cost savings and time schedule reduction. An overview of the results is tabulated in the following Table 6. Hence, it can be inferenced that as much as we depart from the baseline scenario, the entropy values are increasing, thus denoting that the resource utilization profile does not correspond to the initial one. Consequently, since there is a limit beyond which there is no point in further increasing any resources, the analysis showed that the relevant threshold for the case study was the increase of the "Architect Engineer" and the "Skilled Labourer" by more than two units.

Table 6. Summary project indices (source: own study)

Scenario	Entropy	Cost saving	Duration reduction
Increase Architect (by one unit)	1,25	26.600,00€	72,5
Increase Architect and Skilled Labourer (by one unit)	2,04	31.175,72€	105,5
Increase Architect and Skilled Labourer (by two units)	3,25	36.776,44€	115,50

Secondly, it is evident that the reduction of the project resources creates a risky project management framework in the sense that it causes costs overruns and time delays. The latter is anticipated, since any RCSP is based on the assumption that resources are scarce and, hence, compete to fulfil the project objectives. All three metrics (entropy 0,26; cost overrun 68.156,76€; time delay 261,50 days) have been proportionally increased and the main inference is that the project is rather sensitive to resource diminishment scenarios.

In that sense, it is worth analyzing further the last case, where both the "Architect Engineer" and "Unskilled Labourer" are diminished concurrently by one unit for the activities mentioned in Section 4.4.5. In more detail, Figures 2, 3 and 4 illustrate the probability histograms for the total construction cost, the total entropy and the total delay based on the simulation results. As it is understood from the analysis, the entropy is equal to zero when the deployed resources are equal to the requested amount in the baseline time schedule, while it takes up larger values when the deployed resources are different than the ones in the baseline scenario.

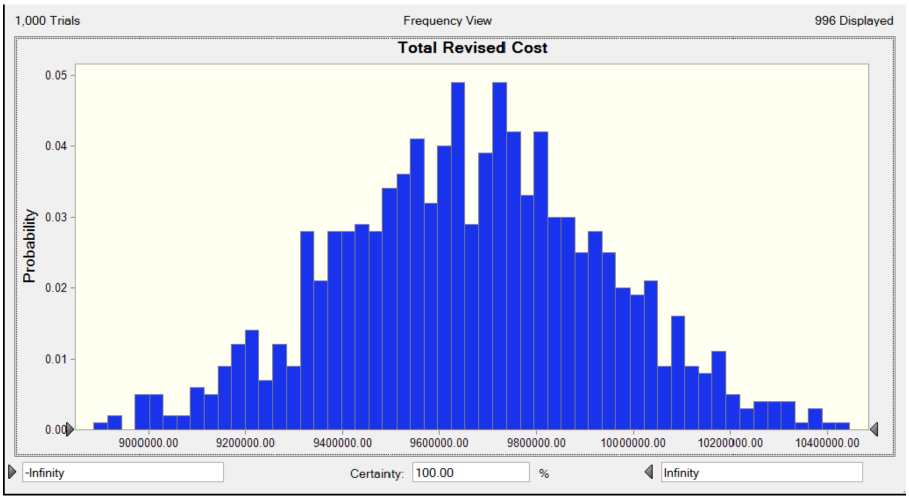

Figure 2. Probability distribution histogram for the total revised cost (source: own study)

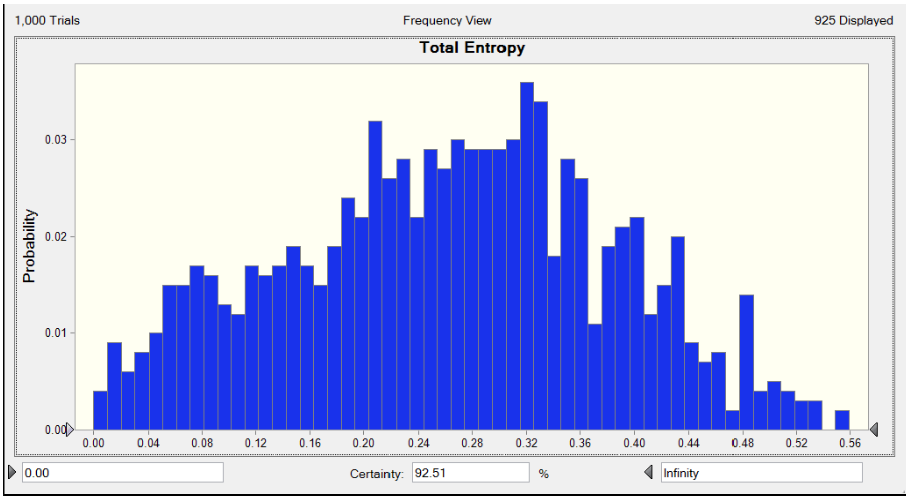

Figure 3. Probability distribution histogram for the total entropy (source: own study)

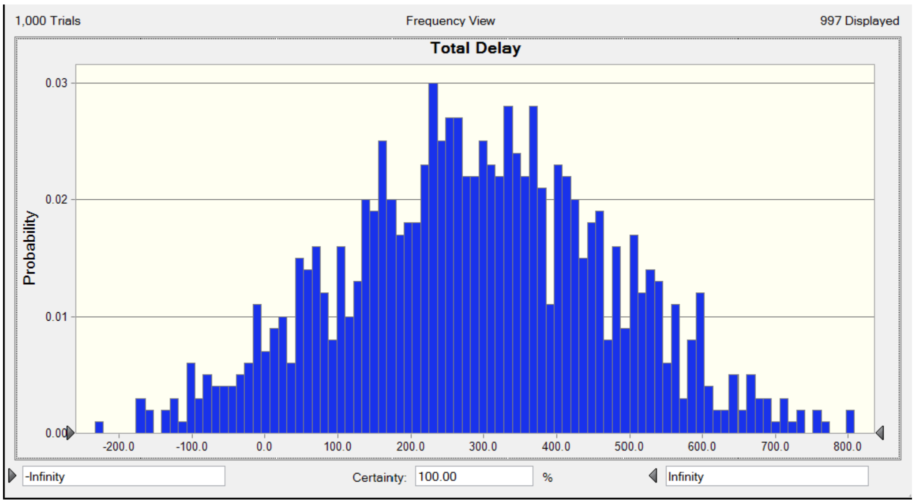

Figure 4. Probability distribution histogram for the total delay (source: own study)

5. Conclusions

The present research has presented a methodological approach, in order to associate the project duration, project cost and entropy, while applying the developed concepts on an actual large-scale construction project as a case study.

Specific resources associated primarily with critical activities were scrutinized, in order to investigate their effect on the main project parameters, such as entropy, construction cost, completion time, delays etc. The increase of the deployed resources, for a specific activity, result in the reduction of the activity's duration and, hence, leads to a shorter project duration under the condition that the affected activity belongs to the critical path. The analysis evidently proved that there is a plateau beyond which any further increase of the activities' resources does not lead to a reduction in the project duration. In a similar fashion, a decrease of the deployed resources for one or more activities results in the increase of their duration. In addition, the project's entropy is increased along with the project's cost.

The project's productivity is affected by unforeseen parameters (e.g. weather conditions, labour legislation) whose inclusion in the research analysis falls out of the scope of the current investigation. In that respect, it was decided that the resource entropy would be the critical metric for the characterization of the project status. In case the entropy's values are close to zero, then it is inferenced that the system is stable and the productivity stays relatively constant. Any deviation of the resource entropy from the close-to-zero values, leads a variation in productivity. Further research can be initiated for the association of resource entropy with different types of resources or with resources that do not possess the same productivity rate. In essence, these variations introduce an additional level of complexity that bring the analysis closer to the real-life construction setting.

6. Aknowledgments

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Predicting the Outcome of Future Construction Projects with a Neural Networks

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Abstract:

The research is focused on developing a neural network to predict time and cost overruns of construction projects during the construction phase. Previous studies have identified seven key performance areas that affect the final outcome: productivity, quality, time, cost, safety, team satisfaction and client satisfaction. Although the interconnections among these performance areas are recognized, their exact relationships and impacts are not fully understood. Hence, the utilization of a neural networks proves to be highly beneficial in predicting the outcome of future construction projects, as it can learn from data and identify patterns, without requiring a complete understanding of these mutual influences. The neural network was trained and tested on the data collected on five completed construction projects in several phases of construction. A total of 182 experiments were conducted to explore various neural network architectures for predicting time and cost overruns in construction projects. Following a detailed analysis, the most optimal neural network architectures for each prediction model were selected and discussed in more detail.

Keywords: *neural networks; prediction; construction project; performance area; stakeholders*

1. Introduction

The construction sector is considered one of the most vital and profitable industries worldwide, yet it is fraught with uncertainties and risk. Despite numerous attempts to improve processes, construction projects frequently fail to achieve the desired outcomes due to various challenges.

Earlier research and an extensive analysis of the literature have highlighted the key performance areas essential for the success of construction projects. Some of them are inherently challenging to quantify. Nevertheless, they are all fundamental in achieving project success, including productivity, quality, time, cost, safety, team satisfaction, and client satisfaction (Galjanić and Marović, 2024).

Five completed construction projects with a financial value between 15 and 25 million euros were analyzed using the multiple case study method. Interviews were conducted with key project stakeholders to gather their opinions about the project's progress and to gain detailed insights into the situation, such as circumstances, causes of problems, reasons for work stoppages, and the presence of identified performance areas in their projects. Communication was established with representatives of clients, consultants, and contractors, and comprehensive project documentation was collected. By comparing the opinions of key stakeholders and analyzing the agreed and realized deadlines and costs, it was found that there is a significant gap between stakeholder expectations and the realized performance of construction projects. This finding underscores the necessity of further research and efforts to improve project outcomes. The analysis revealed that none of the projects exceeded the contractual deadline to the extent of requiring penalty payments, but the deadlines were significantly extended compared to the initial contracts. In each analyzed project, the contractor and the client signed annexes to extend the deadlines, primarily due to significant off-budget works and exceeding the anticipated scope of works. Although some projects did not show significant deviations in total costs, there were notable changes in the cost structure, which could pose problems for the contractor in certain cases (Galjanić et al., 2023).

To address these issues, it is essential to develop a predictive tool that can assess whether a project is likely to exceed its deadlines and costs during the execution phase, and to what extent. Such a tool would provide project managers and stakeholders with timely insights to help steer projects toward successful completion. This is considered crucial for the success of a construction project, as each stakeholder enters the project with specific expectations. A certain amount of money and time is allocated, according to which the resources of all stakeholders are organized, while client plan the use of the facility, often for commercial purposes to generate profit. Any deviation from the planned time and costs can significantly disrupt the plans and ideas of all involved stakeholders, leading to losses rather than benefits.

To address this gap, it is essential to explore innovative methods and technologies that can improve project forecasting and management. One such promising approach is the use of artificial neural networks (ANNs), which have been applied to develop various predictive models. Their advantage lies in their ability to efficiently process and analyze large datasets, handle incomplete data, and generalize learned patterns to new, unseen data. ANNs have proven particularly effective in addressing complex problems, and their application in construction project management research has been growing over the past few decades (Liu et al., 2021). For instance, Jha and Chockalingam (2009) developed a quality performance prediction model using ANNs with 'MATLAB,' demonstrating that the model could achieve desired project performance by managing identified critical factors. Alaloul et al. (2018) created an ANN model to assess the impact of coordination factors on construction project performance, showing high accuracy in predicting cost, time, and quality outcomes. Furthermore, Maya et al. (2021) developed an ANN model to predict construction project performance based on 34 factors, helping project teams understand key aspects to monitor for successful project completion. Car-Pušić et al. (2022) developed ANN-based models for predicting highway construction time and costs in Croatia, achieving significant improvements in estimation accuracy and practical applicability. Similarly, Tijanić et al. (2019) demonstrates that an artificial neural network, specifically GRNN, can significantly improve the accuracy of cost estimates for road construction projects, particularly during the initial design phase, with results surpassing MLP, RBFNN, and linear regression models. El-Sawah and Moselhi (2014) evaluated different neural network types for cost estimation, reporting MAPEs between 16.83% and 19.35%, which were more accurate than regression models. These studies highlight the effectiveness of neural networks in enhancing prediction accuracy across various aspects of construction projects.

Given the promising results of artificial neural networks in predicting construction project performance (Marović et al., 2018, Knezevic et al., 2018, Marović, 2020, Juszczyk, 2020, Juszczyk et al., 2023), this study aims to develop models for predicting time and cost overruns, with a focus on critical performance areas essential for project success. The process of designing and selecting the optimal neural network architecture for predicting these overruns has been established. The goal is to conduct a series of experiments to determine the most effective neural network architectures by analyzing the performance metrics of the developed models. The accuracy of these predictive models will be evaluated using a dataset from completed construction projects. The hypotheses being tested in this research include:

1. Artificial neural networks can provide high accuracy in predicting time and cost overruns in construction projects by analyzing critical performance areas.

2. Evaluating various performance metrics will lead to the identification of the most effective neural network architectures for predicting construction project overruns.

2. Research Methodology

2.1 Model

RapidMiner Studio 10.2.000 was chosen to create the model. Although there are many advanced software tools available for similar purposes, such as Keras, TensorFlow, Weka, and Chainer, the user-friendly visual interface of RapidMiner Studio makes it accessible even to those with limited programming experience. It allows quick testing and modification of models without writing code, using graphical representations. Additionally, it offers extensive documentation and examples that aid in learning and troubleshooting. These resources have proven to be extremely helpful during this research.

The process of creating and selecting the most optimal neural network architecture in predicting overruns is shown in Figure 1. It begins with assigning values to the input data shown in Table 1. Since the goal of this research is to create two models, one that will predict cost overrun and the other that will predict time overrun, slightly different input data were used. The previously defined performance areas and evaluation approaches (Galjanić and Marović, 2024) were refined and corrected in order to make the input data of better quality (Table 1). Based on the collected data, the input parameters for this predictive model were selected. For each of the five projects, three specific points during the project timeline were identified and analyzed in detail, corresponding to approximately one-third intervals of the total project duration on the construction site.

Table 1. Attributes - list of applied and evaluated input data

	Input data
1	Planned payment amount
2	Realized amount charged
3	Off-budget work cost
4	Project documentation quality
5	Project change management
6	Dynamic plan analysis
7	Adherence to activity deadlines
8	Cost ratio
9	Trend of changes and additional works
10	Hazard identification
11	Incident and accident frequency
12	Workforce
13	Employee turnover
14	Conflict management
15	Client satisfaction with communication (with the contractor)

16	Client satisfaction with contractor expertise and work quality
17	Client satisfaction with costs
18	Client satisfaction with work progress
19-1	Time overrun
19-2	Cost overrun

Criteria 1-18 are common in both models. To create the cost overrun prediction model, it needs to be provided with data about cost overruns from past projects. Similarly, to develop the time overrun prediction model, the model must be supplied with information regarding time overruns from previous projects. It was crucial to limit this attribute because if the model proves to be useful and is utilized in the initial phase of the work, all necessary data must be enterable into the process.

At the beginning of the RapidMiner process, the input data has to be evaluated and imported. It is essential to determine the attributes to be used for further prediction. In this research, it was decided to utilize all the collected data shown as attributes 1-18 and attribute 19 depending on model. Only regular and label roles were assigned to the attributes. Regular attributes do not have a special role and are used as input variables for learning tasks. The label role, on the other hand, is a special role that serves as the target attribute for learning operators and is often referred to as the "target variable." Two separate models were developed for predicting outcomes, with minor differences starting from this point. In one model, the label was defined as time overrun, while in the other model, the label was defined as cost overrun.

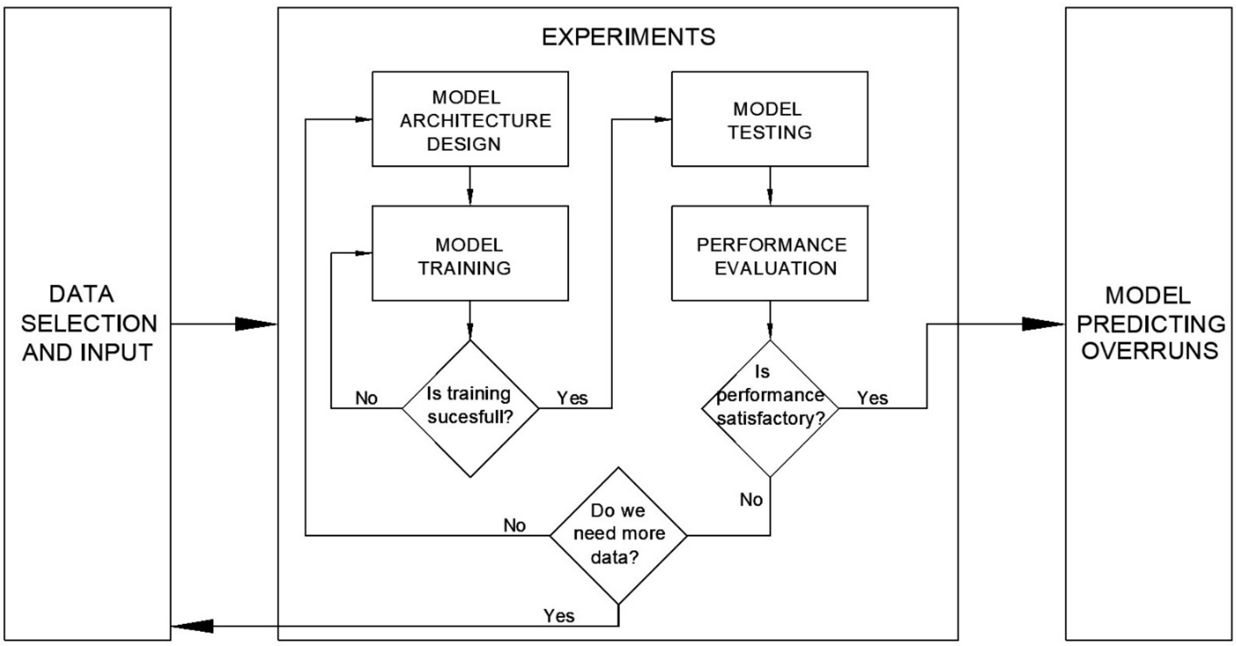

Figure 1. The process of creating and selecting the most optimal NN architecture in predicting overruns

The input data set was divided into two parts: 70% for model training and the remaining 30% for model testing. After the training, the model was applied to the test dataset to generate predictions and verify its performance. This approach helps evaluate model performance by ensuring that the model is tested on unseen data. In this example of predicting time and cost overruns, a neural network was applied that learns a model by means of a feed-forward neural network trained by a backpropagation algorithm (multi-layer perceptron).

Experiments were conducted to select the optimal prediction model architecture. In general, the effectiveness of a neural network model is influenced by the balance between the number of input facts and the complexity of the network's architecture, specifically the number of hidden layers and nodes. An excessive number of hidden layers or nodes can lead to a phenomenon known as overfitting (ElSawy et al., 2011). The implications of these experiments are discussed further in the chapter Results and discussion.

After several iterations of adjusting the number of training cycles, it was ultimately decided to adhere to the default program setting of 200 training cycles for training the neural network. In backpropagation, the output values are compared with the correct answer to calculate the value of some predefined error function. The error is then returned over the network. Using this information, the algorithm adjusts the weights of each link to reduce the value of the error function by some small amount. The learning rate specifies the size of the weight updates in each iteration. The most commonly used learning rate values are between 0.0 and 0.2. For the purposes of this model, a value of 0.01 was determined. Momentum adjusts the current weight update by adding a fraction of the previous update, which helps in overcoming local maxima and smoothest optimization directions.

2.2 Evaluating Model

In model evaluation, understanding the learning process and adjustment mechanisms of a model is crucial. The backpropagation algorithm is a supervised learning method used for optimizing weights in artificial neural networks. This algorithm consists of two main phases: propagation and weight update. During the propagation phase, the network's output is compared to the expected results to compute the error using a specified error function. This error is then propagated backward through the network, with incremental adjustments made to the weights of connections to minimize the error. This process is repeated over numerous training iterations until the network's performance reaches an acceptable level. A Multilayer Perceptron (MLP) is a type of feed-forward artificial neural network designed to map input data to appropriate output values. The network structure includes several layers of nodes organized in a directed graph, where each layer is fully connected to the subsequent one. Except for the input layer, each node in the network functions as a neuron and employs a nonlinear activation function, such as the sigmoid function. MLPs utilize backpropagation as their learning mechanism, adjusting weights across the network's multiple layers to enhance prediction accuracy. For evaluating the performance of an MLP, it is essential to use relevant metrics. By analyzing errors, one can determine how well the model generalizes to new data and identify potential areas for improvement. (Rapid Miner, 2024)

The performance of each model was evaluated using Mean Absolute Percentage Error, Root Mean Squared Error and Correlation values (table 2).

Table 2. Measures to evaluate model

Performance measure	Formula	Explanation
Mean Absolute Percentage Error		P_i is value predicted by ANN based on i record of input data; P_{i0} is original (real) value of P_i; n is number of elements of a given data type (i vary from 1 to n)
Root Mean Squared Error		
Pearson's Correlation Coefficient		X_i and Y_i are the individual sample points; - and X- ar the means of the X and Y samples, respectively

Mean Absolute Percentage Error (MAPE) is a measure that indicates the average deviation of model predictions from the actual values, relative to the magnitude of the measured item. Expressed as a percentage, it provides insight into the accuracy of experimental measurements by illustrating how close the predicted values are to the true values. A smaller percentage signifies higher accuracy and better model performance. Interpretation of MAPE values is shown in table 3.

Table 3. Interpretation of MAPE values (Anggrainingsih et al., 2015)

MAPE Value	Prediction Accuracy
MAPE ≤ 10%	High
10% < MAPE < 20%	Good
20% < MAPE ≤ 50%	Reasonable
MAPE > 50%	Low

The Root Mean Squared Error (RMSE) quantifies the average deviation between the predicted values and the actual values, providing an estimate of the model's predictive accuracy. It indicates how well the model is able to predict the target value. RMSE values range from zero to infinity. A lower RMSE signifies smaller differences between the predicted and observed values, reflecting better model performance (Hodson, 2022).

Correlation represents the relationship between predicted and observed values. The Pearson correlation coefficient was used, which measures the strength and direction of the linear relationship between two variables. A higher correlation value (close to 1) indicates a stronger relationship, meaning that the value of one variable can be predicted with greater certainty based on the value of another variable. A lower correlation value (close to 0) signifies a weak connection and low predictability. Interpretation of correlation values is shown in table 4.

Table 4. Interpretation of correlation values (Selvanathan et al., 2020)

Correlation Value	Prediction Accuracy
$0 < r < 0.2$	Very low
$0.2 \leq r < 0.4$	Low
$0.4 \leq r < 0.6$	Moderate
$0.6 \leq r < 0.8$	High
$0.8 \leq r \leq 1.0$	Very high

3. Results and discussion

3.1 Cost overrun prediction model

Ninety-one experiments were conducted to determine the optimal model for predicting cost overruns. Various configurations with different numbers of hidden layers and nodes were tested. The initial setup began with a single hidden layer featuring 18 nodes, progressively reducing the number of nodes by one in each subsequent experiment until only five nodes remained. Additionally, experiments included configurations with two hidden layers, exploring different combinations of nodes across these layers.

After analyzing the results from all 91 experiments, it was observed that the RMSE values are relatively low, suggesting that the models are generally accurate in their predictions. However, the MAPE values across all experiments were found to be extremely high, with some experiments reaching up to 523% indicating extremely low prediction accuracy. Table 5 highlights 10 experiments where the MAPE values are below 180%.

Table 5. Experiments for determining the optimal architecture for the cost overrun prediction model

Number of hidden nodes in		MAPE	RMSE	Correlation	R^2
hidden layer 1	hidden layer 2	(%)			
16	5	172.43	0.441	0.929	0.863
15	5	179.90	0.393	0.938	0.880
11	10	166.76	0.417	0.936	0.876
11	9	163.59	0.437	0.939	0.882
8	6	179.81	0.440	0.941	0.885
7	5	169.17	0.400	0.955	0.912
6	2	177.45	0.441	0.969	0.939
5	4	173.44	0.443	0.971	0.943
4	3	171.83	0.439	0.936	0.876
4	2	172.99	0.442	0.919	0.845

The RMSE values, ranging from 0.393 to 0.443 for the 10 most successful experiments, are acceptable but fell short of expectations. Although the correlation values are reasonably good, MAPE values are too high, indicating that the models are not suitable for practical application. According to Table 3, the calculated values mean low prediction accuracy. Nevertheless, the three most optimal solutions were selected for further detailed analysis and commentary (Table 6). These models are characterized by having two hidden layers. Based on the RMSE values, the optimal model appears to be the first model, which consists of 15 nodes in the first hidden layer and 5 nodes in the second hidden layer. According to the MAPE values, the third model, which utilizes 11 nodes in the first hidden layer and 9 nodes in the second hidden layer, demonstrates the best performance among the models tested. However, despite this model achieving the best MAPE value in the set of experiments, this value remains exceptionally high. MAPE value of 163.59% signifies that, on average, the model's predictions deviate from the actual values by 163.59%. This exceptionally high MAPE indicates significant inaccuracies in the model's predictions, suggesting that the model's overall predictive performance is poor, pointing to model instability and substantial variability in its predictions. This variability suggests that the model is inconsistent and that its predictions lack reliability. On the other hand, the correlation metric provides favorable results across all models, with the most optimal correlation observed in the model featuring 11 nodes in the first hidden layer and 10 nodes in the second hidden layer.

Table 6. The best model architectures for cost overrun prediction

Number of hidden nodes in		MAPE	RMSE	Correlation	R^2
hidden layer 1	hidden layer 2	(%)			
15	5	179.90	0.393	0.938	0.880
11	10	166.76	0.417	0.936	0.876
11	9	163.59	0.437	0.939	0.882

Considering all the presented parameters, the model with 11 nodes in the first hidden layer and 10 nodes in the second hidden layer was selected as the most optimal architecture for the cost overrun prediction model at this stage of the research. Although the RMSE and correlation values suggest that the model could be capable of accurate predictions, the high MAPE indicate that significant adjustments to the model are necessary. Presented values might indicate that the dataset used for training was too small, potentially failing to capture sufficient variability.

3.2 Time overrun prediction model

Parallel experiments were conducted to identify the best model for predicting time overruns, following the same procedure for hidden layers and node combinations. Table 7 presents the ten models that demonstrated the best prediction performance.

Table 7. Experiments for determining the optimal architecture for the time overrun prediction model

Number of hidden nodes in		MAPE	RMSE	Correlation	R^2
hidden layer 1	hidden layer 2	(%)			
14	8	81.35	0.068	0.985	0.970
13	5	81.88	0.206	0.981	0.962
12	8	65.97	0.119	0.968	0.937
12	7	76.73	0.093	0.978	0.956
10	8	68.81	0.106	0.975	0.951
9	7	29.29	0.121	0.973	0.947
7	5	45.25	0.173	0.986	0.972
6	4	55.34	0.169	0.982	0.964
6	3	17.90	0.121	0.983	0.966
5	3	10.93	0.128	0.979	0.958

The experimental results showed Root Mean Squared Error values ranging from 0.068 to 0.394, indicating strong performance. The correlation coefficients were excellent, ranging from 0.968 to 1.000. However, the Mean Absolute Percentage Error was notably high in many cases, reaching a maximum of 320.05%. Although some of the top 10 optimal architectures for the time overrun prediction model included variants with a larger number of hidden nodes, it was found that models with fewer hidden nodes per layer provided much better predictive performance. Table 8 presents the results of the three experiments with the highest potential for correct predicting time overruns.

Table 8. The best model architectures for time overrun prediction

Number of hidden nodes in		MAPE	RMSE	Correlation	R^2
hidden layer 1	hidden layer 2	(%)			
9	7	29.29	0.121	0.973	0.947
6	3	17.90	0.121	0.983	0.966
5	3	10.93	0.128	0.979	0.958

Based on the results of the experiments, there is strong potential for accurately predicting time overruns. Two models exhibit an RMSE value of 0.121, one with 9 nodes in the first hidden layer and 7 nodes in the second hidden layer, and another with 6 nodes in the first hidden layer and 3 nodes in the second hidden layer. The latter model also exhibited the highest correlation value. Despite this, the model featuring 5 nodes in the first hidden layer and 3 nodes in the second hidden layer was selected as the most optimal architecture. This choice was made based on the fact that, despite having a slightly higher RMSE of 0.128, it achieved a significantly lower MAPE of just

10.93%.

3.3 Discussion

The time overrun prediction model demonstrates a significantly superior performance compared to the cost overrun prediction model when applied to the same set of input data. Based on the optimal neural network architecture selected and the MAPE values presented in Table 3, it is evident that the model achieves a MAPE of 10.93%, which is classified as good and approaches the boundary of high accuracy (MAPE ≤ 10%). Furthermore, the prediction accuracy for correlations, with a value of 0.979, is rated as very high, indicating exceptional performance. These results strongly support the efficacy of the approach taken and suggest that further refinements could substantially enhance the model's performance. Jha and Chockalingam (2011) developed a neural network model to predict schedule performance in Indian construction projects, achieving a mean absolute percentage deviation of 11%. Petruseva et al. (2012) created a model for predicting time overruns based on variables such as structure type, construction year, contracted and realized construction time, contracted and realized construction cost, and reasons for deadline non-compliance. Their study achieved impressive accuracy with metrics: R^2 = 0.970 and MAPE = 2.50%. Alsugair et al. (2023) developed an artificial neural network model to predict the final construction contract duration using contract cost, contract duration, final construction contract duration, contract sector and contract type. Their research obtained a MAPE of 12.22%, surpassing linear regression models. However, aside from the MAPE metric, no additional evaluation criteria were employed to substantiate the quality of the predictions.

In contrast, the cost overrun prediction model exhibits significantly higher MAPE (166.76%) and RMSE (0.417) values with correlation of 0.936, and R^2 of 0.876. For example, Tijanić et al. (2019) developed a model for rapid and efficient analysis of expected road construction costs, achieving a MAPE of 13.06% and an R^2 of 0.9595. The input data included the scope and type of road project, length and width of the road, contracted construction duration, and both contracted and actual construction costs. Car-Pušić et al. (2020a) obtained a MAPE of 0.73%, with a coefficient of determination R^2 of 0.995 and a correlation coefficient of 0.99, using a hybrid model combining Bromilow's process-based model and a data-driven GRNN network. Estimated and real construction costs, construction time (predicted and actual), year of construction, structure type (purpose), construction site region, and technical characteristics of the structure were incorporated into their model. Car-Pušić et al. (2020b) achieved a MAPE of 0.522% and an R^2 of 0.994 in predicting cost overruns using a model based on natural logarithms and Bromilow's time-cost model. Their input data related to the type of intervention, year of construction, and both contractually agreed and realized construction costs. This research aims to expand the scope by examining how various key performance areas for project success (such as productivity, quality, cost, time, safety, team satisfaction, and investor satisfaction) affect cost overruns. The current accuracy level is deemed satisfactory for this stage of development, providing a foundation for future research and guiding subsequent investigations. The potential difficulty is dataset size and number of attributes. Researchers with larger datasets (Alsugair et al., 2023; ElSawy et al., 2011; Hammad et al., 2008; Jha and Chockalingam, 2009; Tijanić et al., 2020) achieve better prediction values, highlighting the importance of data volume and quality. To enhance overrun prediction models, it is crucial, as outlined in Figure 1, to revisit the initial stages of model development, expand the dataset, and re-evaluate preprocessing impact on MAPE, RMSE, and correlation results. While maximum linear standardization has yielded low MAPE values, it is critical to fine-tune standardization methods to address the specific challenges faced by the neural network (Anysz et al., 2016). Additionally, reducing the number of attributes in input data has been shown to improve model accuracy by eliminating redundant or irrelevant information (Sen et al., 2004; Fu and Wang, 2003). However, such reductions should be considered after achieving initially satisfactory results to optimize the network further.

In summary, although the current progress in developing cost and time overrun prediction models is promising, the models do not yet achieve the desired predictive accuracy. Since MAPE values are crucial for assessing model accuracy, the high MAPE value (e.g. 163.59% in the case of cost overrun prediction) clearly indicates significant deviations and a lack of reliability in practical applications. Therefore, significant improvements are required to enhance their practical applicability through the expansion of the dataset and improvement of standardization methods to ensure greater stability and accuracy in predictions. The identified optimal models provide a foundation for future research aimed at advancing the accuracy and utility of cost and time predictions in construction projects. It is anticipated that continued research efforts will yield substantially better results.

4. Conclusion

This research contributes to the understanding of predicting cost and time overruns in construction projects by presenting a comprehensive overview of artificial neural network model generation and the selection of optimal architectures. By employing advanced techniques and performance evaluation this study offers new insights that could enhance prediction accuracy in practical applications.

The research confirms that various metrics are crucial for identifying the most effective neural network architectures. Utilizing data from previous research and refining input quality, two models were created to predict these overruns. A total of 182 experiments were conducted to evaluate various neural network architectures. This process identified the most effective neural network architectures for predicting construction project overruns based on a range of performance metrics. However, achieving high accuracy in predicting both time and cost overruns remains challenging, indicating areas for further refinement.

For predicting time overruns, the optimal model was characterized by two hidden layers, with 5 nodes in the first layer and 3 nodes in the second layer. This architecture demonstrated exemplary performance, achieving an RMSE of 0.128, a MAPE of 10.93%, correlation of 0.979 and R^2 value of 0.958. These metrics indicate good accuracy and reliability.

In contrast, the model for predicting cost overruns, featuring two hidden layers with 11 nodes in the first layer and 10 nodes in the second layer, showed less satisfactory results. Despite a reasonable correlation of 0.936, R^2 value of 0.876 and an acceptable RMSE of 0.417, the high MAPE of 166.76% revealed significant challenges in accuracy and stability. This disparity between the low RMSE and high MAPE suggests potential issues with dataset balance and highlights the need for further model refinement. The model's performance underscores the necessity of improving input data quality and refining model parameters to achieve more reliable predictions.

Given the comparisons with other models in the literature, it is evident that while the developed models show promise, further adjustments and optimizations are required. The current model, based on a dataset of five projects, has offered valuable insights into its performance. However, its scalability to larger datasets and diverse project types remains uncertain. Future research should focus on expanding the dataset and optimizing the model parameters to improve prediction accuracy. Potential challenges may arise from greater variability in input data, necessitating further refinement of the model's architecture and more advanced data preprocessing techniques to ensure consistent prediction accuracy. Furthermore, the model can be fine-tuned by adjusting input data attributes to examine how reducing the number of attributes impacts the model's predictive performance. These advancements have important implications for the construction industry, where accurate predictions of time and cost overruns are crucial for effective project planning and management. Improved prediction tools will enable project managers to enhance planning and control, thereby mitigating the risks associated with budget and schedule overruns and ultimately contributing to more successful project outcomes.

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Organizational-Technological Solution for Assessing the Time Cycle of Excavators and Tipper trucks

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Abstract:

Earthworks are an integral part of most construction projects. They are characterized by working in uncertain, changing, and dynamic conditions with the use of extremely high-cost construction machines. Earthworks include excavation and the removal of large quantities of soil. An excavator is a necessary machine on the construction site due to its versatility and efficiency. One of the excavator's prominent operations is the excavation and loading of material into the tipper truck. The productivity of machines has a significant role in the progress and success of earthworks. By knowing the machine's productivity, the expected duration to complete the activity can be obtained. High productivity leads to a lower unit cost for performing activities. Tracking and monitoring of productivity enables assessment of performance success, timely detection of performance improvement possibilities, and the application of corrective measures. A significant aspect of the machine's productivity is its time cycle of work operation. Manual collection of data from the construction site to evaluate the time cycle of the machine's work operations is today considered an outdated, time-consuming, and subjective method. Therefore, manual data collection is being replaced by audio-visual and sensing technology devices. This paper will present the organizational-technological solution for the application of a video camera (audio-visual device) and GPS technology/receiver (location-sensing device) for assessing the time cycle of excavator and tipper truck work operations. The application of different technology devices (i.e., video camera and GPS receiver) enables optimal recording of excavator and tipper truck activity performance.

Keywords: *earthworks; excavator; tipper truck; video camera; GPS receiver*

1. Introduction

Construction projects usually include earthworks (Lin *et al.*, 2012). Earthworks often take place in uncertain conditions and circumstances (Zhang, 2008), can be very significant for the project (Liu *et al.*, 2019), and are characterized by intensive use of construction machinery (Christian and Xie, 1996). The most common construction machine used for earthworks is an excavator, and its main function is to excavate and load materials into a tipper truck or (articulated) dumper (Kim J. and Chi, 2019). During earthworks, in most cases, there are consecutive, repetitive laps of tipper trucks between the construction site (loading place) and the unloading place (Mustaffa, 2020). Excavators and tipper trucks are mostly used for earthworks (Kim, J. et al., 2017).

Productivity refers to a satisfactory, usefully performed amount of work within a specific time (Nichols and Day, 2005). By knowing the productivity of the resource, the expected duration for completing the activity can be obtained concerning a given amount of labor or material (Dagostino and Peterson, 2011).

Tracking and monitoring of the productivity of construction machinery include various measurements and analysis and plays a significant role in the successful management and successful completion of earthworks (Kim J. and Chi, 2020), as well as in avoiding unwanted events that can negatively affect one or more goals of the project (Salem and Moselhi, 2018).

However, construction projects have uncertain resource productivity (Sears *et al.*, 2008). The unique characteristics and environment of each project, as well as the activities and measures taken, cause different productivity of the same resources among projects (Park, 2006). Improving productivity is an eternal pursuit in construction, but productivity must first be measured (Nasir *et al.*, 2012).

Assessing the productivity of construction machinery is very challenging (Ok and Sinha, 2006). Productivity assessment manuals provide average values, data collection from the construction site is demanding, and various unexpected situations and problems can occur on the construction site (Han *et al.*, 2011). Numerous cases have shown that productivity estimates based on using productivity estimation manuals and empirical data from past projects lag far behind the actual situation on the construction site (Smith *et al.*, 2000).

The manual collection of data from the construction site to track and monitor the productivity of construction machinery is time-consuming, insufficiently accurate, can delay the timely application of appropriate corrective measures, and make it challenging to analyze the causes of unwanted deviations about planned and actual productivity (Navon and Shpatnitsky, 2005). Researchers have recently been using methods and tools of sensing or audio-visual technologies to collect data from construction sites. One of the representatives of location-sensing technology is the Global Positioning System (GPS), while one of the representatives of audio-visual technology is the video camera.

GPS technology is a valuable tool for earthworks (Morely *et al.*, 2014) and a cost-effective solution for automated data collection (Lu *et al.*, 2007). However, since the data is primarily limited to time and location, GPS technology, as an independent tool, cannot meet all the requirements for solving research problems (Salem and Moselhi, 2021).

Video recording devices, such as video cameras, are widely used on the construction site for property protection, human safety, better insight into work performance, productivity analysis and improvement, inspection of the facility, and progress monitoring (Chi and Caldas, 2011; Kim H. *et al*., 2019; Kim J. *et al.*, 2019). Further research into audio-visual technologies should be directed towards tracking and monitoring productivity and applying audio-visual technologies together with sensing technologies (Kim J. and Chi, 2019; Kim J. and Chi, 2020).

This paper aims to propose a modern organizational-technological solution for collecting and processing data on the operation of excavators and tipper trucks during earthworks. The application of the proposed solution enables the parallel creation of data on the operation of excavators and tipper trucks. These machines depend on each other and are important for the progress of earthworks. Data collection is carried out using a video camera and a GPS receiver. With the application of different technology devices (i.e., video camera and GPS receiver), the shortcomings of the technologies are compensated, and an optimal recording of the machines' activity performance is enabled. The proposed solution should (especially) be used by contractors for efficient organization of machine work on construction sites with a large volume of earthworks.

2. Literature review

2.1. Application of location-sensing technology

Montaser and Moselhi (2014) proposed a Truck+ system that uses GPS technology and the Geographic Information System (GIS). They pointed out that the system is practical and simple. It estimates the duration of the tipper truck cycle time and stochastic prediction of the tipper truck's actual productivity in earthworks within near real-time. Ibrahim and Moselhi (2016) presented a method that uses GPS technology, sensors, and a microcontroller to estimate tipper truck actual productivity in near real-time. More precisely, GPS technology is used to track tipper trucks, while sensors and a microcontroller are used to monitor loading and unloading activities. Alshibani and Moselhi (2016) proposed a system that uses GPS technology and a GIS system and consists of five modules and four algorithms. They highlighted that the system estimates the duration of the tipper truck cycle time and stochastic prediction of the tipper truck's actual productivity, as well as the prediction of the necessary cost and time when performing earthworks (under the tipper truck influence) in near real-time. Salem and Moselhi (2018, 2021) presented a model that consists of four modules and uses GPS technology, sensors, and a microcontroller. They emphasized that the model serves to assess the actual productivity of tipper trucks and to analyze driver habits and road conditions for the timely detection of unwanted outcomes.

2.2. Application of audio-visual technology

Bügler *et al.* (2017) proposed a methodology for monitoring progress and assessing earthworks productivity using photogrammetry and video analysis. Roberts and Golparvar-Fard (2019) presented a system based on audio-visual technologies for detecting, tracking, and analyzing construction machinery work activities (with an emphasis on excavators and tipper trucks). Kim J. and Chi (2019) proposed an applicable vision-based framework for recognizing excavator work activities (considering the sequential working patterns of excavators) and for automating cycle time analysis and productivity monitoring of excavators. Chen *et al.* (2020) presented a research framework for automatically recognizing work activities and analyzing the productivity of many excavators on a construction site. Kim J. and Chi (2020) proposed a methodology for monitoring earthworks productivity using multiple (non-overlapping) cameras on a construction site. Chen *et al.* (2021) presented a computer vision (CV) method to control excavators' and tipper trucks' work efficiency and productivity and to identify the causes of idling. Šopić *et al.* (2021) proposed a simple research framework that uses a video camera and video analysis to estimate excavators' cycle time and actual productivity. Cheng *et al*. (2023) presented a vision-based framework that uses deep learning and average cycle time calculation to recognize excavator work activities and estimate productivity. Chen *et al.* (2023) proposed a vision-based method for activity recognition of excavators and loaders by adopting zero-shot learning (without pre-training or fine-tuning) and productivity estimates.

3. Organizational-technological solution

The organizational-technological solution for collecting data on the operation of excavators and tipper trucks includes applying a video camera (or smartphone) and a GPS receiver. With a video camera, the excavator's work during the excavation and loading of material into the tipper truck is recorded, while with GPS technology, the tipper truck's laps from the construction site to the unloading place (with return) are tracked.

The time cycle of a tipper truck usually consists of the time required for loading materials, driving a full tipper truck to the unloading place, (self)unloading, driving an empty tipper truck to the construction site, and total time for positioning (Linarić, 2007). In the organizational-technological solution, one video of material loading into the tipper truck (t_L) and one tipper truck lap from the construction site to the unloading place with return, tracked with GPS technology (t_{GPS}), form one time cycle (t_c^{TT}).

An excavator's time cycle takes significantly less than a tipper truck's time cycle. The excavator time cycle usually lasts up to one minute (Linarić, 2007). It consists of the time required for excavation, swinging a full bucket, loading it into a tipper truck (or dumping), and swinging an empty bucket. In the organizational-technological solution, the time cycle of the excavator (t_c^B) can be obtained by analyzing the videos that show the operation of the excavator. Video analysis involves inputting appropriate labels to break down the excavator's work into its work operations.

By applying the organizational-technological solution, it is possible to express the time cycles of excavators and tipper trucks precisely. Measurement of the time cycle of machines (with cyclical work) is essential for tracking and monitoring their actual productivity (Lee *et al.*, 2018; Wu *et al.*, 2021). The organizational-technological solution serves as a basis for assessing the actual productivity of excavators and tipper trucks (Šopić *et al.*, 2023) and calculating these machines' cost-effectiveness (Šopić et al., 2024).

3.1. Organizational-technological solution devices (video camera and GPS receiver)

The video camera and GPS technology include recording the excavator's operation and tracking the tipper trucks' driving. Using a video camera (or smartphone) and GPS technology does not disrupt the normal workflow of excavators and tipper trucks and does not cause delays in the progress of excavation, loading, and removal of materials.

When collecting data, a video camera compensates for the shortcomings of GPS technology and vice versa. More precisely, it is not practical to use GPS technology to track the operation of an excavator on a construction site, and a video camera is not a suitable device for monitoring the driving of a dump truck from the construction site to the landfill.

The advantage of using a video camera (or smartphone) is the visual reproduction of real situations on the construction site, which leads to less possibility of misinterpretation of the collected data. However, it is necessary to find the optimal position for the video camera or to move it according to the progress of the work.

GPS technology is an advanced satellite radio navigation system for locating and tracking the movement of individuals or objects. GPS receivers with weaker characteristics, satellite maintenance, maps with missing content, weather conditions, terrain configuration, and tall buildings can reduce the accuracy of locating and tracking. However, GPS technology has a wide and indispensable application for collecting data about location, movement, distance, speed, travel time, etc.

Data on the operation of excavators and tipper trucks must be collected in good or excellent working conditions and utilization of working hours.

Given that the length and resolution of the video can create difficulties during video analysis, it is recommended to record short videos that will cover the loading of materials into the tipper truck from the beginning until the tipper truck is fully loaded. The usual duration of loading is from 5 to

15 minutes.

At the end of loading and immediately before starting the drive to the unloading place, it is necessary to turn on the GPS receiver (which can store data). When returning the tipper truck to the loading place, turning off the GPS receiver is necessary. GPS technology will, therefore, track the tipper truck's drive from the construction site to the unloading place, self-unloading, and driving back to the construction site (loading place).

3.2.Organizational-technological solution software (MATLAB, Qstarz QRacing, Google Earth)

Video processing of the proposed organizational-technological solution can be done using MATLAB software. MATLAB is an abbreviation of the English name MATrix LABoratory, and at the same time, it is a program package intended for numerical calculations, as well as a higher-level programming language intended for various scientific and technical applications (Kovačić, 2013). Video processing in MATLAB involves inputting labels for excavator work operations. Labels can be named "excavation", "swingBucketFull", "loadingTipperTruck", and "swingBucketEmpty" to match the excavator work operations. After entering labels, extracting a list and visual display of labels (i.e., timestamps) entered along the video is possible. The list of labels provides a detailed insight into the time course of the excavator's work operations and serves as a basis for calculating the excavator's cycle time duration. The visual display of the entered labels gives a quick overview of the uniformity of the cycle time duration. Any non-uniformity means that there was a work stoppage.

Data from the GPS receiver on tracking tipper trucks must be downloaded and processed using program support (software), obtained with the purchase of GPS technology (receiver). A suggestion for tipper truck tracking data processing software is Qstarz QRacing. In addition to the GPS technology software, the free Google Earth software can also be used. Data processing using GPS technology software and Google Earth software enables an overview of the course of the tipper truck driving from the construction site to the unloading place, (self) unloading, and return to the construction site in terms of driving time, distance, and speed, as well as a virtual 3D view of driving on the Earth's surface.

Figure 1 shows the presentation of components and activities of the organizational-technological solution. Videos of loading are used to express the duration of loading (required to calculate the duration of the tipper truck time cycle) and to perform video analysis to assess the excavator time cycle. Tipper truck tracking records from the construction site to the unloading place, with returns, provide the remaining data needed to calculate the duration of the tipper truck time cycle. At the same time, appropriate (software) programs are required to apply the organizational-technological solution.

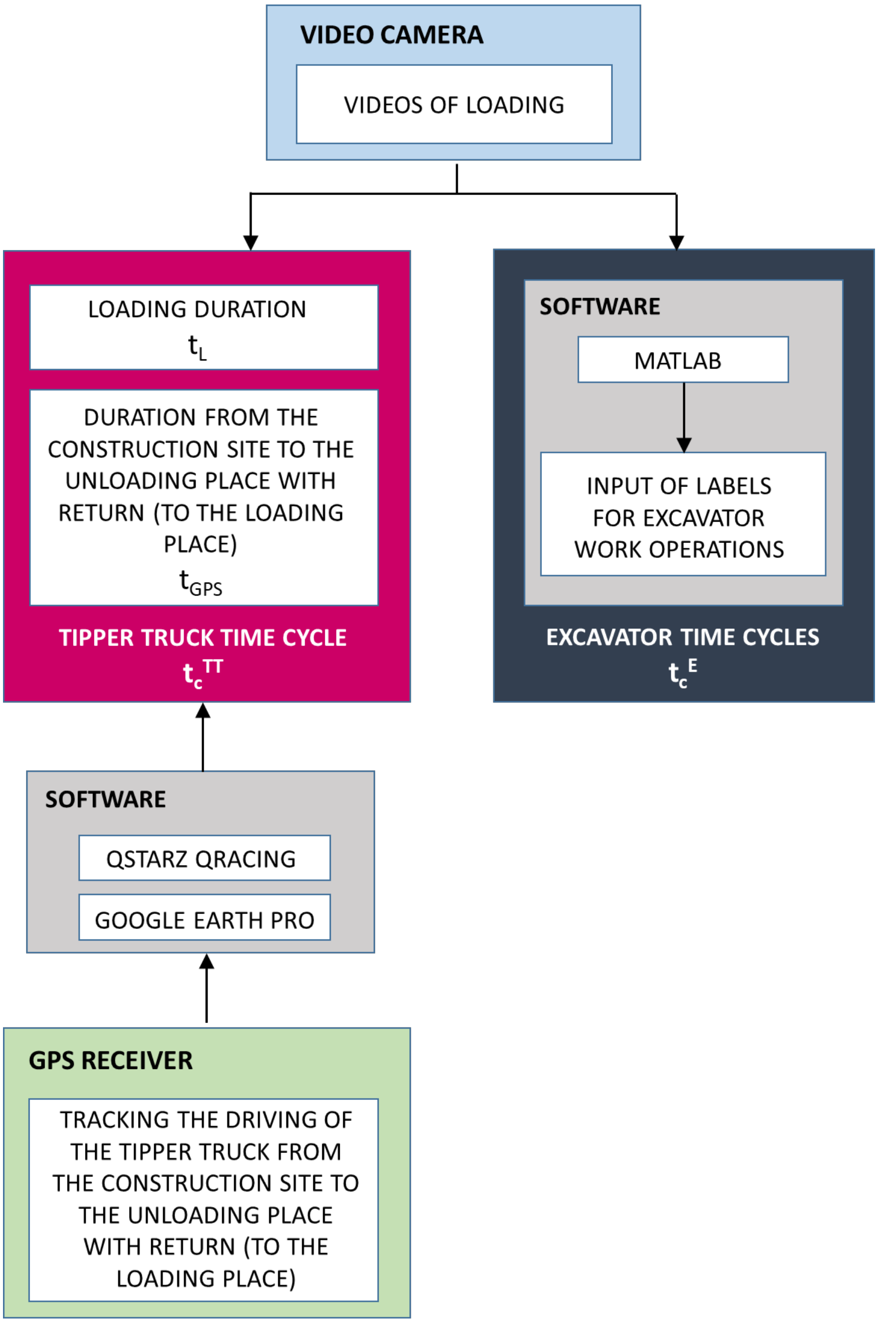

Figure 1. Components and activities of the organizational-technological solution (image created by the first author)

4. Application of the organizational-technological solution on the construction site

The organizational-technological solution was applied at the construction site in Matulji (Croatia). Data collection and processing took place in November 2020. The operation of the new Komatsu crawler excavator, model PC55MR, was recorded. Driving tracking was carried out on a Mercedes-Benz tipper truck with four axles, model 1828 4x4, with a maximum permissible weight of 18,000 kg (18 t) and a box volume of 6 LCM. The material from the excavation was taken away locally. It was used to fill the material at another construction site. The road distance between the construction site and the unloading place was about 6.4 km in both directions.

4.1.Application of the organizational-technological solution devices

A Samsung Galaxy S10 smartphone was used to record the loading, and a Qstarz BL-1000GT Standard GPS receiver was used to track the ride and store the data. During the recording of the material loading, a complete view of the excavator and tipper truck was included in the smartphone frame. Using GPS technology (i.e., a GPS receiver with the ability to store data), the tipper truck was tracked during its drive from the construction site to the unloading place, self-unloading, and driving back to the construction site.

Figure 2 shows the machine work at the construction site in Matulji (Croatia) during earthworks. Recording of the excavator and tracking of the tipper truck took place on days with favorable weather conditions. The machinist and driver had previous experience in operating an excavator, i.e., driving a tipper truck. During the recording and tracking of the tipper truck, no unjustified or long stoppages in the excavator's operation and the tipper truck's driving were observed.

Figure 2. View of the used machines at the construction site in Matulji (Croatia) during earthworks (private album of the first author)

4.2. Application of the organizational-technological software's

Data were processed on a desktop computer HP ProDesk 400 G7 MT, computer code 11M73EA, with an Intel Core i5-10500 processor, 16 GB of working memory (RAM), 512 GB of hard disk (SSD), and in the Windows 10 operating system. Video analysis was performed in MATLAB software version 9.4 (R2018a). GPS tracking data was processed in Qstarz QRacing software version 3.99.810 and in the free Google Earth Pro software version 7.3.6.9345.

Figure 3 gives examples of inserted labels for excavator work operations in MATLAB. Figure 4 provides a visual display of excavator work operations based on label input. In Figure 4, it can be seen that 27-time cycles of the excavator were necessary to fill the tipper truck. In addition to the visual display of excavator work operation from the MATLAB software, it is possible to download a detailed list of labels (timestamps) entered along the video. A detailed list of labels is an indispensable base for calculating the time cycle of the excavator. Figure 5 provides an example of one tipper truck lap in Google Earth software with the data from the Qstarz BL-1000GT Standard GPS receiver and QStarz QRacing software.

Figure 3. Examples of inserted labels for excavator working operation (image created by the first author)

Figure 4. Visual display of excavator work operations based on label input (image created by the first author)

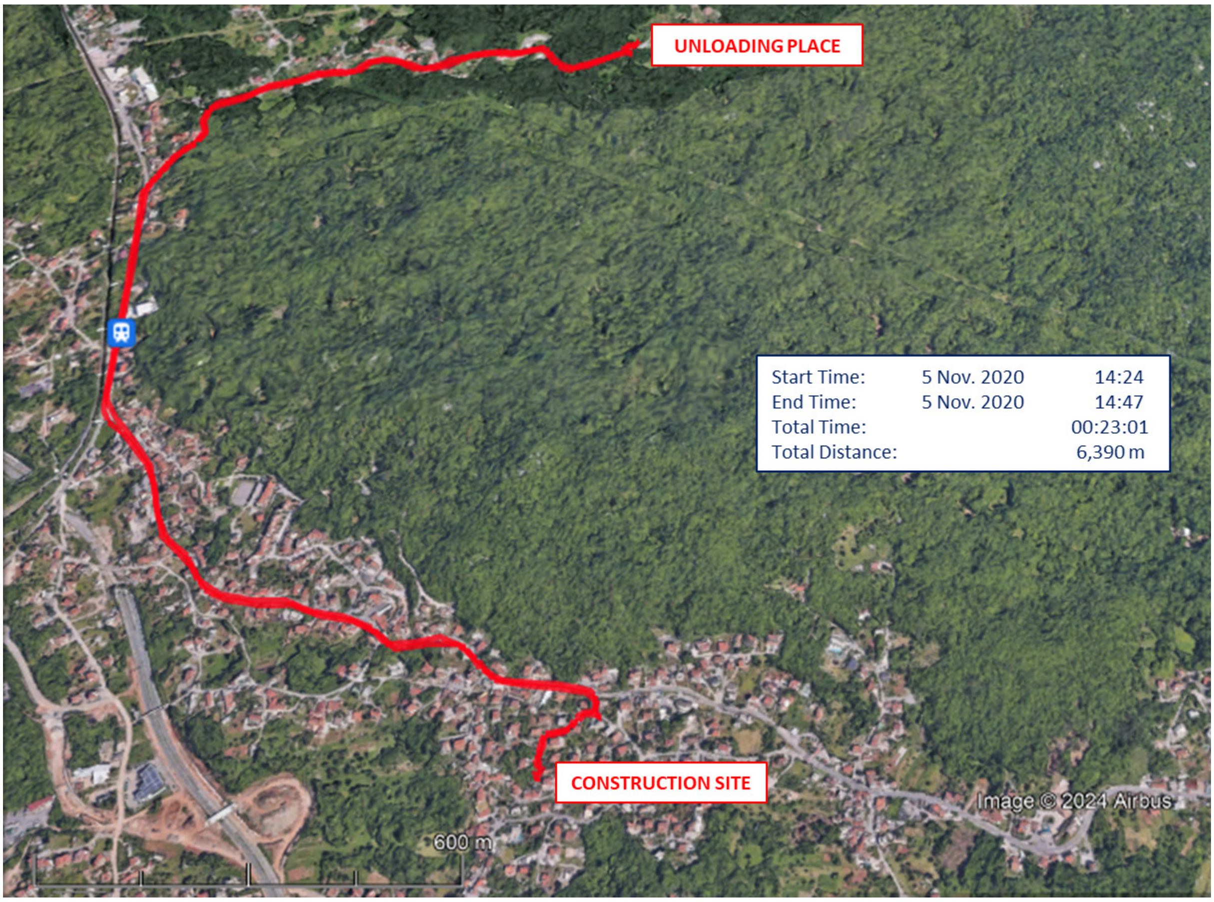

Figure 5. Example of one tipper truck lap in Google Earth Pro software (image created by the first author, map data: Google, ©2024 CNES/Airbus, Maxar Technologies)

5. Discussion

Applying the organizational-technological solution at the construction site during earthworks showed practicality and inventiveness in use. A smartphone was used to record the work of an excavator, and a GPS technology/receiver was used to track the driving of the tipper truck. Video analysis made it possible to break down the excavator operation into its component work operations. Breaking down the excavator's operation into its component work operations allows for assessing the excavator's time cycle. Since the excavator's time cycles usually last up to one minute, a sufficient amount of data can be collected quickly by recording and analyzing the excavator's operation. On the other hand, the estimation of the time cycle of the tipper truck, apart from the data from the video (i.e., loading duration), is highly dependent on the GPS tracking data (i.e., the duration of driving from the construction site to the unloading place with return). Therefore, in cases of a long distance between the unloading place and the construction site, the data collection on the driving of tipper trucks can be very slow. In other words, collecting data on the operation and driving of tipper trucks can be demanding.

A prominent disadvantage in applying video analysis is the time that must be spent. Also, it should be noted that certain videos will not be usable. Reasons, why certain videos will not be usable are, for example, passing or stopping other machines on the construction site in front of the video camera (or smartphone), blurry or poorly recorded content, overheating of the video camera (or smartphone) on hot days (when daily temperatures are higher than or equal to 30 °C), empty battery and similar. The recorded content should be of appropriate quality and length, considering the requirements and capabilities of the video analysis software and the computer configuration.

GPS technology enables position detection and movement tracking. In the organizational-technological solution, a GPS receiver with a data storage feature is suggested (to avoid using a GPS system with a monthly or annual subscription). Tracking records contain data about the driving of tipper trucks in the form of driving duration, speeds, and distance traveled, and enable the display of the completed driving on a map of the Earth's surface. The disadvantage of using a GPS receiver with a data storage feature is turning on the GPS receiver before starting the drive to the unloading place and turning off the GPS receiver after arriving at the construction site at the loading place. In this way, displaying each route separately (tipper truck lap) is possible, which facilitates data processing.

6. Conclusion

By knowing the productivity of machines, the expected duration and cost of the activity can be obtained. The actual productivity of machines on the construction site may differ significantly from the planned. Tracking and monitoring the productivity of machines enables insight into the progress of activities on the construction site and the timely application of appropriate corrective measures. Improving the productivity of machines contributes to reducing the costs and duration of activities and is of great interest to contractors. The time cycle of the machines (with cyclical work) is the key information to assess the actual productivity of the machines when performing the work. With the use of the organizational-technological solution, it is possible to express extremely precisely the time cycles of the work of excavators and tipper trucks. The proposed solution should be used by contractors to better organize the work of machines on the construction site and make the right decisions.

Further research moves towards faster data processing, greater automation, and improved accuracy. An important direction of further research is modifying the proposed solution when the material is taken to several different unloading places and when machines are frequently changed. In addition, the application of other audio-visual and/or sensing technologies should also be explored for additional benefits.

Acknowledgments

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Multiple layers of stakeholder engagement and project success: framework model for infrastructure projects

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Abstract:

Infrastructure is essential for the development and prosperity of countries and societies. Nowadays we are witnessing a major investment cycle in infrastructure around the world. Management failures in infrastructure projects are widely known from many examples of large infrastructure projects underestimating the costs and duration and overestimating the benefits. Part of the problem lies in the weak identification and engagement of numerous project stakeholders. The importance of proper stakeholder engagement in infrastructure projects is widely recognized but the literature provides few answers on how this process manifests itself in projects. The research aims to explore who conducts activities and processes related to project stakeholder engagement, what organizational aspects influence the process, and how success is achieved in infrastructure projects. Initially, eight experienced experts involved in a whole range of (complex) infrastructure projects were interviewed. Based on the interview analysis, success and failure factors related to the stakeholder engagement process were defined. These insights were used to develop a framework model for stakeholder engagement based on three levels of management and three levels of project success. Four additional interviews were conducted for the verification purposes and discussion on practical implications of model. Clients and PMs could use insights from this research to improve the engagement of the stakeholders in complex infrastructure projects.

Keywords: *stakeholder engagement, project succees, infrastructure, framework model, organization*

1. Introduction

Infrastructure projects are complex undertakings that require the coordination and collaboration of multiple stakeholders, including project owners, contractors, regulatory bodies, local communities, and end-users (Bahadorestani, Karlsen, & Motahari Farimani, 2020). Large infrastructure projects are used to create a capacity for the transportation, transmission, distribution of goods, services, or people (e.g., pipelines, highways...) and to enable the promotion of cultural norms and a healthy population (e.g., courts, schools...) (Mok, Shen, & Yang, 2015). Effective stakeholder engagement is widely recognized as a critical factor in the success of these projects, as it helps to align diverse interests, manage expectations, and mitigate potential conflicts (Prebanic & Vukomanović, 2021; Widianingrum, 2018). By actively involving stakeholders throughout the project lifecycle, project teams can better understand their needs, concerns, and priorities, and incorporate them into the project design and implementation (Heravi, Coffey, & Trigunarsyah, 2015). Despite the acknowledged importance of stakeholder engagement, the practical implementation of such strategies often poses significant challenges (Chinyio & Akintoye, 2008). Project teams may struggle to identify and engage with all relevant stakeholders (R. J. Yang et al., 2018). These challenges can lead to delays, cost overruns, and even project failures, highlighting the need for a more systematic and comprehensive approach to stakeholder engagement (Flyvbjerg, 2014.; Wagner & Radujković, 2022).

This research aims to explore who conducts activities and processes related to project stakeholder engagement, what organizational aspects influence the process, and how success is achieved in infrastructure projects. The primary objective of this research is to develop and verify a comprehensive framework model for stakeholder engagement in infrastructure projects based on insights from infrastructure project management experts. To attain the research objective, we addressed the following key questions:

1. What are the critical factors influencing stakeholder engagement in infrastructure projects?

2. How can these factors be systematically incorporated into a structured framework model?

3. What are the practical implications of implementing this model in real-world projects?

This study is set in the context of infrastructure projects in Croatia, a country that has experienced significant investment in transportation, energy, and other critical infrastructure in recent years. The Croatian context provides a relevant and timely setting for exploring the challenges and opportunities of stakeholder engagement, as the country continues to navigate the complexities of large-scale infrastructure development.

The remainder of this paper is organized as follows. Section 2 presents a review of the existing literature on stakeholder engagement in infrastructure projects, highlighting the key concepts and theoretical foundations. Section 3 outlines the research methodology, including the development of the multi-layered framework and the verification process. Section 4 presents the results of the study, including the proposed framework and the opinion of project experts on its usefulness and practical implication. Section 5 further discusses the implications of the findings, the limitations of the study, and potential avenues for future research.

2. Literature Review

2.1 Stakeholder Engagement

According to stakeholder management theory, projects are successful when they consider the needs and requirements of stakeholders through the process of stakeholder management (Pascale et al. 2020). Littau et al. (2010) investigated the application of stakeholder theory in the field of project management and defined four categories of research related to the theory:

1. “Project evaluation context” which includes specific topics of success criteria, as well as project risk and project performance.

2. “Project strategy context” which includes specific topics of project management concepts, different strategic frameworks and business processes in projects.

3. “Project social context” which includes articles focused on topics such as trust, communication, and leadership in projects.

4. “Project environment context”, discussing the roles of clients, sponsors, users, etc., as well as concentrating on other external factors in projects.

In the construction industry often, stakeholders are described as an important factor of the project environment. The client whether a firm, public body or private individual is commonly the first level primary player or stakeholder in any construction project and this primary level also includes project managers, designers, contactors (Harris, 2010). According to Harris (2010) secondary players exercise influence on the construction process beyond the direct control of the primary players such as building inspectorate, government departments or general public. Similarly Winch (2010) classifies construction stakeholders as internal, which are further break into client based and contractor based and external which are further divided in public and private. It is useful to categorize the different types of stakeholders to aid the analysis and to dive deeper into various needs and interests.

Stakeholder engagement can be defined as "*the various communication practices, processes and actions that an organization (or project) must undertake to engage its stakeholders to secure their involvement and commitment or reduce their indifference or hostility*" (Bourne, 2016). Chinyio and Akintoye (2008) examined stakeholder engagement practices in construction projects, classifying two approaches (overarching and operational approaches) and the activities within them (i.e., high-level support, effective use of communication and negotiation etc.). Yang et al. (2011) established a typology of operational approaches to stakeholder analysis and participation (e.g., categorization, public presentation, interviews...). Yang and Shen's [76] model identified five levels of stakeholder engagement (used in public projects in Australia) as core to the stakeholder engagement decision-making process:

- Inform: Provide stakeholders with balanced and objective information that helps them understand issues, alternatives, and/or solutions.

- Consult: Solicit stakeholder feedback on the analysis, alternatives, and/or decisions made.

- Involve: Work directly with stakeholders throughout the process to ensure that their concerns and desires are consistently understood and addressed.

- Collaborate: Work in partnership with stakeholders on every aspect of the decision.

- Empower: Place final decision making in the hands of stakeholders.

Study by Eyiah-Botwe (2016) highlights the importance of early stakeholders' identification, management of culture and political environment and communication as critical factors to meet stakeholder needs and achieve satisfaction. Research by Javed et al. (2014) explored the role of stakeholder engagement in enhancing project success in the construction industry. They found that effective stakeholder engagement can lead to improved project outcomes, including better project performance, increased stakeholder satisfaction, and enhanced project reputation (Javed et al., 2014; Nguyen, Mohamed, & Mostafa, 2021).

Despite the recognized importance of stakeholder engagement, practical implementation often poses significant challenges. Project teams may struggle to identify and engage with all relevant stakeholders, effectively communicate project plans and progress, and address the diverse and sometimes conflicting interests of different stakeholder groups (Di Maddaloni & Davis, 2017; Prebanic & Vukomanović, 2022). These challenges can lead to delays, cost overruns, and even project failures (Prebanic & Vukomanović, 2023). In large infrastructure project key challenges is the complexity of stakeholder landscapes (Aaltonen & Kujala, 2016) and there is a question whether traditional management approach can achieve success and stakeholder satisfaction (Hu, Chan, Le, & Jin, 2015). Many agree that stakeholder engagement is of paramount importance in large infrastructure projects (Di Maddaloni & Davis, 2017; Prebanic & Vukomanović, 2023), and yet stakeholder engagement is poorly implemented (Molwus, Erdogan, & Ogunlana, 2014; R. J. Yang et al., 2018). Collinge (2020) concluded that stakeholder engagement is a complex, intertwined process of responsibility, organizational actions, and work package requirements and is a fundamentally unexplored area.

2.2 Project Success in infrastructure projects

The concept of project success is multifaceted and often depends on the perspective of the stakeholders involved (Davis, 2016). Success criteria can vary from project to project and can include factors such as project management success, product success, market success, and social and environmental value (Al-Tmeemy, Abdul-Rahman, & Harun, 2011; Vuorinen & Martinsuo, 2019). For instance, the success criteria of building projects may focus on contractor perspectives (Williams, 2015), while those of public projects may emphasize the satisfaction of key stakeholders and the achievement of organizational strategic goals (He, Wang, Chan, & Xu, 2021).

There are a number of studies in the field of construction project management that address the issue of project success, either by defining success criteria and success factors or by exploring ways and perspectives to evaluate project success or value (Kate Davis, 2018; Gunathilaka, Tuuli, & Dainty, 2013; Turner & Zolin, 2012; Westerveld, 2003). Prebanic and Vukomanovic (2023) show different approaches to defining project success in construction from the perspective of different key stakeholders.

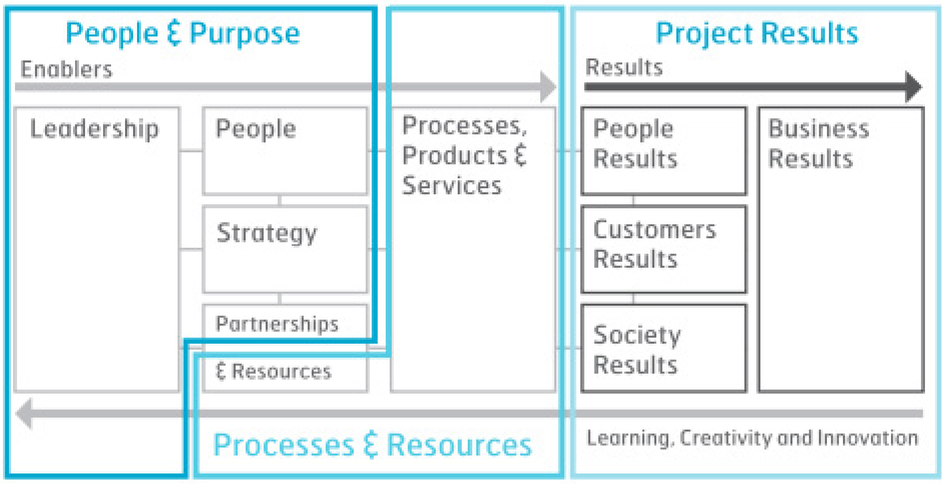

Figure 1 Mapping between IPMA PEM areas and EFQM criteria (IPMA, 2016)

Project success notion is best explained in comprehensive models which encompasses both success factor and success criteria. This approach is best portrayed in IPMA Project Excellence Model (IPMA, 2016) which put stakeholders as a part of enablers of project success (e.g. leadership, people and partnerships) and also as the part of the project results as people, customers and society are described as the recipients of success. In the context of large public infrastructure projects, success is often measured by the overall satisfaction of stakeholders which includes project team, contractors but also the local community, regulatory bodies, and end-users (He et al., 2021; Turner & Zolin, 2012). This makes the task of measuring project success more complex since it is dependent on the project context and overall organizational and administrative environment.

2.3 Organizational and Administrative Context for large infrastructure projects: Overview of Large Construction Infrastructure Projects in Croatia

Beside operational approaches to engage and form a relationship with stakeholder, stakeholder engagement is also observed from the perspective of organizational and institutional theory (Biesenthal et al.,, 2018; Sydow & Braun, 2018) as well as a part of the concept of project governance and complexity (Bosch-Rekveldt et al, 2010; Brunet & Aubry, 2016). Also stakeholder landscapes were introduced as a vehicle to understand complex project environment (Aaltonen & Kujala, 2016). Developed countries such as Norway, United Kingdom and Australia have introduced governance frameworks (i.e., phase gates, audits and reviews, collaborative procurement etc.) to deal specifically with the complex nature of large public infrastructure projects (Burcar Dunović, 2010; Office of Government Commerce, 2004; Walker & Lloyd-Walker, 2014). Khan et al. (2021) tested and proved that project governance mechanisms such as transparent reporting and effective use of the public project sponsorship approach improve project performance, which is further enhanced by implementing a stakeholder management process. The characteristics of project governance mechanisms are consistent with the principles of stakeholder engagement (Khan et al., 2019): active participation (e.g., making the right decision at the right time); project control to achieve strategic goals and satisfy stakeholders; and the promotion of equity in the sense that all parties have equal opportunities to improve or maintain their own well-being. Klakegg et al. [46] concluded that governance frameworks represent progress in managing complex infrastructure projects but further emphasized that organization of major projects is still poorly understood.

Croatian organizational and managerial context for infrastructure projects

Since joining the European Union (EU) in 2013, mainly thanks to the European Union's Cohesion Policy, Croatia has had very substantial financial resources allocated to the development or reconstruction of its infrastructure (Ministry of Regional Development and EU funds 2023.; The Croatian Chamber of Economy, 2015). Legal acts and bodies are an indispensable part of all (infrastructure) projects co-financed by the EU, i.e acts defining the institutional framework for implementation of EU structural funds and government regulations defining rules and control procedures for particular investment funds (Technical Gazzete 2014). For civil infrastructure, i.e., transport and utilities infrastructure (municipal infrastructure), more than 3 billion EUR are available under the OPKK program 2014-2020, and projects can be implemented until the end of 2023 (Ministry of Regional Development and EU funds, 2023). The SAFU (Central Agency for Financing and Contracting, 2018)) manual (guide) itself can be considered part of the project governance framework, as it defines the obligations of the "contracting authority" (e.g. public client) in terms of governance and management of the project. The following are some of the key obligations of contracting authorities in relation to their own project delivery system:

- Establish its own system for project implementation (e.g. systematic updating and monitoring of the project implementation plan; management of the project team; management of outputs and results; project procurement management etc)
- Update and, if necessary, detail the schedule provided for in the project proposal
- Update the responsibilities for the implementation of the project activities...

Stakeholder engagement is a critical factor in the success of infrastructure projects, but its practical implementation is often complex and challenging. The concept of project success is multifaceted, and its evaluation depends on the perspective of various stakeholders. Understanding the complexities of stakeholder engagement and the factors influencing project success is essential for developing effective stakeholder engagement strategies and operational approaches.

3. Methodology

1) Research Design

This study is part of a larger mixed methods study which used interviews with experts in infrastructure project management, collection of the numerical data on infrastructure projects in Croatia and second round of interviews for verification purposes. This paper focuses on qualitative part of the study, particularly on newly developed framework model and its implication. Semi-structured interviews were used to collect qualitative data from experts which were then analysed using thematic analysis. Seven success/failure factors for stakeholder engagement were identified (intermediary result) which served as an input for the development of the framework model for stakeholder engagement as a driver for project success. This framework model was verified through other series of interviews. Beside verification expert views on practical relevance of framework model are collected.

2) Semi-structured interviews with experts, thematic analysis and derivation of success factors

Interviews were conducted with experts covering all key roles in infrastructure construction projects. The objective of the semi-structured interviews was to explore in detail wider context, processes and practice related to stakeholder engagement in infrastructure projects. A total of eight interviews were conducted with the following expert profile: construction project manager, public client, public client, contractor, designer, professional supervisor/superintendent/FIDIC engineer. Based on thirty-one main questions and associated sub-questions, seventeen themes were analyzed, with each question or set of questions representing a specific theme, e.g.:

1. How are infrastructure construction projects managed and which parties are responsible for the management of large infrastructure projects (3rd to 12th question)

2. Whether formal stakeholder engagement is conducted on projects and how stakeholder engagement is generally conducted (15th to 19th)

3. To what extent do the procurement process, contracts, and project complexity impact stakeholder engagement and project delivery (25th to 28th) etc.

Based on the results of thematic analysis, we identified seven distinct success/failure factors for stakeholder engagement and three organizational and management levels at which stakeholder engagement occurs (e.g. linked success/failure factors with management levels). This part of the research (e.g. data collection and thematic analysis) is explained in detail in another article.

3) Development of the multilayer framework model for stakeholder engagement and achievement of the success in infrastructure projects

The organizational context of infrastructure projects is presented as complex and multi-faceted, and similarly project success is observed as multi-layered concept. Stakeholders are seen as both enablers of success and evaluators of success. We used these theoretical lenses to interpret our findings from thematic analysis and build a framework model. Researchers related the data to the theoretical framework. Opinions from interviewees could be easily related to a certain management level, i.e. “client hires a project manager before public bidding has begun...” (assigned to level 2 - client’s project management process). The model clarifies the characteristics of the relationship between stakeholder engagement success factors, the management levels at which they occur, and the project success layer. This approach illustrates the practical intricacies of stakeholder engagement process in complex settings of infrastructure projects.

4) Verification and discussion on practical intricacies of stakeholder engagement process

To verify the conceptual framework, four additional interviews were conducted with six verification questions for each model construct. Before asking verification questions, each verifier was briefly presented with a summary of the entire research that led to the development of the framework. This was followed by an explanation of the conceptual framework, which lasted 15 minutes. Next, six verification questions were asked and finally the ratings and explanations of verifiers were recorded. In addition to ratings (i.e., 1 - not at all applicable, 5 - completely applicable), verifiers provided comments on each rating. In addition to the previously mentioned verification questions, the respondents who verified the model also answered on the additional four questions covering the practical relevance of stakeholder engagement framework model and direction for further development.

4. Results

4.1 Insights from thematic analysis → Success/Failure Factors for stakeholder engagement in infrastructure project:

The profiles of the interviewees were chosen in such a way as to cover most of the common roles in the infrastructure project and thereby gain insight into the engagement of stakeholders from the perspective of key experts. Profiles of interviewers were addressed through the first four themes. The other eleventh themes are linked with broader context of infrastructure project organizations and specific context of hands-on experience with engagement of the project stakeholders. Answers and insights from thematic analysis are covered in another article from authors (Prebanic & Vukomanović, 2023). The authors gained a detailed insight into the organizational and managerial complexity of infrastructure projects and its inherent stakeholders. Insights from our analysis resulted with the identification of the seven success/failure factors for stakeholder engagement process in infrastructure projects (code and short form of success factor provided in italic):

4. Some stakeholders must be prioritized because of their great influence over the project (e.g. those named in the Building Act and possibly others). → *SF 1 - prioritization of stakeholders*

5. The project manager needs to be engaged earlier than the usual (current) practice to enable proper engagement of other key stakeholders. → *SF 2 – PM employed in early project phases*

6. There are several key engagement activities (operational approaches) which must be systematically implemented to assure quality in the stakeholder engagement process. → *SF3 – formal use of key engagement activities*

7. There is a great importance of both “soft” and “hard” skills for the proper engagement of stakeholders. → *SF4 – SE implies simultaneous use of “soft” and “hard” skills*

8. The procurement model and accompanied definition of key project roles and responsibilities have a significant influence on the stakeholder engagement process. → *SF5 – Procurement model influences SE*

9. The complexity of project organization and environment has a significant influence on the

stakeholder engagement process. → *SF6 – Complexity of project environment influences SE*

10. A significant difference occurs in the engagement of external (non-contractual) stakeholders in infrastructure projects and is often a source of unforeseen project risks. → *SF7 – Different approach to external stakeholders is source of risk*

In the Republic of Croatia, the Construction project manager must be employed according to the valid legislative framework (e.g. named role with described responsibilities) for infrastructure projects worth more than 1,4 million EUR, or transportation infrastructure worth more than 6,67 million EUR, which includes most infrastructure projects. Thus, project managers and their core team has the responsibility to assist clients in certain operational project management activities. Client organizations are responsible for their project portfolio and for each of their project they are obliged to procure each of the key services (e.g. project designs and technical documentation) which are covered by internal project stakeholders (e.g. designer, project manager, contractor etc.). There are factors that neither the client (public procurer) nor the project manager can influence or can only partially influence, and they are related to the wider context of the project, e.g. legal regulations, rules of financing, governance of major (public) programmes and projects. Thus, the framework model for engaging stakeholders and achieving success in infrastructure projects has a basic structure through three management layers:

- Layer 3 – Layer of the broader industry and regulatory context – success/failure factors that are related with aspects that are not under client organization or the project management direct influence
- Layer 2 – Layer of the client's organization – success/failure factors that are related with the client's organizational processes/activities and competences
- Layer 1 – Layer of operational project management – success/failure factors that are related with activities/processes of the project manager and his core team

Seven distinct stakeholder engagement success/failure factors listed above can be exploited in one or more than one management layer (e.g., managerial levels). This means that factors addressed in level 1 can be also repeated at level 2 and/or level 3 and vice versa. Detailed description of success/failure factors for each management layer is provided in other article (Prebanic & Vukomanović, 2023).

Framework Model for stakeholder engagement as driver for infrastructure project success

Success factors was defined in literature as project elements that can be influenced in order to increase the probability of success, i.e. those that represent independent variables and make success more likely (Westerveld, 2003). Westerveld (2003) stated that good success factor model should separate those factors that are within the authority of the project manager and those that are outside his authority, which was the guiding thread in the development of this framework model. Thus, our model consists of seven success factors (e.g. SFs) for stakeholder engagement linked with three management layers. Level 1 which implies operational project management "layer" is devised out of five success factors, Level 2 which implies client organization and management "layer" comprises four success factors: and Level 3 which implies mandatory conditions arising from state and industry regulatory framework and governance approach. In next table we provide a brief explanation on how we related engagement activities with management layers.

Table 1 Ways to exploit success factor for stakeholder engagement with related management layers in infrastructure projects

Success factor (SF) for Stakeholder engagement (SE)	Level 1 – operational project management	Level 2 – client organization and management	Level 3 – state and industry regulatory framework and governance approach

SF 1 – Prioritization of stakeholders	More detailed (tailored) approach for prioritized stakeholders		More clear demarcation of PM responsibilities vs. other Named roles (e.g. improve Building Act, guidelines)
SF 2 – PM employed in early project phases		Systematic approach to the project development process (e.g. early stages) – define the exact moment when PM should be assigned	More detailed rules and procedures for PM in complex or financially significant projects (e.g critical projects) – introduce specialized governance framework for critical projects.
SF3 – formal use of key engagement activities	proven effectiveness of several stakeholder engagement activities – systematically implement in regular PM practices		
SF4 – SE implies simultaneous use of "soft" and "hard" skills	Improve people skills (i.e. communication, cooperation) and hard skills (i.e. planning, monitoring)		
SF5 – Procurement model influences SE	Improve competences for the development of the tender documentation (precise definition of roles and responsibilities to prevent overlaps)	Clear demarcation of the client and PM responsibilities regarding the organization and execution of the project procurement processes	Introduce new types/ models of the so-called collaborative contractual arrangements
SF6 – Complexity of project environment influences SE	Improve competences and develop methods for evaluating the project (organizational) complexity	Assess the project complexity and accordingly plan the number and size of different procurements, (e.g., contracts)	
SF7 – Different approach to external stakeholders is source of risk		Educate the (public) client to engage external stakeholders in clear and disciplined manner (prevent differences in approach)	industry effort to change the perception about involving external stakeholders in key project decisions (frameworks, guidelines)

Activities through which stakeholders are engaged in infrastructure projects are very versatile and multifaceted. Thus, logical way to portray this complex nature was through multiple layers of management through in which they occur. Significant part of the project success literature advocated for multilevel view of project success which is presented through satisfaction of numerous stakeholders. Satisfaction of primary stakeholder with vested interests in project (e.g. time, resources…) could be observed as the first level of project success and this is directly related with first management layer e.g. operational project management. Second level of project success can be linked with the advancement and success of (public) client organization and its close network and third is linked with wider societal stakeholders such as end users and local community. Proper exploitation of stakeholder engagement success factor in each specific management layer corresponds with certain level of project success e.g. project can satisfy only "primary" stakeholder, or it can achieve system-wide benefits for numerous “secondary” stakeholders which requires broader efforts. Figure 1 depicts graphical representation of our newly developed framework.

Transforming Construction: The Synergy of SfM-MVS Tools in Enhancing Quantity and Quality Control On-Site

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Abstract:

The Architecture, Engineering, and Construction (AEC) industry is undergoing a significant transformation due to the integration of advanced digitization tools like drones, 360-degree cameras, and LIDAR scanners. This shift is propelled by the increasing complexity of modern construction projects, which demand more precise coordination and management than traditional methods can provide. These digitization tools are enhancing the efficiency, accuracy, and safety of construction projects by facilitating real-time data collection, automated progress monitoring, and improved decision-making processes. However, achieving seamless integration remains challenging.

This paper explores the practical applications and effectiveness of these technologies, focusing on Unmanned Aerial Vehicles (UAVs) and 360-degree cameras. Through a case study drawn from our experiences in digitizing construction processes, we illustrate how these tools can be implemented to improve progress tracking, quantity control, and overall project management. By examining this real-world application, we aim to demonstrate the tangible benefits of adopting digitization tools, offering insights for professionals seeking to upgrade their practices. This abstract encapsulates the essence of a broader discussion on how digitization tools are reshaping the AEC industry, promising efficiency, precision, and innovation in construction practices.

Keywords: *digitization tools; construction management; SfM-MVS; quality and quantity control;*

1. Introduction

The Architecture, Engineering, and Construction (AEC) industry, long characterized by its reliance on traditional methods and manual labor, has been undergoing a profound transformation over the past few decades. This transformation is driven by the advent of digital technologies that have begun to change every aspect of the industry - from design and planning to construction and maintenance. The integration of these technologies - collectively referred to as digitization tools - has brought about significant changes in how projects are conceived, executed, and managed. This paper explores the critical role of digitization tools, specifically drones, 360-degree cameras, and LIDAR scanners, in enhancing the quantity and quality control of the preparatory works on site - earth excavations phase of construction projects.

One of the key drivers of digitization in the AEC industry is the increasing complexity of construction projects. Modern buildings and infrastructure are more sophisticated than ever, requiring precise coordination among various stakeholders, including architects, engineers, contractors, and clients. Traditional methods of managing construction projects, which often relied on manual inspections, paper-based documentation, and fragmented communication, are no longer sufficient to meet the demands of today's projects (Golparvar-Fard et al., 2015). This transformation is particularly evident in the construction sites management and the control of quantities, where traditional methods are being supplemented or replaced by advanced digital tools. Among these tools, the integration of Structure-From-Motion (SfM) Multi-view Stereo (MVS) techniques with digital technologies such as drones, 360-degree cameras, and LIDAR scanners is revolutionizing the way construction sites are managed and monitored.

The paper develops around achievements drawn from a case study in digitizing the construction process, particularly through the scanning and monitoring of a building site. This case study will serve as a practical example of how these technologies can be implemented to improve progress tracking, quantity control, and overall project management. By examining this real-world application, we aim to demonstrate the tangible benefits of adopting such digitization tools in the construction process, providing valuable insights for professionals looking to enhance their own practices.

1. 1Structure-From-Motion Multi-view Stereo (SfM MVS) in Quantity Control

Quantity control is a critical aspect of construction management, as it ensures that the quantities of materials used, and work completed align with the project's plans and budget. Traditional methods of quantity control often involve manual measurements and inspections, which can be time-consuming, labor-intensive, and prone to errors. The use of SfM-MVS, combined with digital tools like drones and LIDAR scanners, offers a more efficient and accurate alternative (Kaamin et al., 2023).

Structure from Motion (SfM) is a powerful computer vision technique that reconstructs 3D structures from sequences of 2D images. The process begins with feature detection and matching across multiple images, creating tracks that represent potential 3D points (Schönberger and Frahm, 2016). A critical step is the selection of an initial image pair that optimizes both match quantity and geometric reliability (Snavely et al., 2008). From this pair, camera poses are estimated using the fundamental matrix, establishing the coordinate system. Subsequent camera poses are computed through the Perspective-n-Point (PnP) algorithm within a RANSAC framework (Lepetit et al., 2009). As camera poses are determined, 2D features are triangulated into 3D points (Hartley and Sturm, 1997). The reconstruction grows incrementally, guided by a "next best view" selection algorithm (Goesele et al., 2007). Crucially, bundle adjustment is performed periodically to refine camera parameters and 3D point positions, minimizing reprojection errors (Triggs et al., 2000). The process iterates, adding views and triangulating new points while filtering out unreliable observations, until no new views can be localized. Recent advancements in SfM have focused on improving scalability and robustness, enabling reconstructions from large, unordered image collections (Schönberger et al., 2016). Still this process of 3D reconstruction of an real environment, requires adaptation from the operator recording the site to understand the principles and technical capabilities of hers/his tools as well as adaptation of the analyst using the SfM-MVS results to structure those into usable data for the end user.

1.2 Advantages of Using SfM-MVS for Quantity Control and Construction Site Tracking

Structure from Motion-Multi-View Stereo (SfM-MVS) technology has revolutionized quantity control and site tracking in the construction industry, offering a multitude of advantages across various applications:

- Enhanced Accuracy and Precision - SfM-MVS significantly improves the accuracy of quantity measurements by eliminating human errors associated with manual methods (Golparvar-Fard et al., 2015).

- Efficient Data Collection and Analysis - The automation provided by SfM-MVS dramatically reduces the time and labor required for quantity control and site tracking (Kim & Khan, 2022).

- Comprehensive Site Documentation - SfM-MVS enables the creation of a rich, visual record of the construction process (Golparvar-Fard et al., 2011).

- Progress Tracking and Quality Control: SfM-MVS enables comparison of as-built conditions with BIM models or other forms of documentation for real-time progress assessment (Golparvar-Fard et al., 2015), additionally SfM-MVS enables Identification of construction defects or deviations from plans through high-resolution 3D models (Kim & Kim, 2018).

- Cost-Effectiveness

2. Methodology and Short description of the case

2.1 The monitored case

Construction site is a private investment of Alfa stan Group ltd. Situated in the mere vicinity of Zagreb city center. The investment is called FRANC. FRANC is a residential and commercial complex located in western part of the city center of Zagreb. It consists of nine standalone buildings, designed to harmonize with the Lower Town structure and integrate public spaces. The architecture emphasizes luxury living, with high ceilings, large glass facades. Sustainable design, smart-home technology, and green spaces enhance living comfort.

The building site at hand is active across 6.400 m2 floor area construction site. The construction site is surrounded completely with 2 bordering streets on the eastern and western borderlines of the building site and 2 buildings next to the construction site on the other 2 sides. Due to spatial limitations presented the investor has decided to use a top-down-up construction method which stressed the contractors to their logistical and technological limits.

The large excavations, with a volume of 44.810 m3 of earth were happening 8m below the street level (right below the strut slab). These excavations were evolving parallelly to concreting works on 2 of 9 building blocks.

We were tasked to monitor excavation quantities, as well as to control the verticality of constructed elements that were executed below the earth surface (diaphragm and pilots), geological positioning of elements, thicknesses of construction elements (blinding concrete, executed foundation thickness, outer wall thickness, etc.), and conformity of the execution with the designed state.

2.2 Monitoring methodology

Methodologically we were able to choose the best possible solution or combination of solution for the execution of these works while having a respectable list of equipment and software at our disposal:

- 4 DJI Air 2s drones with a possibility of a 360 camera attachment (Insta360 Sphere)
- DJI Inspire 2 drone with a Zenmuse X7 camera
- DJI Matrice 300 RTK drone with Zenmuse P1 camera
- FARO Focus M – LIDAR scaner
- Cloudcompare software
- FARO Scene software
- Faro BuildIt Construction software
- Agisoft Metashape software
- PointCab Origins 4.2 software

The construction site was subject to regular monitoring over an extended period. Specifically, site inspections were conducted at a minimum of once per week over the period of 10 months. This consistent and long-term approach to site monitoring ensured a comprehensive understanding of the construction progress and allowed for timely identification of any issues or deviations in the monitoring process, enabled identification of technological limitations and enabled the monitoring problems to be rectified within a short span of time.

The long-lasting monitoring was actually split into two research phases:

- Setting up the process and identifying the technological limits
- Monitoring of the construction process and reporting to the investor

The main aim of the monitoring was to speed up the process on the construction site while the duration of the post processing process had a secondary importance. Both of the processes had to provide a recording of the construction site (3D model) of similar quality.

The quality of the recording was controlled through point cloud dissipation for flat surfaces and through recorded dimensions of the construction site where LIDAR scans were used as a objective measurement for the testing phase.

In this paper we are only discussing the results of the monitoring process / the second phase of the research.

3. Achieved results

3.1. Enhanced Accuracy and Precision

Structure from Motion (SfM) and Multi-View Stereo (MVS) technologies have revolutionized quantity measurements in the construction industry. These advanced photogrammetry techniques significantly enhance the accuracy of measurements by eliminating human errors inherent in traditional manual methods.

SfM-MVS works by processing multiple overlapping photographs (or 360 photographs) taken from different positions to create highly detailed, three-dimensional digital models of construction sites (figure 1). These detailed recordings allow for highly accurate measurements of excavations, stockpiles, and structures. This precision is particularly valuable for earthwork quantities, where even small errors can lead to significant cost implications (figure 2).

Figure 1. Dense point cloud recreating the excavation works under ground

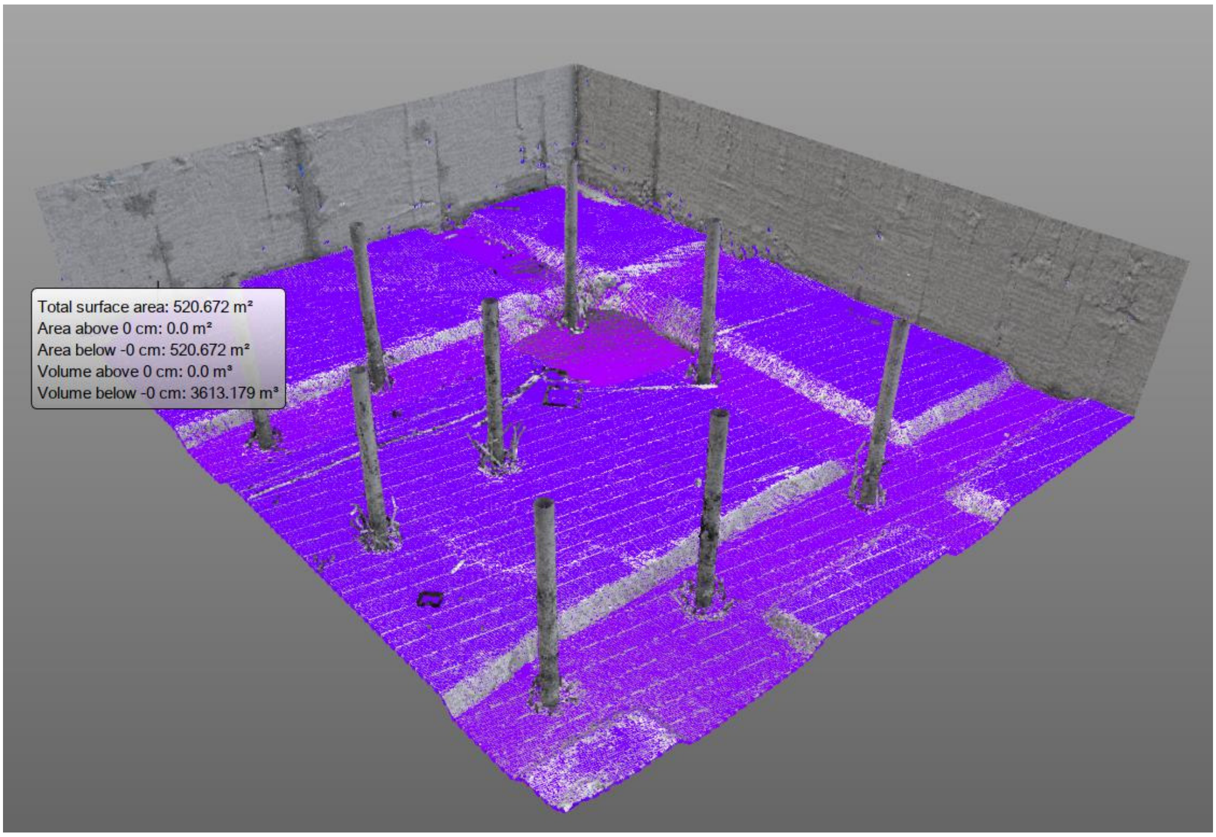
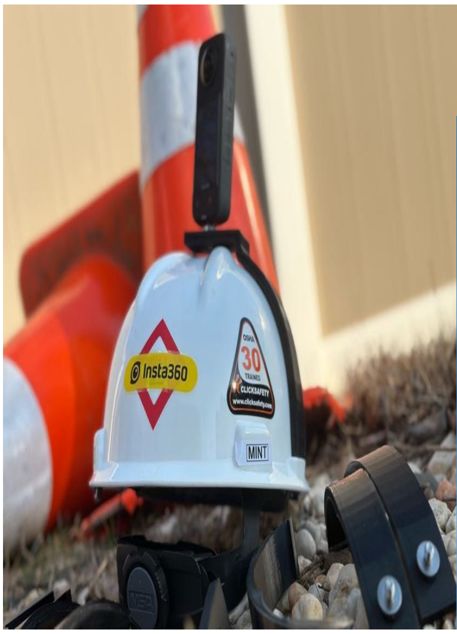


Figure 2. Excavation analysis presentation

3.2. Efficient Data Collection and Analysis

The automation provided by SfM MVS technologies has revolutionized quantity control and site tracking in the construction industry. These advanced photogrammetry techniques dramatically reduce the time and labor required for these crucial project management tasks.

Drones equipped with high-resolution cameras, or 360 cameras for in-door recordings, or workers equipped with 360 cameras (figures 3 and 4), can rapidly collect data from large areas or construction sites. By capturing detailed imagery one can collect a number of information within a fraction of time compared to traditional methods. Once the raw image data is collected, sophisticated SfM-MVS software processes it to generate highly accurate 3D models and point clouds of the construction site. These models provide precise measurements and volumetric calculations. This technology-driven approach to site monitoring represents a significant leap forward in construction project management.



Figures 3 and 4. 360 cameras attached to a hardhat and a DJI Air 2s drone

3.3 Comprehensive Site Documentation

One of the primary applications of SfM-MVS is progress reporting. The 3D models provide accurate, almost real-time visual representations of construction advancements, allowing project teams and stakeholders to assess the state of the work at any given moment. This level of detail supports more transparent communication between stakeholders, ensuring that everyone involved has a clear and consistent understanding of the project's status (figure 2). Furthermore, these models are invaluable for dispute resolution, providing an objective, visual record of construction progress or anomalies, which can help resolve disagreements between parties over the quality or timeline of work.

Additionally, SfM-MVS enables the preservation of detailed historical records of construction sites. These records allow users to virtually revisit any stage of the construction process long after physical access to the site has changed or been restricted. For project managers and engineers, this ability to access earlier stages of the construction can be crucial for decision-making, particularly when assessing deviations or troubleshooting issues that arise later in the project.

In the case study the survey results were actively used in coordination and planning of the construction site in order to effectively organize and parallelize the works, thus speeding up the construction process.

3.4. Progress Tracking and Quality Control

Through this case study we have demonstrated how the use of 3D models generated from SfM-MVS can be aligned with project documentation to provide a clear, visual comparison between the planned and actual states of construction at any given point in time. This process enables the automatic tracking of deviations from the project schedule, offering immediate feedback on whether a project is on track or falling behind. Moreover, this real-time comparison facilitates more efficient decision-making, allowing stakeholders to make necessary adjustments before delays escalate, ultimately contributing to better time and cost management.

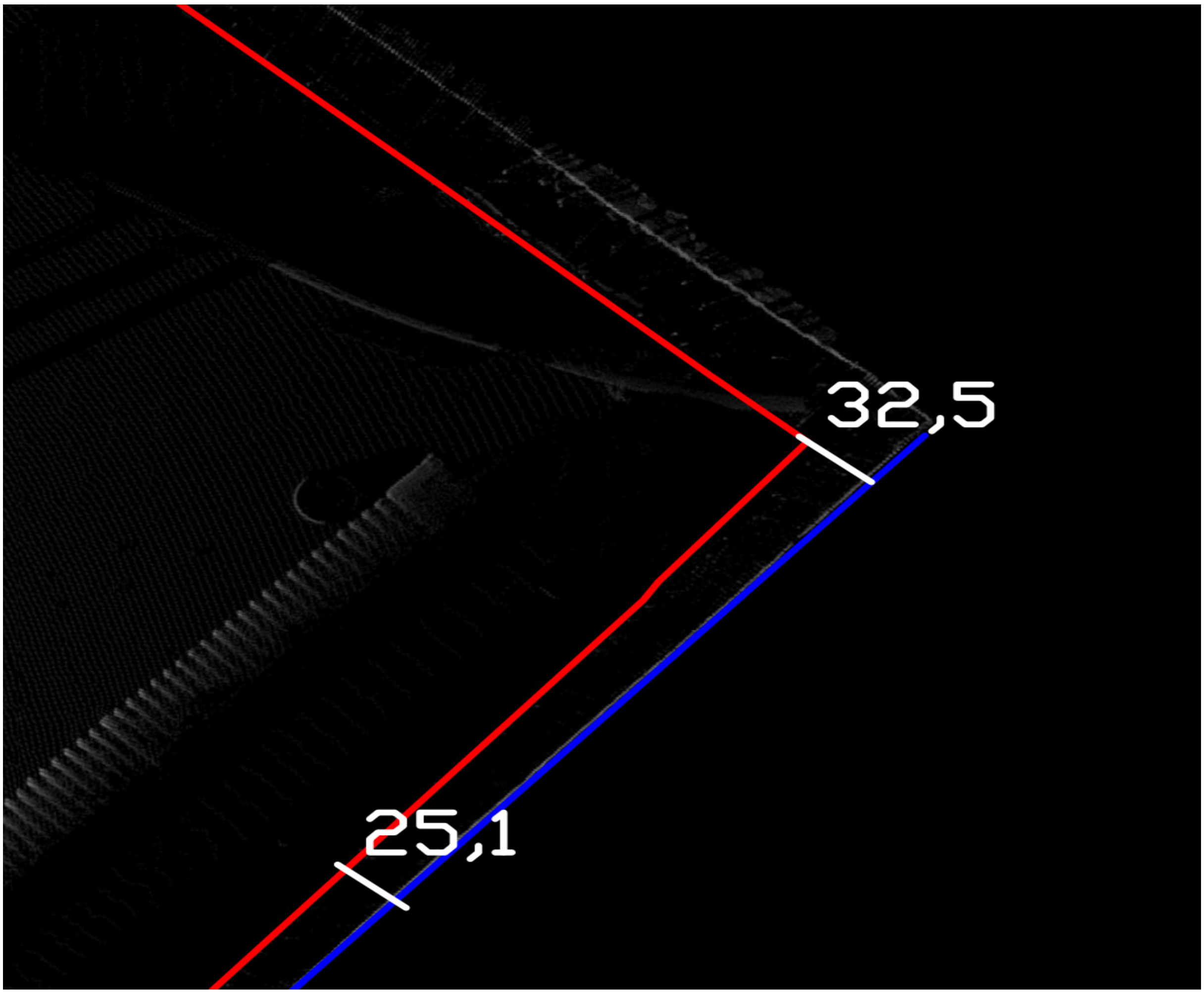


Figure 5. Detail of an control overlay of execution phases

Beyond progress tracking, the use of high-resolution 3D models also played a critical role in identifying construction defects or deviations from design specifications. These models, which capture intricate details of the construction site, allow for close inspection of structural elements. Any discrepancies between the as-built conditions and the original design can be quickly detected and addressed, preventing potential issues from compounding later in the construction process (Figure 5). The ability to identify defects at an early stage helps reduce rework and ensures that quality standards are met throughout the project.

3.5. Cost Effectiveness

Although the initial investment required to implement SfM-MVS technology in construction projects may appear substantial, research and case studies increasingly demonstrate that the long-term benefits far surpass the upfront costs. SfM-MVS technology introduces efficiencies across various aspects of project management, from progress tracking to quality control, resulting in significant cost savings over the entire lifecycle of a construction project.

Jacob-Loyola et al. (2021) emphasize that one of the most compelling advantages of integrating

SfM-MVS into construction workflows is the reduction in the need for frequent manual surveys. Traditional methods of site surveying often require significant time, labor, and equipment, leading to high recurring costs throughout the project. In contrast, SfM-MVS enables the rapid generation of high-resolution 3D models of construction sites, drastically reducing the frequency and cost of manual surveying. By automating much of the data capture process, these technologies free up resources that can be redirected to other critical project activities.

Comparatively, as discussed before, for this case study, surveys were done usually merely once a week and for a duration of no more than 30 minutes per visit. Comparatively, a professional surveyor would have spent at least 3-4 hours per visit on-site.

4. Conclusions

In conclusion, this study emphasizes the significant advantages of integrating Structure-from-Motion (SfM) and Multi-View Stereo (MVS) technologies in modern construction management, particularly for enhancing both quantity control and progress tracking. These advanced digital tools have been proven to drastically improve precision, minimize human error, and optimize data collection and analysis processes. Through the successful implementation of UAVs, LIDAR scanners, and 360-degree cameras, our case study demonstrated how these tools can create accurate 3D models that support efficient monitoring of excavation quantities, structural integrity, and construction progress.

The practical implications of adopting these technologies go beyond improving accuracy. They provide valuable efficiencies in terms of time and labor, reducing the need for manual inspections and extensive on-site surveying, while also allowing real-time adjustments and informed decision-making. The capability to compare as-built conditions with planned models ensures ongoing quality control and supports early identification of deviations or construction defects, which in turn minimizes costly rework and delays.

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Implementation of BIM in FIDIC contracts: critical review and guidelines

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Abstract:

BIM has recently begun to be adopted on a widespread basis and in many countries worldwide but also mandatory for public projects throughout the whole lifecycle of a project. Therefore, there is a need to implement BIM transparently and unambiguously in contracts for works, especially in widely used standardized contracts such as FIDIC Conditions of Contract which will be analyzed in this paper. FIDIC (International Federation of Consulting Engineers) announced the development of the *Technology Guideline* and the *Definition of Scope Guideline Specific to BIM* with intention to address implementation of BIM principles in standard FIDIC contracts. As these two documents have not been published yet, there is a lack of guidelines, protocols, and general involvement in contract conditions when preparing works contracts. Therefore, this paper will address this problem by analyzing relevant clauses and providing guidelines for implementation of BIM in FIDIC Conditions of Contract. The results of this paper aim to provide support for employers when preparing bidding documentation for construction projects.

Keywords: BIM; construction contracts; FIDIC; guidelines

1. Introduction

The construction industry is undergoing a significant transformation driven by advancements in digital technology, with Building Information Modeling (BIM) at the forefront of this change. BIM is an integrated process that allows creation and management of digital representations of physical and functional characteristics of construction projects (Sacks et al, 2018; ISO 19650-1, 2018). By enhancing collaboration, improving design accuracy, and enabling better decision-making across the project lifecycle, BIM has the potential to greatly improve the efficiency and outcomes of construction projects.

The adoption of openBIM standards (e.g., Industry Foundation Classes – IFC, BIM Collaboration Format – BCF, Information Delivery Specification – IDS, etc.) further amplifies potential of BIM by ensuring open and neutral standards, interoperability, reliable data exchanges, seamless collaboration, data exchange across various platforms and stakeholders and sustainability. OpenBIM provides a vendor-neutral, non-proprietary approach that promotes interoperability and long-term data accessibility, which are essential for improving project transparency, reducing errors, and streamlining communication across all project phases (buildingSMART, 2024). This ensures that the benefits of BIM can be maximized, regardless of the specific tools or software systems used.

In parallel, FIDIC contracts have long been regarded as the global standard for managing construction projects. These contracts provide a robust framework that outlines the roles, responsibilities, and risks associated with project stakeholders, offering clarity and consistency in contractual relationships. The integration of BIM into FIDIC contracts presents a promising opportunity to combine modern digital tools with traditional legal frameworks, yet it remains underexplored and challenging.

The integration of BIM into a FIDIC contract offers significant potential to streamline project execution by enhancing communication, transparency, and coordination among all parties. While traditional FIDIC contracts provide a solid foundation, incorporating BIM requires some adjustments to ensure that the digital and collaborative aspects of BIM processes are fully supported (Ragab and Marzouk, 2021). These modifications would enable the contract to better reflect the benefits of BIM within the FIDIC framework, helping to optimize project outcomes.

Key areas for consideration include collaboration and information exchange, data ownership and intellectual property, roles and responsibilities, risk allocation, dispute resolution, and time and cost management (Menna et al, 2024; Valkova, 2022).

- Regarding collaboration and information exchange, BIM promotes early collaboration and real-time information sharing, while FIDIC traditionally defines strict roles for contractors, employers, and engineers. For effective BIM implementation, contracts should redefine the responsibilities of each party concerning BIM processes. Moreover, a BIM Execution Plan (BEP) should be integrated into the contract, specifying the protocols for BIM use, including data formats, software platforms, data-sharing rules and workflows, and requirements related to the Level of Information Need (LOIN) (ISO 19650-2, 2018; ISO 19650-3, 2020; ISO 19650-4, 2022; ISO 7817-1, 2024).

- Data ownership and intellectual property are also major concerns with BIM. Since multiple stakeholders contribute to a shared model, it is vital to clearly define who owns the data at different project stages (ISO 19650-5, 2020). FIDIC contracts should address intellectual property rights related to BIM-generated models and data. Provisions should also be included to define data ownership after project completion, especially during the operational and maintenance phases, as BIM provides valuable lifecycle information.

- The integration of BIM also introduces new roles and responsibilities. Roles such as the BIM Manager or Information Manager are crucial for coordinating the flow of information and ensuring the accuracy of the BIM model (Sacks et al, 2018). The FIDIC contract should explicitly define these roles and responsibilities. Additionally, the traditional role of the Engineer may evolve, requiring them to manage both construction and digital components of the project. This shift necessitates a rethinking of how the Engineer's responsibilities are outlined within the FIDIC framework.

- Another critical aspect is risk allocation. While FIDIC contracts are known for their clear risk allocation (Spassova et al., 2019; Menna et al, 2024), BIM introduces new risks such as data management and software compatibility. The contract must clarify which party is responsible for the accuracy of the BIM model at each stage. Miscommunication or errors in the model could lead to cost overruns or delays, and therefore the contract should establish protocols to verify the accuracy and integrity of BIM data.

- In terms of dispute resolution, while BIM can reduce disputes by providing a clear record of design changes and project progress, disputes related to the interpretation of BIM data may still arise. FIDIC contracts typically include mechanisms for adjudication and arbitration, but BIM introduces new complexities such as interpreting 3D models and digital data. The contract should anticipate these issues and offer guidelines for resolving disputes involving BIM data (Muhammad and Nasir, 2022).

- Finally, time and cost management are key areas where BIM adds value. BIM tools for cost estimation and scheduling depend on accurate and timely data inputs (Sacks et al, 2018). FIDIC contracts should define how time and cost data are incorporated into the BIM model and who is responsible for managing these elements. The contract could also include provisions for regular updates and audits of the BIM model, allowing real-time monitoring to ensure the project remains on track.

Integrating BIM with FIDIC contracts offers several significant benefits (Menna et al, 2024; Valkova, 2022). Firstly, it can lead to improved efficiency and reduced errors. By utilizing BIM, project stakeholders can decrease the likelihood of costly errors and omissions. The shared digital model enhances coordination between parties, enabling real-time updates and minimizing rework. Secondly, enhanced collaboration is achieved as BIM fosters a cooperative environment that breaks down silos between various project teams. When combined with a FIDIC contract that clearly defines roles and responsibilities, this leads to better teamwork and more efficient project execution. Furthermore, the digital nature of BIM facilitates better risk management. It provides increased visibility into potential issues before they escalate into costly problems, allowing FIDIC contracts, known for their emphasis on risk allocation, to be adapted to capitalize on this transparency. Finally, BIM supports lifecycle management. Its value extends beyond the design and construction phases, offering long-term benefits throughout the asset's lifecycle. When integrated into a FIDIC contract, BIM can significantly enhance the operation and maintenance of the facility after handover (Menna et al, 2024; Valkova, 2022).

The importance of BIM adoption is further highlighted by recent research. Mgbere et al. (2018) emphasize BIM's role in managing smart city projects, promoting efficiency and sustainability. However, for BIM to fully realize its potential, especially in large-scale projects, contractual frameworks such as FIDIC need to evolve to incorporate BIM's collaborative processes. Valkova (2022) underscores the increasing importance of integrating digital technologies like BIM into FIDIC contracts for construction project management. She points out that while FIDIC offers a solid legal foundation, its traditional structure is not fully aligned with the dynamic nature of BIM, which may lead to inefficiencies and contractual conflicts. This misalignment is a key issue that needs to be addressed to ensure seamless collaboration among project stakeholders. Despite the potential benefits of combining BIM and FIDIC, the current literature identifies several challenges related to their integration. Muhammad and Nasir (2022) propose a contractual framework for resolving construction disputes using BIM, highlighting the need for contracts that reflect the collaborative and iterative nature of BIM workflows. Similarly, Ragab and Marzouk (2021) pointed out that traditional contracts, including FIDIC, require substantial adaptation to support BIM processes effectively. Also, Spassova et al. (2019) explore project integration management within FIDIC contracts, suggesting that a more flexible and collaborative approach, such as FAC-1, may be better suited to support BIM. In addition, Abdelwahab and Nassar (2024) explore legal barriers to BIM implementation in Egypt, revealing that existing contractual frameworks often pose significant hurdles to BIM adoption, particularly in countries with traditional construction practices.

In the BIM environment, the outputs of any appointed party start with the Exchange Information Requirements (EIR), prepared by the appointing party. But EIR cannot solely define and frame all the processes, procedures, the authority, and the governance within a contract, especially in contract for works and that is why a written protocol incorporated in the contract is required to bridge the outputs in BIM environment with general obligations of the appointed party (in this case – the Contractor). Therefore, to successfully integrate BIM into a project governed by the FIDIC Red Book 2017 (Conditions of Contract for Construction for Building and Engineering Works

Designed by the Employer), specific clauses should be amended or added to address the new challenges and workflows introduced by BIM. In Advisory notes to users of FIDIC contracts, FIDIC Red Book 2017 states that FIDIC intends to publish a *Technology Guideline* and a *Definition of Scope Guideline Specific to BIM* – documents with the aim of providing detailed support in preparation of particular contract conditions. It also states that these documents are under preparation and are expected to be released shortly after the publication of the updates of the 1999 suite of FIDIC contract forms (FIDIC, 2017). However, until today, these documents have not been published yet.

Given these evolving dynamics, this paper seeks to provide an overview of how BIM can be implemented within the context of the FIDIC Red Book 2017, referencing key clauses related to intellectual property rights, data exchange, and collaboration. While efforts in this study have been made to identify and cover the most pertinent clauses, it is possible that some sub-clauses or specific aspects of the FIDIC contract conditions may not be fully addressed or interpreted differently depending on project-specific requirements. Therefore, it is strongly recommended that legal professionals and contract specialists conduct a thorough review of the contract, as well as any project-specific amendments, to ensure that all relevant clauses and provisions are appropriately incorporated and tailored to the specific needs of the project. The content provided here should not be considered as exhaustive legal guidance but rather as a starting point for the preparation of the contract.

The paper is organized as follows. First, an analysis of relevant clauses and guidelines for implementing BIM is presented, focusing on synergies between collaborative BIM processes and FIDIC contract structure. The conclusion will summarize key findings, offer practical recommendations for integrating BIM into FIDIC contracts, and identify areas for future research that can further enhance the intersection of digital technologies and construction contracts.

2. Analysis of relevant clauses and providing guidelines for implementation of BIM

Despite the lack of *official* support from FIDIC, it is still possible to prepare and implement the contract for works in BIM environment under FIDIC contract conditions, however, many of the clauses and sub-clauses require significant interventions. In this section, certain aspects of the contract for works are identified as those requiring alignments with implementation in BIM environment. Below are key areas where amendments or supplementary clauses should be considered.

2.1 Clause 1: General Provisions

<u>1.1 Definitions:</u> Definitions related to BIM should be added, such as: BIM model which define the basic structure of a project (known as a 3D BIM Model), BIM model with time, scheduling and logistics information (known as 4D BIM Model), BIM model with estimating and cost information (known as a 5D BIM Model), Project Information Model (PIM), Asset Information Model (AIM), BIM Execution Plan (BEP), BIM Manager/BIM Coordinator, Common Data Environment (CDE), Exchange Information Requirements (EIR), Level of Information Need (LOIN), etc.

<u>1.3 Notices and other communications:</u> This clause should be updated to include provisions for electronic communications, particularly BIM-related exchanges, specifying formats, software, and protocols for data exchange between parties. Communication in BIM environment implies the use of CDE for all communication and collaboration between stakeholders. Here, the CDE should be defined as an official mean of communication. Furthermore, the use of openBIM standards,

such as BCF, should be encouraged to allow structured communication in a standardized format, which enhances clarity and traceability within CDE. This means that any notice, approval, decision, consent, claim, instruction etc. should be transmitted through the CDE and uniquely assigned to authorized stakeholders' representatives. Of course, there might be some exceptions such as the issuing of Interim Payment Certificates (IPCs), notice for termination of the contract, notice of an exceptional event (force majeure) and maybe a few more, depending on the employer's internal administration systems. Throughout the whole general conditions, written (physical) communication should be replaced with the CDE.

<u>1.5 Priority of Documents:</u> This sub-clause outlines the priority of contract documents in case of any inconsistency or conflict between them. Here, any of the documents governing BIM implementation should be incorporated in the hierarchy sequence. This should at a minimum include the EIR, 3D BIM models (including the designer's BEP from the design phase, if applicable), and the Contractor's BEP. The standard clause typically lists the order in which the documents take precedence, but in the context of integrating BIM into a FIDIC contract, it is important to address how the BIM models, BEP and EIR interact with the traditional project documents. Here's how the priority of contract documents in sub-clause 1.5 can be amended to reflect the role of BIM:

- (a) the Contract Agreement;
- (b) the Letter of Acceptance;
- (c) the Letter of Bid;
- (d) the Particular Conditions Part A – Contract Data;
- (e) the Particular Conditions Part B – Special Provisions;
- (f) General Conditions;
- **(g) the Exchange Information Requirements (EIR);**
- (h) the Specification;
- **(i) 3D BIM Models;**
- (j) the Drawings;
- (k) the Schedules (Bill of Quantities);
- **(l) Contractor's BIM Execution Plan (BEP);**
- (m) the JV Undertaking (if the Contractor is a JV);
- (n) any other documents forming part of the Contract.

Inconsistencies between the BIM model and traditional drawings, specifications, or schedules are a common concern. A decision should be made about whether the BIM model should take precedence over traditional 2D documents. Given BIM's central role in modern construction projects, and the general idea that the BIM model should be a single source of truth, the model should be given higher priority, but this will depend on the specific project setup.

Updates and changes to the BIM model should also be covered. The dynamic nature of BIM means that the model will be updated regularly as the project progresses. It is essential to establish a process for version control and for ensuring that the most recent version of the BIM model is the one being referred to as part of the contract. Sub-Clause 1.5 could be amended to state that only approved versions of the BIM model will have contractual authority, and the BIM Manager or Engineer should be accountable for approving these updates.

The BEP is central to the successful implementation of BIM and must be included as a contractual document. The BEP outlines how BIM will be used and maintained throughout the project, and it should be given weight in the priority of documents.

<u>1.10 Employer's Use of Contractor's Documents:</u> In projects involving BIM, this sub-clause be-

comes highly relevant as it governs the use of digital models and intellectual property created by the Contractor within the BIM environment. The Particular Conditions should clarify the extent of the Employer's rights to use, modify, or further develop the BIM model. If the Employer seeks broader rights (such as ownership of the model or the right to share it with third parties), these should be clearly articulated. Usually, the Contractor maintains ownership of the intellectual property (such as the design or the methods used in creating the model), while the Employer has a license to use the model for its intended purpose. If the BIM model integrates components or designs that involve third-party intellectual property (such as proprietary software, licensed components, etc.), the Employer's rights under sub-clause 1.10 should be carefully aligned with the terms of any third-party licenses (Abdelwahab and Nassar, 2024).

<u>1.11 Contractor's Use of Employer's Documents:</u> The BIM model (or parts of it) provided by the Employer should also be covered by this sub-clause. The Contractor must ensure that any digital documentation, models, or BIM-related information provided by the Employer is used solely for the project and not for other purposes without prior approval. Any modifications or permissions to reuse BIM data should be explicitly outlined in the Particular Conditions of the contract, specifying restrictions on sharing and confidentiality regarding the Employer's intellectual property (Abdelwahab and Nassar, 2024).

Clause 3: The Engineer

<u>3.1 The Engineer:</u> this clause should be amended to include the Engineer's role in BIM management such as overseeing the general alignment with the EIR, the accuracy of the BIM model, the development and approval of the integrated BIM models with information related to the basic structure, time and cost information (known as integrated 4D and 5D BIM models), coordination with the BIM Manager, and approving updates to the BEP. Also, responsibilities regarding reviewing and approving design submissions within the BIM environment and verifying that the design meets the required Level of Information Need (LOIN) at specific project milestones should also be included.

<u>3.7 Agreement or Determination:</u> BIM introduces real-time information and data-sharing capabilities, which means determinations of changes, variations, or potential issues can be identified earlier. The Engineer's role should be expanded to incorporate making determinations based on digital model assessments, ensuring that the model is up to date before any critical decisions are made.

2.3 Clause 4: The Contractor

<u>4.1 Contractor's General Obligations:</u> this sub-clause needs to clarify that the Contractor is responsible for developing design documentation in the BIM environment. This includes maintaining and updating the Federated BIM model, coordinating with subcontractors and other parties within the digital framework, and ensuring that all deliverables meet the project's BIM standards. Therefore, obligations to be incorporated are such as:

- submitting design deliverables (such as models, drawings, and specifications) in the agreed BIM format and at the specified LOIN;
- ensuring that all subcontractors or consultants contribute to the BIM model in accordance with the contractual obligations and the BEP;
- integrating various disciplines (architectural, structural, MEP, etc.) into the BIM model to ensure comprehensive and clash-free design documentation;
- developing and maintaining integrated 4D and 5D BIM models throughout the project lifecycle.

4.5 Training: this sub-clause should be amended to include the Contractor's responsibility for providing facility management training as part of the obligations under the Contract. The training should cover the use of the AIM and any relevant facility management systems.

4.9 Quality Management and Compliance Verification Systems: this sub-clause could include specific obligations related to the quality control of BIM data. The Contractor must ensure that the models are continuously updated, accurate, and usable for both construction and post-construction phases.

4.20 Progress Reports: Under this sub-clause, the Contractor is already required to submit regular progress reports detailing the status of the works. For a BIM project, these progress reports should be expanded to include the status of the works based on metrics from the integrated 4D and 5D BIM models.

2.4 Clause 5: Subcontracting

5.1 Subcontractors; 5.2 Nominated Subcontractors: throughout these sub-clauses it is necessary to ensure that subcontractors working on the project are also bound by BIM-related obligations. All nominated subcontractors should be required to use the BIM environment for developing and coordinating their parts of the design. These sub-clauses should specify that:

- subcontractors must contribute to design documents in BIM format, ensuring consistency with the overall project model;
- the Contractor remains responsible for managing the integration of subcontractor models into the project Federated BIM model.

2.5 Clause 8: Commencement, Delays and Suspension

8.3 Programme: this sub-clause should be amended to require the Contractor to submit a programme aligned with the EIR. The programme should outline the information deliverables and their respective deadlines, ensuring the proper flow of data during the project lifecycle. The inclusion of an integrated 4D and 5D BIM Model as part of the programme is also necessary. It is recommended that integrated 4D and 5D BIM models are developed based on a well-structured Work Breakdown Structure (WBS) and using relevant scheduling methods (e.g., Critical Path Method – CPM, Location Based Scheduling – LBS). International standard which provides guidelines for development of well-structured WBS is ISO 21511 (ISO 21511, 2018). The contractor should be obligated to provide regular updates to the integrated 4D and 5D BIM Model, ensuring that the actual progress of the works is reflected accurately in the digital model.

It is important not to intertwine the programme with the BEP too much, to avoid causing duplication and confusion between these two documents and their scope of obligations.

2.6 Clause 12: Measurement and Valuation

12.1 Works to Be Measured: In a traditional FIDIC contract, this sub-clause outlines that works must be measured based on physical quantities. In a BIM environment project, this sub-clause could be expanded to specify that the 5D BIM model will be used for measurement purposes. The 5D BIM Model integrates the quantities extracted from the 3D design model with cost data, enabling automatic and more accurate measurement of works performed. The modified sub-clause could introduce:

- BIM Model as a Source of Quantities: The 5D BIM Model could be recognized as the primary source for measuring quantities, replacing manual take-offs from 2D drawings. Quantities for payment purposes could be

extracted directly from the BIM model and validated by the Engineer.
- Automatic Quantity Extraction: The Contractor must ensure that the 5D BIM Model is regularly updated, with automatic quantity take-offs reflecting the current state of the works.

12.2 Method of Measurement: this sub-clause outlines how the works will be measured. In a BIM environment project, this sub-clause could be amended to incorporate BIM-based measurement methods. The following considerations should be made:
- Model-Based Measurement Standards: The contract could reference a BIM-specific method of measurement that aligns with the project's requirements.
- Consistency with the 5D BIM Model: The method of measurement must be consistent with how the 5D BIM Model is structured. For example, the model must clearly differentiate between different construction elements and types of works, enabling accurate measurement.

12.3 Valuation of the Works: this sub-clause governs the valuation of the works, which in a traditional setting is based on the quantities measured in accordance with sub-clause 12.1 and valued using the rates in the Bill of Quantities (BoQ). In BIM environment, this process could be integrated into the 5D BIM Model, ensuring that valuation is based on real-time quantities and costs. The sub-clause could be amended as follows:
- Valuation Based on 5D Model Data: The valuation of the works will be based on the quantities extracted from the 5D BIM Model and the corresponding rates from the BoQ. The Contractor is responsible for updating the model to reflect the actual progress of the works.
- Real-Time Cost Tracking: The 5D BIM Model should be updated regularly to track the real-time cost of the works. The valuation will reflect the quantities and costs updated in the model, providing a more dynamic and accurate picture of project costs.
- Engineer's Review of the 5D BIM Model: The Engineer will review the 5D BIM Model as part of the valuation process, ensuring that the quantities and costs in the model are correct and align with the BoQ.

2.7 Clause 13: Variations and Adjustments

13.1 Right to Vary: The introduction of BIM does not change the right to vary the works, but it does alter the way variations are managed and valued. This sub-clause should be expanded to reflect the digital management of variations through the CDE and the 5D BIM Model:
- BIM-Based Variations: Variations should be updated and reflected in the BIM model. Once approved by the Employer, the Contractor must incorporate the variation into the BIM environment, adjusting the model's quantities and cost estimates accordingly.
- Engineer's Review of Variations in the 5D BIM Model: The Engineer will use the 5D BIM Model to assess the impact of any approved variations on the project cost. The Contractor must provide updated cost information through the model to facilitate this review.

2.8 Clause 17: Care of the Works and Indemnities

17.3 Intellectual and Industrial Property Rights: This sub-clause is highly relevant to BIM, where the ownership of digital models, embedded data, and design rights must be clarified. The Particular Conditions should outline who holds ownership of the BIM model and who retains rights to use the data beyond the project lifecycle. Clear guidelines on the use, sharing, and reuse of BIM models are critical, especially when third-party intellectual property (such as software or licensed components) is integrated into the BIM environment (Abdelwahab and Nassar, 2024).

17.6 Shared Indemnities: this sub-clause should be amended to address liabilities related to BIM, such as software failures, data corruption, or errors in the BIM model that lead to project delays or defects. It should be clarified which party is responsible for ensuring that BIM data is accurate and complete, and how risks related to BIM data errors will be allocated.

2.9 Supplementary Clauses: Introducing BIM-Specific Provisions

1. BIM Execution Plan (BEP)

Supplementary Clause: a clause making the BEP contractual document should be introduced. The BEP should be identified as the Contractor's Document in 4.4 [Contractor's Documents] and should outline how the parties will use BIM, the responsibilities of each party regarding the model, software requirements, data formats, and procedures for collaboration.

It should be specified how the BEP will be updated, who approves changes, and the procedures for managing updates to the BIM model during the project lifecycle.

2. Common Data Environment (CDE)

Supplementary Clause: a clause governing the use of the CDE, defining the platform, data-sharing protocols and workflows, access permissions, and security measures for the digital project space should be introduced. This clause should also define the obligations of each party in maintaining the CDE.

3. BIM Manager Appointment

Supplementary Clause: there should be a provision for appointing a BIM Manager or BIM Coordinator, who will be responsible for overseeing the implementation of BIM, ensuring that the model is updated regularly, and coordinating data flow between stakeholders. The BIM Manager's tasks should include:

- ensuring compliance with the BEP;
- coordinating contributions from various parties;
- managing the CDE and ensuring proper access to design documentation;
- running clash detection processes and verifying that the design is coherent and buildable.

4. Asset Information Model (AIM) Delivery

Supplementary Clause: there should also be a clause specifically for the delivery of the AIM, which is the finalized as-built BIM model that the Employer will use for facility management. The Contractor should deliver the AIM to the Employer as part of the handover process. The AIM should include all necessary information for the operation and maintenance of the Works, including as-built data, equipment specifications, warranties, and maintenance schedules. The AIM should be submitted in a format agreed upon in the EIR.

3.Conclusion

The integration of BIM into FIDIC contracts represents a transformative approach that aligns with the evolving demands of the construction industry in the digital era. This paper explores how traditional FIDIC contracts offer a strong foundation for project management but need to be further adapted to fully embrace the collaborative and technological opportunities BIM introduces. Adapting FIDIC contracts to better reflect the collaborative nature of BIM will help clearly define roles, responsibilities, and risk allocation in projects that leverage these digital tools.

This study has highlighted the importance of modifying FIDIC contracts to accommodate BIM processes. Key areas requiring attention include collaboration and information exchange, data ownership and intellectual property, the identification of new roles and responsibilities, risk management strategies, dispute resolution mechanisms, and effective time and cost management.

Integrating BIM into FIDIC contracts offers numerous advantages. Enhanced coordination and real-time information sharing improve overall project efficiency and reduce the likelihood of errors, resulting in smoother project delivery. Collaborative BIM environment encourages teamwork and leads to better project outcomes. Its digital nature also supports proactive risk management by providing greater visibility into potential challenges. Additionally, using BIM throughout the asset lifecycle creates long-term value that extends well beyond the construction phase.

In conclusion, successfully integrating BIM into FIDIC contracts requires stakeholders to collaborate to develop clear guidelines and amend existing contractual frameworks. This involves defining roles such as the BIM Manager, clarifying data ownership rights, and establishing protocols for accurate model management and verification. By addressing these aspects, project teams can unlock the full potential of BIM, promoting innovation and efficiency in construction projects.

Future research should continue to explore the legal and procedural aspects of BIM integration within different contractual frameworks globally. This ongoing work will help the construction industry evolve toward a more integrated and efficient future, benefiting all parties involved.

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Sustainability projects in insurance industry - case study on insurance company

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Abstract:

Sustainability is a concept that is well known, but often not fully understood. It consists of a wide range of activities that are environmentally responsible, socially just and economically sustainable in the long term. In other words, these types of activities take into account the factors of sustainable development that have been defined by United Nations Sustainable Development Goals (SDGs). In this context, it is important to mention that sustainability projects are applicable in every industry and company, which increases their importance for all stakeholders to achieve global CO2 emission goals, thus affecting the climate neutrality and general sustainability of our planet earth.

The purpose of this paper is to investigate sustainability projects in real life and their results in practice in the insurance industry by examining the case study of a Croatian insurance company. Analysis and discussion of its practical experience and the value it creates can be of great benefit to other insurance companies and financial institutions in their project portfolio management. Furthermore, it enables the financial industry to lead by example in sustainable development.

The outcome of this case study contributes to the understanding of the entire issue and provides practical examples of how insurance companies can effectively implement sustainable development processes in their business strategies and daily operations. The aim of this paper is to provide guidelines for further research into successful implementations of sustainable development in the business environment.

Keywords: *Sustainability; ESG, Insurance industry, Insurance company, Project management; Financial institutions*

1. Introduction

Climate change refers to a lasting shift in the typical weather patterns that affect the local, regional, and global climates of Earth that are largely caused by human activities, especially the burning of fossil fuels. This process elevates the concentration of heat-trapping greenhouse gases in the atmosphere, leading to an increase in the planet's average surface temperature.

Global warming refers to the sustained rise in Earth's surface temperature due to same reasons as climate change. Since the pre-industrial period, human actions have raised Earth's global average temperature by approximately 1 degree Celsius, with the rate of increase now surpassing 0.2 degrees Celsius per decade. The current warming trend, which has accelerated since the 1950s, is clearly a result of human activity and is occurring at a speed unmatched over millennia (NASA, https://science.nasa.gov/climate-change/what-is-climate-change/).

In order to mitigate the effects of climate change and global warming, it is essential to cut greenhouse gas emissions (i.e. CO2 emissions) by a large amount. Countries around the world have formally committed to this initiative, as part of the 2015 Paris Climate Agreement (i.e. Paris Agreement), to lower their emissions by setting new standards and crafting new policies to meet or even exceed those standards (MacMillan and Turrentine, 2021, https://www.nrdc.org/stories/global-warming-101#causes).

The year 2015 was also globally significant because of the adoption of the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States. At the core of the initiative are the 17 Sustainable Development Goals (SDGs), which serve as an urgent appeal for action by all nations through global collaboration. These goals acknowledge that eradicating poverty and other hardships must be accompanied by efforts to enhance health and education, decrease inequality, and drive economic growth, all while addressing climate change and protecting our oceans and forests (https://sdgs.un.org/goals).

Europe, as the fastest warming continent (C3S, 2024), has set ambitious climate goals when it comes to climate change and global warming. In 2019, the European Union (EU) adopted the European Green Deal. It represents an ambitious plan to achieve climate neutrality1 in the EU by 2050, while by 2030 it is planned to reduce greenhouse gas emissions by 55% compared to 2019. The implementation of the plan is based on the adoption of the relevant regulatory framework by the EU such as the "Fit for 55" legislation package. According to the EU Green Deal, a strong emphasis is placed on increasing the sustainability of the operations of public and private sector companies. Increasing the sustainability of companies is closely related to their impact on environmental, social and management factors (i.e. ESG factors).

Accordingly, a trend of ESG standardization has been launched in the world, which aims to assess the level of sustainability of companies regardless of their location, industry or size. Numerous financial institutions and consulting firms have launched their ESG ratings for various purposes to assess the credit and other risks and opportunities of each company. In addition to risk assessment, the ESG rating provides a representative benchmark for measuring companies' performance in terms of sustainable development and ESG factors, which brings numerous benefits for all stakeholders.

1 The technically correct term is "net carbon neutrality". In other words, it is the moment when the total amount of (annual) reduction of CO2 emissions will be equal to the amount of (annual) CO2 emissions.

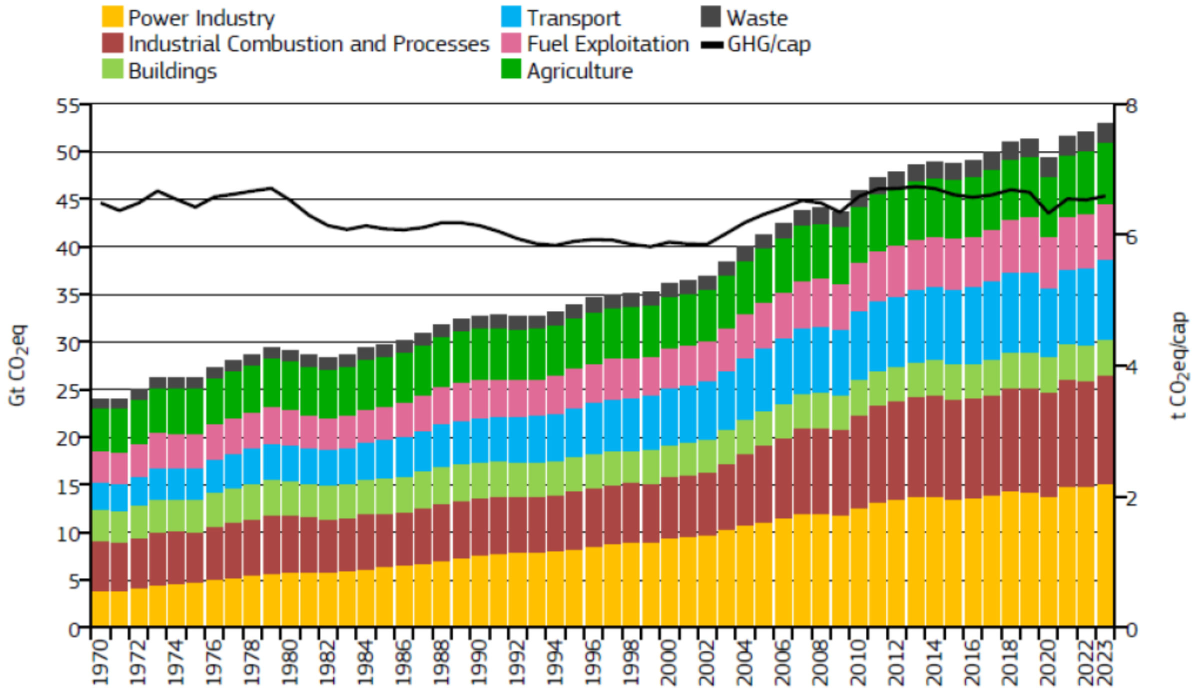

Figure 1. Global GHG emissions by sector (left axis, bars) and per capita (right axis, black line), 1970-2023 (source: JRC, 2024)

Figure 2 shows the movement of total global GHG emissions over the period 1970-2023. Global emissions reached by the end of 2023 the level of 53.0 Gt CO2eq, which is 1.9% higher than the 2022 value. This represents an increase in annual relative change when compared to the relative change in GHG emissions between 2022 and 2021 (1.4%). Since global emissions are still steadily increasing, these kind of result suggest that the activities being carried out are not enough to stop this trend.

On Figure 2 emissions are broken down in main sectors (power industry, industrial combustion and processes, transport, buildings, agriculture, waste and fuel exploitation). In 2023, all sectors increased their emissions, with transport showing the largest increase, both in relative (+3.7%) and absolute terms (301 Mt CO2eq). Therefore, it is evident that there is room for improvement in all industries, especially when it comes to developing and realizing sustainability projects.

In the following chapter, an overview of existing literature on sustainability projects in companies is given.

2. Overview of existing literature

There are currently tens of thousands of scientific papers addressing sustainability, with a growing number published annually. According to bibliometric studies, sustainability research has seen an explosive increase, particularly since 2015 with the introduction of the UN's 17 Sustainable Development Goals (SDGs). In just one journal, Sustainability, there has been a significant growth rate, with an annual rise in publications of around 53% (Sheu and Lee, 2023).

Across all research fields, sustainability science encompasses interdisciplinary research, with key areas including climate, biodiversity, energy, and economic development. By 2020, over 4,500 articles specifically referenced SDGs (Meschede, 2020), and sustainability continues to be one of the most active fields in science, covering broad domains such as life sciences, social sciences, and environmental studies (Schirone, 2024).

The vast number of papers reflects global efforts to address sustainability challenges, driven by scientific, policy, and social priorities. Sustainability in the insurance industry has become an increasingly researched topic due to the rising importance of Environmental, Social, and Governance (ESG) practices. Recent studies explore how insurers integrate sustainability into their business models, both in terms of operational risk management and investment strategies.

Several papers highlight the positive impact of ESG factors on the financial stability of insurance companies. For example, research shows that insurers with higher ESG scores, especially in the environmental and social dimensions, tend to exhibit greater stability, particularly among life insurers. These firms benefit from long-term objectives, given their investment activities in sustainable projects and infrastructure (Rumyantseva and Tarutko, 2022; Weber, 2023).

Moreover, regulations such as the EU's Solvency II and SFDR (Sustainability-Related Disclosure Regulation) push insurance companies to disclose sustainability risks and opportunities, encouraging the industry to focus on decarbonization and resilience to climate risks. This shift not only mitigates risks like market and credit risk from unsustainable investments but also creates new opportunities in areas like renewable energy and climate-resilient infrastructure (Clarke and Comerford, 2022; DLA Piper)

While still an emerging field, the intersection of sustainability and insurance continues to grow as insurers increasingly recognize the strategic importance of ESG factors in both risk mitigation and value creation. Some of the most popular and influential journals that focus on sustainability are presented in the following table.

Table 1. Popular journals that focus on sustainability (source: Triglav Group, 2023A)

#	Journal	Description
1	**Sustainability (MDPI)**	A prominent open-access journal that focuses on various aspects of environmental, cultural, economic, and social sustainability. It encompasses a wide range of topics, including climate change, renewable energy, and corporate social responsibility (CSR), making it a valuable resource for researchers and practitioners in the field.

#	Journal	Description
2	**Journal of Cleaner Production**	The journal emphasizes environmental and sustainability science, aiming to advance cleaner production methods and promote sustainable consumption practices. It addresses various topics, including industrial ecology, green supply chain management, and life cycle assessment (LCA).
3	**Sustainable Development (Wiley)**	This journal publishes interdisciplinary research aimed at furthering the objectives of sustainable development. It encompasses a wide range of topics, including the formulation of policies, environmental sustainability, economic sustainability, and social sustainability.
4	**Ecological Economics**	This journal focuses on the convergence of ecology and economics, exploring the ecological and economic principles that underpin sustainable development. It addresses a wide array of topics, including natural resource management, sustainability metrics, and the valuation of ecosystem services.
5	**Global Environmental Change**	This highly cited journal publishes research on global environmental changes that are often tied to sustainability issues. By providing insights into these critical areas, the journal aims to enhance understanding and foster discussions around effective strategies for addressing global environmental challenges.
6	**Sustainability Science (Springer)**	This multidisciplinary journal addresses the complex challenges in sustainability research, particularly at the intersection of natural and social systems. It focuses on critical topics such as land use, energy systems, and sustainable urban development.
7	**Environmental Science & Policy**	This journal serves as a platform for merging environmental science with policymaking, emphasizing solutions that foster sustainability. It covers a range of topics, including environmental governance, sustainable agriculture, and water resource management.

These journals are highly esteemed within both academic and professional realms, playing a crucial role in advancing the field of sustainability science. Globally, there are hundreds of sustainability journals that reflect the interdisciplinary essence of sustainability research. These publications cover a wide array of topics, ranging from environmental sciences to economic and social sustainability. The number of such journals has been rapidly increasing in recent years, largely driven by a heightened focus on sustainability objectives, climate change, and corporate social responsibility (CSR) initiatives.

In total, across various publishing platforms, there are over 500 sustainability-specific journals. This number continues to grow as interest in environmental, social, and governance (ESG) issues expands across different sectors.

3. Impact of sustainability projects on company's business performance

Sustainable development is something that should be present in the business of every organization. It consists of areas that are focused on environmental, social and governance issues (i.e. ESG factors). When it comes to environment, the main element of this aspect is how company's businesses affect the climate in terms of energy consumption and greenhouse gas emissions.

3.1 Greenhouse gas emissions (GHG)

These emissions can come from Scope 1, 2 and 3 which is a way of categorizing the different kinds of carbon emissions a company creates in its own operations. The term first appeared in the Green House Gas (GHG) Protocol of 2001 and today, Scopes are the basis for GHG reporting (Deloitte, 2021).

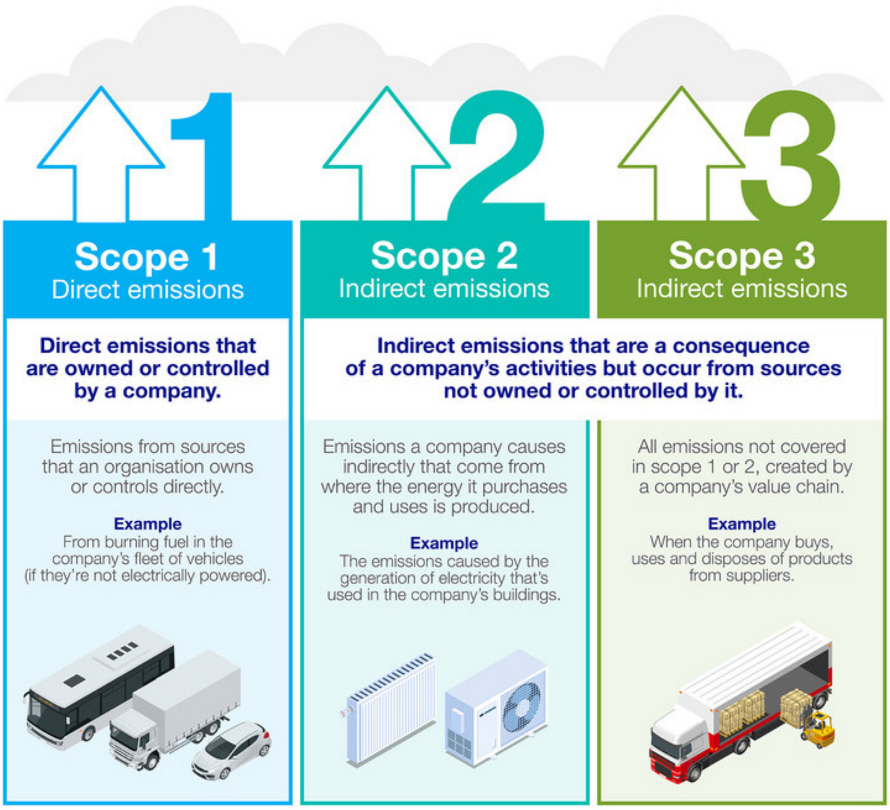

Figure 2. Definition and examples of Scope 1, 2 and 3 emissions (source: https://www.nationalgrid.com)

Since the beginning of the 21st century, global GHG emissions have grown in comparison to the two previous decades, mainly due to the increase in fossil CO2 emissions. China, the United States, India, the EU27, Russia and Brazil were the six worlds' largest GHG emitters in 2022 according to (Crippa et al., 2023).

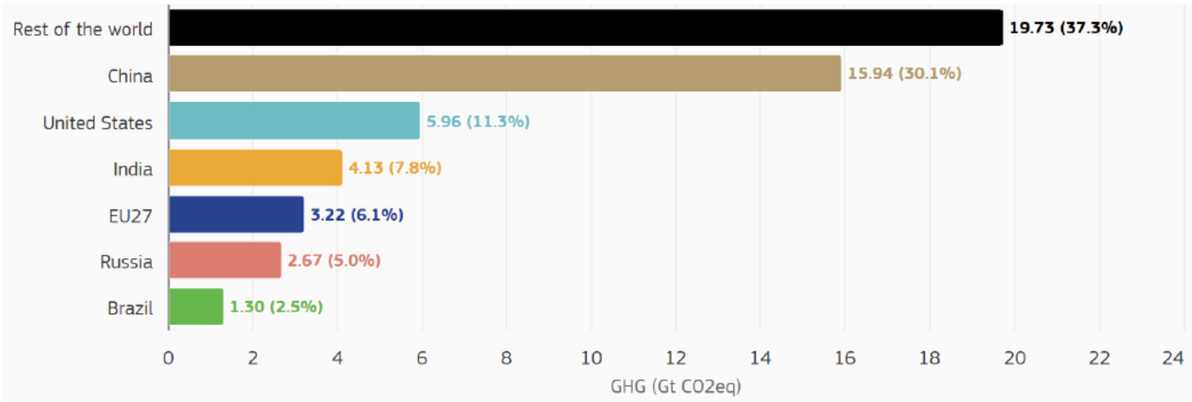

Figure 3. GHG emissions of the major emitting economies and the rest of the world in 2023 (source: JRC, 2024)

From the previous figure we can see a large dispersion between China and USA and other countries such as Europe which is represented by 27 members of the European Union (EU). Nevertheless, Europe is the fastest warming continent; twice as fast as the world average (C3S, 2024). The EU has set ambitious climate goals including the reduction of greenhouse gases by 55% by 2030 and achieving net carbon neutrality until 2050 (European Green Deal).

To achieve climate goals of the European Green Deal, significant public and private investments are necessary. The greatest reduction of GHG emissions is possible in the production of electricity and thermal energy, decarbonization of the processing industry, increase of energy efficiency of buildings and the transformation traffic towards electrification. Reduction in emissions is associated with significant additional investments, which are estimated at 2% of global GDP annually until 2030 (Pisani-Ferry and Mahfouz, 2023.).

The motives for investments through sustainability projects by companies can be multiple (Vujčić, 2024):

- reducing dependence on energy sources whose prices are subject to fluctuations.
- reducing energy costs
- fulfilling legal obligations
- sustainability reporting obligations
- preferences and requirements of end consumers
- expectations of (future) employees
- bank requirements / achieving more favorable financing conditions.
- reputational concern

In the following part of this paper, it is presented how sustainability projects positively impact company's business performance through targeting specific ESG factors, i.e. environment, social responsibility, and governance.

3.2 Impact of sustainability projects on business performance and ESG factors

The environmental part of the ESG is the main component in reducing greenhouse gas emissions. Two similar and often used terms come up when dealing with this issue. The first one is the term "net zero" which represents minimizing greenhouse gas emissions as much as possible through actions such as shifting to renewable energy sources, enhancing energy efficiency, and implementing sustainable practices. Net-zero emissions occur when all emissions generated by human activities are offset by removing an equivalent amount of carbon from the atmosphere, a process called carbon removal. Achieving net zero involves a two-part strategy: first, human-caused emissions, such as those from fossil fuel-powered vehicles and industrial processes, must be reduced as much as possible. Second, any remaining emissions should be balanced by carbon removal methods, either through natural solutions like forest restoration or through technological innovations (WRI, 2023).

The second term is "carbon neutrality," and it refers to company's actions that aim to balance the total amount of GHG emissions it generates by either cutting its emissions or investing in initiatives that remove or reduce an equivalent amount of greenhouse gases from the atmosphere. The objective is to reach equilibrium between the emissions produced and those removed, ensuring no net rise in the overall greenhouse gas levels. This concept is also central to the European Green Deal's target for 2050.

The key distinction is that net zero focuses on the goal of eliminating greenhouse gas (GHG) emissions, while carbon neutrality refers to the state achieved by both reducing emissions and offsetting any remaining ones. Achieving carbon neutrality requires organizations to actively reduce their environmental impact and invest in projects that lower emissions. The goal of both net zero and carbon neutrality is climate neutrality. Understanding the difference between these terms helps companies guide efforts to reduce their climate impact and progress toward climate neutrality (https://net0.com/blog/carbon-neutral-net-zero).

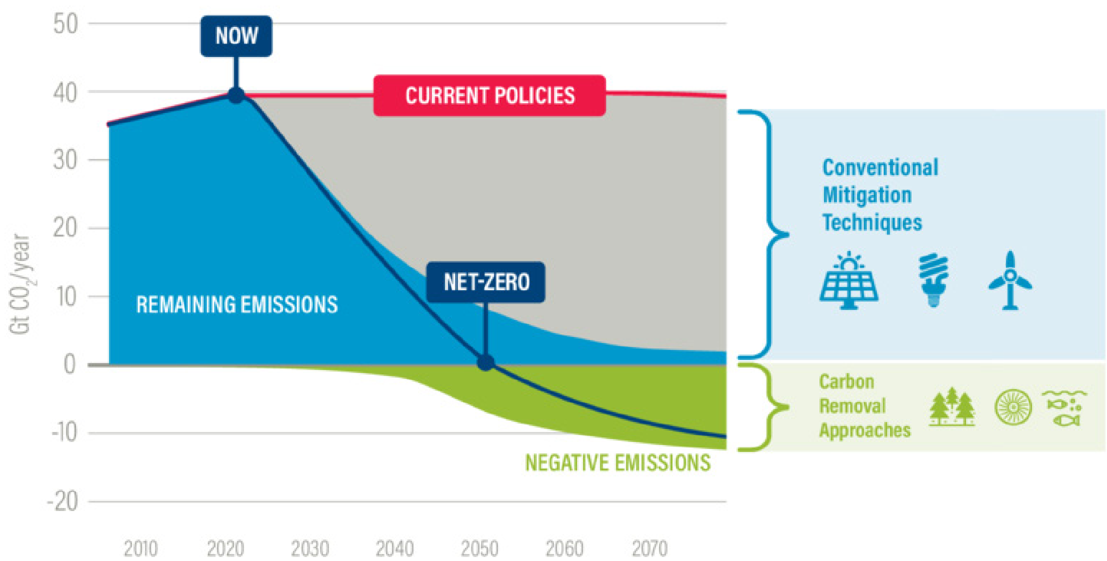

Figure 4. Pathway to net zero and staying below 1.5 degrees of global warming (source: WRI)

In order to get to net zero, companies first need to set their net zero plans and targets that need to be credible and attainable. There are benchmarks to measure and assess net-zero plans by companies from all industries. In their 2022 report, the UN high-level expert group gives 10 recommendations on how business entities can set up their net zero plans.

Table 2. 10 recommendations for companies on how to set up their net zero plan (source: UN expert group report, 2022)

#	Recommendation	Description
1	Announcing a Net Zero Pledge publicly	Should be made public by the leadership of the company and cover all emissions along the value chain in all authorities where business is conducted
2	Setting Net Zero Targets	Targets need to include Scope 1, 2, 3 emissions. If Scope 3 is missing, an explanation is due on what estimates are being used. Set 3-5-year target and after that every five years.
3	Use high-integrity voluntary carbon credits	Use carbon credits for permanent removals to balance out emission that cannot be abated or residual ones.
4	Creating a Transition Plan	The plan must include capex, skills, public advocacy, value chain approach and how to bring the whole organization on board with sustainability initiatives. Progress needs to be reported annually.
5	Phasing Out of Fossil Fuels and Scaling Up Renewable Energy	Pledges need to include targets for ending the use of fossil fuels that need to be matched by transition towards renewable energy. Companies need to explain how they will phase out fossil fuels, gas and non-renewable electricity.
6	Aligning Lobbying and Advocacy	Align external policy and engagement efforts -including membership in trade associations, to the goal of reducing emissions 50% of emissions by 2030 and reaching net zero by 2050.
7	Eliminate activities that negatively affect natural ecosystem from supply chains	Operations and supply chains should avoid conversion of natural ecosystems (e.g. deforestation). A good example of this is given in (Joppa et al., 2021)
8	Disclose emissions data and plans annually	Prepare sustainability reports according to regulatory framework (e.g. CSRD Directive)

#	Recommendation	Description
9	Financial institutions must support development-friendly net-zero	Financing projects that contribute to net-zero goal.
10	Accelerate the road to regulation	Encourage the associations to advocate for positive action.

Sustainability projects with environmental impact help companies achieve carbon neutrality targets. The main priority for this kind of projects is to eliminate emissions through more sustainable alternatives and improve energy efficiency. That is why they need to focus on: (2024 Action Guide (speedandscale.com):

- **Procuring clean energy** – converting office, factory, store, or restaurant to carbon-free electricity

- **Decarbonize transportation –** year-by-year procurement target to 100% electric vehicles by 2030 or electric trucks by 2035.

- **Decrease the carbon footprint of the goods and services a company manufactures or offers** - identifying and cutting emissions for anything a company produces. Find suppliers with high ESG ratings. Use cleaner heat sources for daily operations and switch to climate-friendly materials and packaging.

4. Sustainability projects - Case study of a croatian insurance company

Triglav osiguranje d.d. is part of the Triglav Group, the largest insurance group in Southeastern Europe. Triglav osiguranje d.d. has been present on the Croatian market since 1967 and with a tradition of more than 50 years rightly bears the epithet of one of the oldest insurance companies in Croatia. The business network of Triglav osiguranje consists of approximately 70 sales offices and over 520 employees. Thus, we are ready to provide a complete and timely insurance service - from the conclusion of policies of all types of insurance, to the payment of claims.

The company's mission is to build a safer future and in doing so, it is guided by three values that pervade its daily operations, personal relationship with customers and with the environment: Engagement, Simplicity and Reliability. The Triglav Group's sustainability orientation is based on linking the operations of the Group's companies with the following sustainability aspects (Triglav Group, 2023A):

- **Environmental factors** - These include a company's carbon footprint (greenhouse gas emissions), consumption of natural resources, energy efficiency, climate-related risks, water and waste management, and efforts to protect biodiversity.

- **Social factors -** Focus on responsibilities toward employees, clients, and suppliers, promoting diversity, equality, and inclusion, respect for human rights, and the impact on local and global communities.

- **Governance factors -** Encompass corporate governance practices, a zero-tolerance approach to corruption and bribery, effective risk management, business transparency, investor relations management, tax policy, and ensuring diversity in management and supervisory bodies.

The purpose of the Sustainable Development Policy is to define:

- the method of realizing strategic ambitions in sustainable development (ESG).

- the identification, measurement and management of sustainability factors, which includes identifying risks and opportunities to achieve business objectives.

- the sustainable development management system.

- the guidelines on economic activities sensitive to sustainability risks.

- key corporate governance policies.

- other key aspects of sustainable development, such as responsibility to employees and corporate social responsibility projects.

- the manner of sustainability reporting and collaboration with key stakeholders.

Through its sustainable development policy of Triglav osiguranje and Triglav Group, the company has developed specific sustainability key performance indicators (KPI).

Table 3. Sustainability KPI's (source: Triglav Group, 2023A)

#	KPI	Description/Target by 2025
1	Share of sustainable financial instruments	Double the share of green, sustainable and social impact bonds;
2	Exposures to issuers on the Coal Exit List	Reduce exposure to issuers on the Coal Exit List (companies at which at least 20% of electricity production or income stems from coal) to less than 1% of our total investment value.
3	Carbon footprint per employee	Reduce the location-based carbon footprint (Scope 1 and 2) per employee by 15% compared to the 2019 base year
4	Share of "green" electricity	Increase the share of electricity from renewable energy source to 75%
5	Share of electric/hybrid vehicles	Increase the share of electric and hybrid vehicles in the fleet to at least 30%
6	Share of online training	Maintain a high share of online training, i.e. 30% of training at Group Triglav level will be held online
7	Energy, paper consumption and total waste generated per employee	Reduce energy, paper consumption and total waste generated per employee

4.1 Sustainability projects in Triglav osiguranje d.d.

Triglav osiguranje has realized several major sustainability projects in 2024 that are presented in the following part of the paper in chronological order.

4.1.1 Green electricity

In first quarter of 2024 the company has decided to switch its usage of electricity to exclusively renewable sources and concluded a contract with the local electricity provider2. The renewable source electricity will be used in all company offices and real estate.

The effect of this sustainability initiative is expected to decrease Triglav osiguranje CO2 footprint by more than 15% in year 2024 compared to 2023. Additionally, in year 2025 company is expected to decrease CO2 emissions by 9% compared to 2024 solely from this business decision. Total CO2 emissions reduction from this sustainability project amount to 131 tons of CO2.

For using green energy, the company will also receive guarantees of origin in the Registry of Guarantees of Origin managed by the Croatian Electricity Market Operator (HROTE).

2 More details about this solution on the following link: https://zelen.hep.hr/en

I 4.1.2 SO 50001 – Energy management system

Since measuring and analyzing energy data is essential for implementing sustainability practices, Triglav osiguranje decided to implement the ISO standard 50001 for Energy management system.

In that way, the company achieved multiple benefits. First, an energy baseline was created that is the starting point of measuring and monitoring energy efficiency. Regarding to the energy baseline, a set of potential improvements for energy efficiency was identified and planned in the future period. Whole point of the ISO standard is based on establishing a system for continuous improvement of energy efficiency.

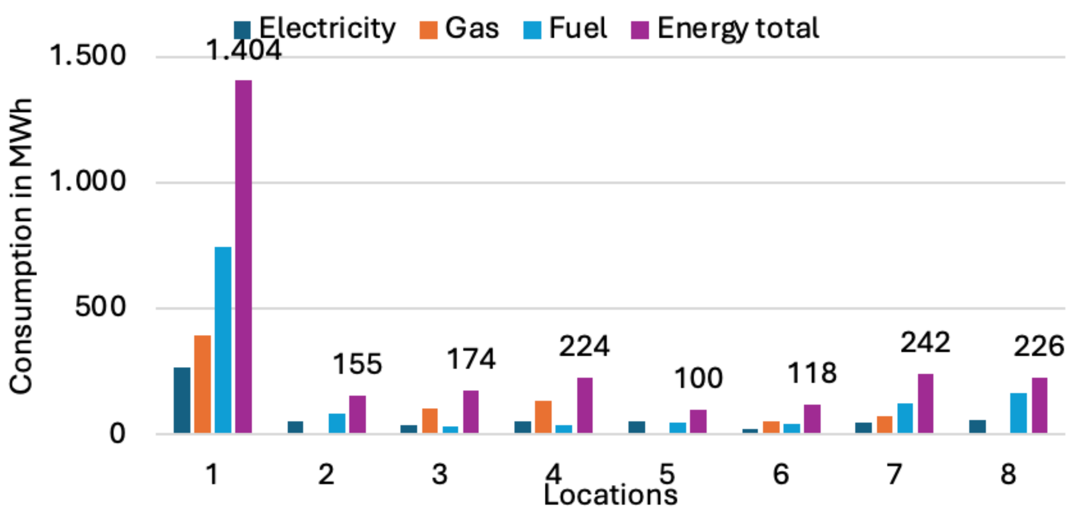

Figure 5. - Overview of Triglav osiguranje consumed energy by type in MWh (source: authors creation)

To calculated energy efficiency Triglav introduced energy performance indicators (i.e. EnPI), which refer to:

- **EnPI 1** – The ratio of the gross written premium in EUR to the total energy consumption by all significant energy sources (electricity, gas, fuel) expressed in kWh by the Company's main locations.

- **EnPI 2** – The ratio of the number of purchased policies and the total energy consumption by all significant energy sources (electricity, gas, fuel) expressed in kWh by the Company's main locations.

Through energy efficiency monitoring, the company will regularly analyze the adequacy of the defined EnPI and improve the indicators as necessary. As a result of the implementation of the ISO 50001 standard, Triglav will conduct a yearly energy audit which will serve to track the performance of defined EnPI's and monitor the realization of energy efficiency improvements.

4.1.3 Charter on volunteering

When it comes to social aspects of ESG factors, Triglav osiguranje decided to sign a volunteering pledge to solidify its commitment towards being a socially responsible company. By the end of the current year, it plans to develop a policy that establishes a system for employee volunteering.

Employee volunteering is a new form of socially responsible business that offers a unique way for organizations to contribute to the well-being of the communities in which they operate. It broadens the scope of how the private sector can engage in philanthropy by going beyond traditional monetary or material donations. This type of volunteering allows businesses to:

- Have employees volunteer their knowledge and skills pro bono to benefit the non-profit sector or individuals.

- Engage employees in volunteer activities that may not relate to their work but address pressing community needs.

The key advantage of employee volunteering is the immediate, tangible results it delivers, as both the company and its employees actively participate in the initiatives. This involvement adds variety to the typical workweek, fosters team spirit, strengthens employees' sense of belonging to the company, and instills pride in working for an organization that supports the community in which they live (https://www.vcz.hr/).

4.1.4 ESG rating

Since EU adopted the European Green Deal in 2019, a trend of ESG standardization has been launched in the world, which aims to assess the level of sustainability of companies regardless of their location, industry or size. Numerous financial institutions and consulting firms have launched their ESG ratings (approx. 150 in the world) for internal purposes to assess the credit and other risks and opportunities of each company. In addition to risk assessment, the ESG rating enables an authoritative comparability of companies in terms of sustainable development and ESG factors, which brings benefits for all stakeholders. Five key benefits of ESG rating (source: HGK):

- ESG performance assessment of the company - insight into ESG risk exposure and management

- Attracting capital and investors - more favorable financing conditions and easier access to capital

- Business operations – optimization of processes and related costs and increasing competitiveness.

- Comparison with other companies in the sector - factor in competitive analysis

- Reputational benefit to all relevant stakeholders (clients, employees, shareholders, partners and suppliers)

Triglav osiguranje participated in the ESG rating for the first time in 2024. The results showed that the Company has achieved an ESG rating of "High rating" and is well on its way to sustainable business. In the overall ranking of 400 companies that participated in the ESG rating analysis, our Company took the 81st place (81/400), which places Triglav in the upper class of sustainable companies. In terms of ranking within the insurance industry, the Company took a high second place out of a total of 13 comparable companies. This indicates that Triglav osiguranje is one of the leaders of sustainable development within the insurance sector, as well as the financial industry.

The company's high ESG ranking in the financial sector is the direct result of the realization of several important sustainability projects during 2024 which were mentioned in the previous part of this chapter. The projects will also help significantly decrease Triglav osiguranje CO_2 emissions by the end od 2024 and in the following years. The end goal is to achieve climate neutrality for its business operations.

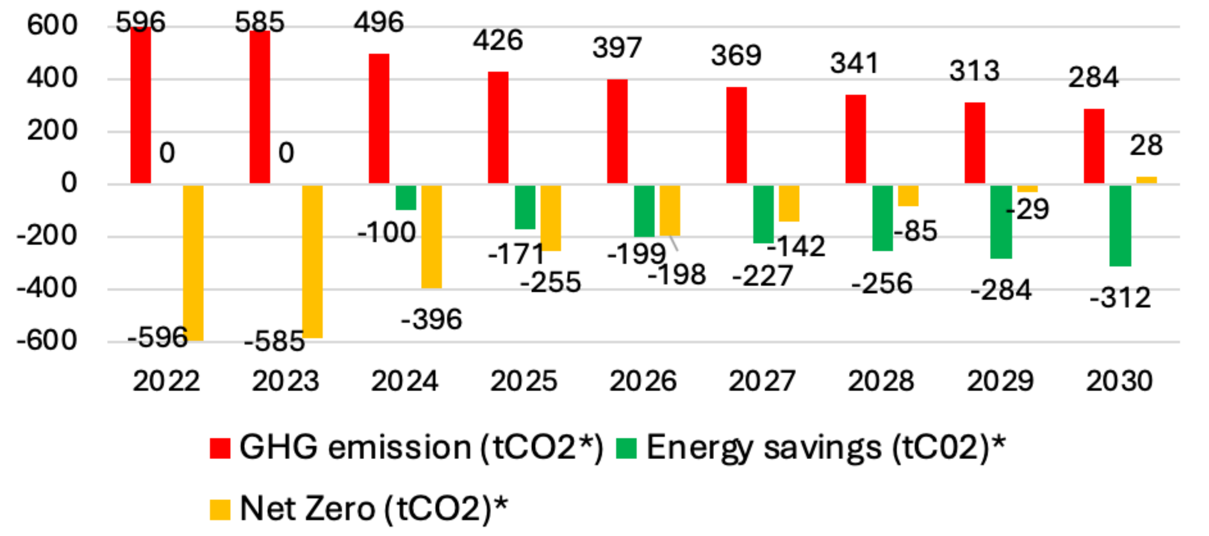

Figure 6. Triglav osiguranje potential pathway to net zero by 2030 (source: authors creation)

4.2. Sustainability reporting in Triglav Group

Triglav Group has been regularly disclosing its non-financial report since 2020 and has also been calculating GHG emissions where the year 2019 was defined as baseline year for tracking the decrease in emissions and energy savings.

In December 2022, the Corporate Social Responsibility Directive (i.e. CSRD) was adopted by the EU and all sized companies are affected by sustainability reporting. Reporting obligations are divided into phases in terms of size of the company and reporting year. Large companies that have more than 500 employees and are quoted on the stock market are obligated to prepare their sustainability reports from 1st of January 2025 for the business year 2024. This also applies to insurance companies, especially if they satisfy the criteria for being considered as large companies.

There is a possibility that if an insurance company is part of a larger Group it can be excepted from sustainability reporting on a solo basis but must be included in the consolidated sustainability report of the parent company. More details on this topic are available in the local regulations in which the provisions of CSRD were transferred.

On the following figure, Triglav Group's ESG key performance indicators are presented for 2023 and 2022. More details about the non-financial reporting are available at: bit.ly/Triglav24.

	2023	2022	Index
1. Environmental aspects			
Carbon footprint (tonnes of CO_2 equivalent)*	8,131	8,649	94
Scope 1 and 2 carbon footprint per employee (tonnes of CO_2 equivalent)*	1.54	1.63	94
Electricity consumption (MWh)	10,342	11,015	94
Share of electricity consumption from renewable sources (%)	61.6	59.0	104
Total quantity of waste at the Triglav Group per employee (kg)	118	125	94
Average daily consumption of office paper per employee**	13	19	68
Written premium from products promoting social and environmental benefits (EUR million)	24.8	20.8	119
Assets under management in funds that incorporate sustainability aspects (EUR million)	1,139.0	49.2	2,313
Investments in social impact, green and sustainable bonds (EUR million)	262.5	222.9	118
2. Social aspects			
Employee satisfaction (ORVI)	3.94	4.00	99
Average employee age	45.1	44.8	101
Women employees to total employees ratio (%)	55.0	54.7	101
Proportion of women at first and second management levels under the management board (%)	42.6	41.2	103
Employee turnover (number of leavers/average number of employees; %)	12.0	11.6	103
Average number of training hours per employee	32	33	96
Lost time incident rate – LTIR (number of work-related incidents/total number of hours of all employees x 200,000)	0.38	0.37	101
Client satisfaction of Triglav Group (NPS)***	73	77	95
Number of insurance products and services sold online	23	22	105
Number of insurance products promoting prevention	62	62	100
Proportion of employees allowed to work from home (%)	36	33	110
Number of suppliers checked against ESG criteria	865	419	206
Investments into the community (prevention, donations, sponsorships) (EUR million)	8.9	10.2	87
3. Governance aspects			
Proportion of women in the management board/supervisory board in parent company (%)	20.0/25.0	25.0/0	
Proportion of women at the first management level under the management board (%)	46.5	45.1	103
Proportion of women in management and supervisory bodies (%)	25.5	23.6	108
Average age of Zavarovalnica Triglav Management Board members	47.8	48.5	99
Independence of Zavarovalnica Triglav Supervisory Board members, shareholder representatives (% of members)	100	78	129
President of the Management Board salary to the average employee salary ratio (factor x)****	5	5	100
Term of office of the current President of the Management Board (years)	10	9	111
Policies adopted: equal opportunities policy, anti-corruption policy, employee protection/whistleblower protection policy	YES	YES	
Fair business practices (number of fraud cases investigated)	1,771	1,651	107
Internationally renowned audit firm (Big 4)	YES	YES	
Period of cooperation with the existing auditor (years)	5	4	125
Investor relations when publishing results	YES	YES	
Economic value generated (EUR million)	1,642.4	1,318.9	125
Economic value distributed (EUR million)	1,682.9	1,409.9	119
Economic value retained (EUR million)	-40.5	-91.0	

Figure 7. ESG aspects of the Triglav Group (source: Triglav Group, 2023)

5. Conclusion and discussion

The first step toward creating a successful and sustainable society is recognizing sustainability challenges and being prepared to address them. In line with the Paris Agreement and the European Green Deal, EU Member States have committed to achieving climate neutrality by significantly reducing greenhouse gas emissions. To meet this goal, they must prioritize improving energy efficiency and expanding the use of renewable energy sources. Moreover, the demand for sustainability from clients, shareholders, investors, and employees is growing, a trend that is likely to increase due to generational shifts.

Although transitioning to a low-carbon, circular economy presents short-term cost challenges, it can also generate new competitive advantages for businesses. Incorporating sustainability into business decisions is essential for long-term success and increasing a company's value. By reducing their carbon footprint, companies not only lower energy costs and risks but also benefit from a more stable, cost-effective, and predictable energy mix, boosting their performance and adding value for all stakeholders. While sustainability projects may require significant initial investments, the decreasing costs of green technologies make them increasingly accessible.

However, reflecting on the impacts of extreme weather and rising temperatures, it is clear that the reduction in CO2 emissions is not happening fast enough. Immediate action is needed to mitigate the risks of climate change and global warming. To achieve this, the global public and business sectors must take concrete steps, including decarbonizing electricity generation by shifting from fossil fuels to renewable energy sources like wind and solar, electrifying transportation, and maximizing energy efficiency in all industries—from buildings and appliances to business processes.

In this paper, positive examples of sustainability projects were presented based on a case study of a Croatian insurance company. Triglav osiguranje followed simple yet effective steps to lower its GHG emissions and achieve multiple positive effects on its business performance. Procuring clean electricity, implementing ISO 50001 standard for energy management system and other sustainability initiatives helped the company achieve a high ESG rating and to set a roadmap for improving it in the future.

The most important think to emphasize from this paper is that these sustainability practices can be replicated by other companies in the financial sector, but also in all other industries. This is no longer an option but a necessity if we want to save our planet and leave it in acceptable condition to ones that will come after us.

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