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# 1. THE IMPACT OF NEW DEVELOPMENTS ON RESIDENTS AND THEIR NEIGHBORHOODS

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## Abstract

The article focuses on the impact of increased density, the intensity of new development and related phenomena, and their effect on residents. It deals with the participation of residents in the process of new development. The topic of the contribution of investors in the territory. And whether these processes are set up in such a way that the current requirements for a quality and sustainable urban environment suitable for living can be met. Using the example of the Karlín cadastral area, its changes over time and the analysis of the newly emerging urban districts in its territory, the article analyses the opportunities, but also the threats that can arise due to the process of change. The aim is to provide a more detailed view of how new developments, and with increasing population density and built-up areas, affect the existing urban environment and what impact they have on the residents.

## Keywords

Urban economy; urban planning; housing; urban density

## Introduction

Urbanization and its opportunities, but also its challenges, are a recurring theme in the world's cities. With the increasing concentration of people in urban areas, the question arises about how to ensure a sustainable and quality environment for all. Population density, the intensity of new development and the associated impacts on the lives of residents present challenges that require a thoughtful and flexible approach to urban planning.

Effective planning can help minimize the negative impacts of urbanization and contribute to sustainability and quality of life in cities. For a well-functioning city, it is important to address the intensity of development and the pattern of the percentage composition of planned development, including variations in approaches to decision-making on the location and composition of residential development, with an emphasis on preserving the quality of life of citizens with respect to sufficient public amenities and green space. Therefore, it should be a priority for the city or borough to prepare analyses, including discussion and analysis of the views of the residents of the area, as a basis for future planning decisions and associated minimization of urban problems. Urban planning can be understood as the professional work of guiding urban development through the creation of physical plans and regulations, or more generally as a set of social, economic, environmental, and constructive efforts to make an urban area a better and healthier place to live

This paper focuses on the impact of increased density, the intensity of new development and associated phenomena, and their effect on residents. It addresses the participation of residents in the process of new development. The topic of the contribution of investors in the territory. And whether these processes are set up in such a way that the current requirements for a quality and sustainable urban environment suitable for living can be met. Using the example of the Karlín cadastral area, its changes over time and the analysis of the newly emerging urban districts in its territory, it analyses the opportunities, but also the threats that can arise due to the process of change. The aim is to provide a more detailed view of how new construction, and with-it increasing population density and built-up areas, affects the existing urban environment and what impact it has on ordinary residents.

The data and graphs presented through this paper are part of a more comprehensive questionnaire survey conducted by the author as part of her dissertation on the topic: Urban densification and its economic impact on urban spending. A total of 146 residents took part in the survey and answered questions aimed at determining the quality of life and satisfaction of the residents of the Karlín cadastral area, especially in the context of the intensive development and new construction that has taken place in the area in recent years.

## The Karlín cadastral area

### Questionnaire survey of residents

#### Objective of the questionnaire survey

The main objective of the questionnaire is to get a comprehensive view of how the residents of Karlín perceive the quality of their housing, the availability and quality of public services, changes in the availability and accessibility of public space, the traffic situation and the overall environment in which they live. The focus is on their views on new construction, which brings about a densification of the residential structure, and on changes that affect the daily life of residents.

#### Methodology and structure of the questionnaire

The survey is based on a standardized questionnaire that includes a combination of closed and opened questions. The closed questions are structured as scaled questions that allow respondents to express their level of satisfaction in different areas of life (e.g. housing, transport, public services), which facilitates quantitative analysis and comparison of responses. Open-ended questions provide space for personal opinions and allow respondents to express their attitudes and opinions on current changes and problems they are experiencing in Karlín.

## Purpose of the questionnaire and its contribution

The results of the questionnaire survey will serve as a key source of information for assessing the impacts of urban densification at the local level. This data will contribute to the analysis of the social and economic impact of new development and will allow a better understanding of how the changing character of Karlín is affecting the satisfaction and quality of life of its residents. The information gathered can also be useful for planning further development steps that reflect the needs and desires of residents and promote the sustainable development of these dynamic neighborhoods.

## Cadastral area

"Cadastral territory means a technical unit consisting of a locally enclosed and jointly registered set of properties in the land register" [12]

The territory of the City of Prague consists of 112 cadastral territories. The cadastral territories in Prague refer to the original historical towns (such as Karlín) or the original municipalities that were gradually annexed to Prague. [8]

## History of Karlín

Karlín, historically the first planned suburb of Prague, has undergone many significant changes since its establishment in the 19th century. Due to its location on the Vltava River and proximity to the city center, Karlín soon became a key industrial area, where several factories and commercial enterprises were established to support local economic growth. However, this development was not smooth - while Karlín flourished in the first decades of the 20th century, the socialist period brought a neglect of infrastructure and a deterioration of social conditions. Due to a lack of maintenance, the quality of life gradually declined, and the district lost its attractiveness. [5]

After 1990, the post-socialist transformation and privatization allowed new investors to enter the market, leading to the restoration of neglected buildings and the overall development of the neighborhood. A significant boost came with the flood in 2002, which accelerated the restoration of damaged buildings and the revitalization of Karlín. Many of the damaged buildings were replaced with modern residential and office structures that completely changed the character of the area, and Karlín became an attractive location for both investors and upper-income residents. [5]

However, this renewal also brought significant social changes. Karlín, originally accessible to lower-income residents, became more expensive and more accessible to the middle and upper classes, leading to a process of gentrification. New construction and rising real estate prices thus attracted new residents and contributed to the displacement of the original inhabitants. Developers have played a significant role here, converting former industrial sites into modern residential and office space. Large-scale investments and privatization have also had an impact on the infrastructure and overall structure of Karlín. The newly built residential complexes and offices have not only increased the quality of the local environment, but also the attractiveness of the area as a modern district close to the center of Prague. [5]

## Transformation of Karlín after the floods in 2002

### Gentrification

The process of gentrification needs to be looked at not only from the perspective of the people who become the new residents of a given neighborhood. The neighborhood will shed its old stigma, become interesting and attractive for them to move around in, thus creating investment opportunities. But also, from the perspective of those who had to leave. The adverse effect of gentrification is a process of 'displacement' of the lower income strata. However, this is not only a consequence of high rents, but the original inhabitants find themselves in a situation where they feel alien in a neighborhood where they have lived for many years after a radical transformation; places that were familiar to them and part of their home are gradually disappearing. Because of gentrification, then, diversity - the diversity of the composition of the population - disappears.

Those who lived in Karlín before this event were 38% of the respondents. The transformation of Karlín after the floods in 2002 is perceived as positive by 94% of the respondents. This result, which rates the transformation so positively, and therefore makes it appear that the negative aspects of gentrification do not affect Karlín, may however be heavily skewed by the fact that those most affected by the transformation no longer live in Karlín and are therefore not respondents in this survey.

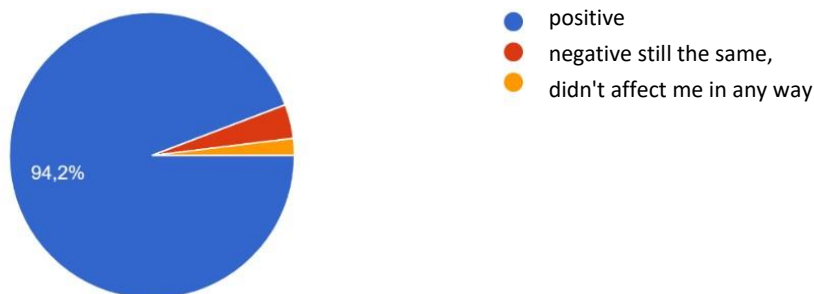


Figure 1: The transformation of Karlín after the floods of 2002(source: authors)

## New construction - Rohan city (Rohanský ostrov), Nový Karlín (Invalidovna)

Although the transformation of Karlín after 2002 was evaluated by respondents as positive, they no longer see the current new construction as such and 57% of respondents described it as negative.

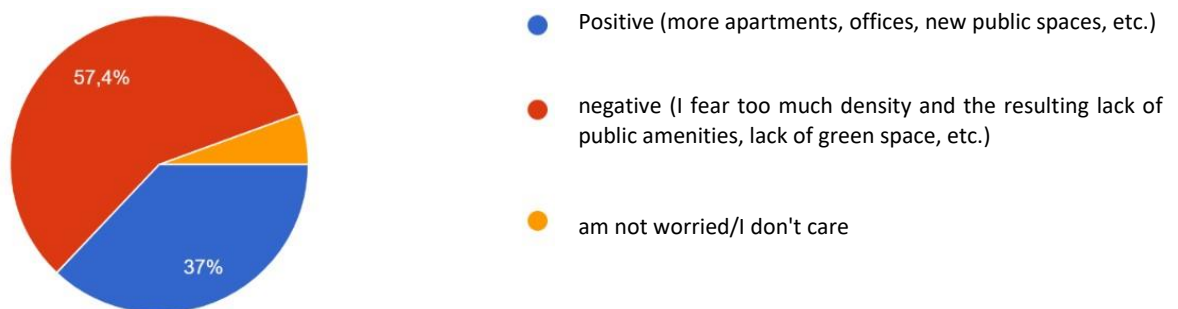


Figure 2: New construction (Rohan city, Nový Karlín) (source: authors)

From the open-ended follow-up questions, What concerns do you have about new development? and What should new development have that you miss? revealed:

- Concern about even more gentrification
- Concern about rising rents
- Lack of construction of affordable urban housing
- Lack of nurseries and schools, which will be exacerbated
- Insufficient transport infrastructure
- Traffic congestion, public transport
- Criticism of the failure to adhere to block building (Rohan City)
- Cancellation of sports facilities (Nový Karlín)

## Contribution of Investors to the area

The Methodology of Investor Participation should be a guide to partially address these negative externalities from new development that result from the financial burden of new development on the district. The purpose of the Investor Participation Methodology is to create a structured framework for fair and transparent cooperation between investors, the Capital City of Prague / urban districts. This methodology should ensure that investors contribute equitably to cover increased costs incurred by the city and urban districts because of zoning changes or other investment activities. [9]

- In the form of a financial contribution (to the HMP/City Fund)
- In the form of land transfer
- Form of implementation
- In the form of separate project documentation
- In the form of an architectural competition
- Form of reserved capacity
- Specific form: Supported housing
- Specific form: operation and maintenance of the Public Space
- Specific form: commitment not to run out of capacity [9]

## Investor participation in the context of Karlín

The Rohan City project on Rohanský ostrov represents the transformation of a Prague brownfield into a new neighborhood. Sekyra Group plans to create a mix of residential, office and retail space totaling 380,000 m<sup>2</sup> with an investment of over CZK 18 billion. Approximately 11,000 people are expected to live and work here upon completion. Expected completion by 2033. The city has contributed to the project by negotiating a voluntary contribution of CZK 560 million with the investor for the construction of a new school and park, following the approval of new rules for developers. [7]

Central Group has purchased 5 hectares of land in Karlín near the Invalidovna metro station, on which it plans to build a new district called Nový Karlín. This project is expected to include more than 1,000 apartments and extensive commercial space, which will be complemented by services, shops, cafes and medical facilities. The company's total contributions to the city and the Prague 8 Municipal District will amount to CZK 325 million. These funds are expected to help finance the 1,000 m<sup>2</sup> of surgeries and offices that will be transferred to the city. The first stages of construction are expected to be completed around 2028, with the overall completion of the district by 2033. [2]

Although both above-mentioned projects are already following the Investor Participation Methodology, the question remains whether this performance is sufficient and why it is not being used for the much-missed urban housing.

## Affordable housing

Housing is one of the key sources of satisfaction and quality of life, which is why ever-increasing housing prices and shortages are a major issue in many of the world's major cities. The level and availability of quality housing, especially for middle- and lower-income households, speaks volumes about the dynamism of a city and its ability to respond to changes in the way society lives and the current needs and interests of its residents.

In the questionnaire survey on the question of what percentage of the monthly income is spent on housing, a decisive threshold of 30% was set, this threshold is decisive in the Czech Republic for the allocation of housing allowance.

"Housing allowance is a benefit that contributes to a person/family in covering housing-related costs." "The owner of a flat, a person who uses the flat on the basis of an easement or a tenant and subtenant of the flat, as well as the owner of a building for individual or family recreation are entitled to housing allowance if their housing costs exceed 30% of the family's decisive (net) income and at the same time this 30% of the decisive (net) income of the family is not higher than the amount of the normative housing costs." [10]

65% of the respondents live in their own housing, 33% in rental housing and the rest indicated other housing as the type of housing. Despite the high number of respondents who indicated that they live in their own housing, almost half of the respondents indicated that they spend more than 30% of their family income on housing costs (with almost 6% spending even more than 50% of their income on housing)

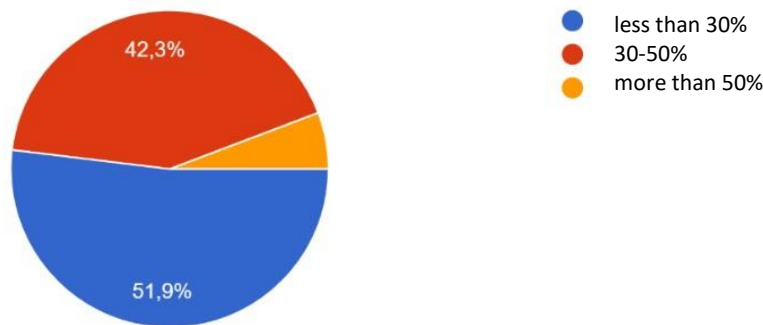


Figure 3: What percentage of your monthly income do you spend on housing? (source: authors)

In response to the current state of the housing market, there is a partial focus of private developers on rental housing. This does not mean that they have stopped building apartments for sale, but developers are increasingly starting to build homes where they either rent the apartments themselves or sell the entire development to a rental corporation. These corporations often raise rents to the maximum, thereby influencing other rents in the locality to become more expensive and thus exacerbating social segregation.

An example of such a building in Karlín is the Fragment apartment building by Trigema, where the rent is CZK 700 per m<sup>2</sup>/month. [11]

The average rental price in Prague is 408 CZK/m<sup>2</sup> and in Prague 8 it is 416 CZK/m<sup>2</sup>. [4]

Trigema is planning other similar projects near Fragment, in Prague's Invalidovna district. It should be another rental house, and one house should be dedicated to coliving. [3]

## Residents' participation in city planning

In city planning, there is an increasing emphasis on involving residents in the process. In the context of the Manual of Participation with the subtitle, how to involve the public in city planning, for the needs of the Prague municipality by IPR Prague, participation can be interpreted as the sum of all activities that enable and mediate active public participation in the creation of documents, proposals and final decision-making. This process shapes not only the physical form and structure of the territory, but also the nature and content of the activities that take place in it. Public participation is therefore a key element in the planning process to ensure that the resulting solutions better reflect the needs, views and priorities of the inhabitants and users of the area. [6]

But do urban residents have the desire and will to get involved at all, and do they know how and where? The questionnaire survey shows that only 13% of the residents of Karlín are actively involved in new development. The open answers showed that this initiative on the part of the citizens comes only as a "fight" against inappropriate



building plans in their neighborhood. The questionnaire also showed that almost half of the respondents would like to get involved but do not know how.



Figure 4: Influence on development in my neighborhoods / civic participation (source: authors)

## Conclusion

Today's cities face many challenges to which they must respond, whether it is climate change, increased demands on transport and public infrastructure, or the deteriorating affordability of housing. Each of the city's sectoral policies, including housing policy, should always respect the general principle of sustainable development in all its basic dimensions: environmental, economic, social and cultural, through the measures and activities implemented. The aim of the management of a sustainable and well-functioning city should be to ensure that all people, without distinction, have the possibility of affordable and quality housing. In this context, it is very important to address the pattern of the percentage composition of planned development, including variations in approaches to decision-making on the location and composition of predominantly residential development. In prosperous metropolitan areas, regulation should operate so that the function of housing as an investment tool does not override its social function. The prices of owner-occupied and rental housing have reached levels that are becoming unaffordable for a large proportion of Prague's population and unacceptable in terms of the cost of living and housing costs.

Urbanization and related phenomena are part of the dynamics of the modern world. For urban areas to become sustainable, healthy and quality places to live in, cities need to implement effective planning and regulatory approaches. By focusing on the balance between density, transport connectivity, green space and public amenities, and proactively addressing affordable housing options and alternatives, cities can create an environment that supports sustainable development while considering the quality of life of all residents.

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## 2. MULTICRITERIAL DECISION-MAKING MODEL FOR PHOTOVOLTAICS INSTALLATION

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### Abstract

This research paper focuses on decision-making regarding installation of photovoltaics in the Czech Republic. A multicriterial decision-making model has been created for investors and owners of buildings to evaluate the costs and benefits of photovoltaics installation. The model includes economic criteria which are selected to optimize the investment costs, operational costs, savings for electricity, subsidies, resulting in the most economically feasible scenario. The model is used to determine the lowest annual cost of electricity over the lifetime of a photovoltaic (PV) system, and the payback period of the photovoltaics installation. The model selects the optimal PV installation size and battery storage. In the paper, results of the multicriterial analysis for an optimal photovoltaic installation for a family house in the Czech Republic are presented.

### Keywords

Decision-making; photovoltaics; real estate; sustainability

## Introduction

In recent years, the shift towards renewable energy sources has become imperative in the face of escalating environmental concerns and also the energy crisis in Europe in recent years. Among renewable energy options, photovoltaics (PV) have emerged as a significant player due to their ability to convert solar energy directly into electricity. This technology not only holds the promise of sustainable energy but also offers economic benefits, particularly for individual investors and property owners. In the Czech Republic the number of photovoltaic installations is rising exponentially in the recent years: in H1 2023 there were 45 197 new photovoltaic installations realized, and the growth of number of PV installations compared to H1 2022 was 383% [1].

However, the decision to install photovoltaic systems involves multiple criteria that must be balanced to achieve the most cost-effective and environmentally beneficial outcomes. This research paper addresses the complex decision-making process associated with photovoltaic installations in the Czech Republic, aiming to develop a multicriterial decision-making model that assists investors and building owners in evaluating the potential costs and benefits of implementing such systems.

The primary objective of this study is to construct and validate a decision-making framework that integrates various economic criteria. This will enable stakeholders to make informed choices about the size of the PV installation and the necessity of accompanying battery storage. By focusing on the Czech Republic, the research taps into a region with increasing interest in renewable energy, influenced by both governmental incentives and a growing public awareness of environmental issues. A comprehensive multicriterial model tailored to the specific conditions and regulations of the Czech Republic will provide clearer guidance for potential PV system investors, leading to optimized installation decisions.

## Methodology

This chapter delineates the methodology employed in developing a multicriterial decision-making model for the installation of photovoltaic systems in the Czech Republic. The model aims to identify the lowest annual costs of electricity throughout the lifespan of a PV system, considering optimal sizing of the PV installation and battery storage. It integrates a comprehensive array of factors including initial investment costs, operational expenses, potential subsidies, and revenues from selling excess power back to the grid.

The model is constructed using Microsoft Excel and its Solver module which can create complex optimization scenarios. This choice of software is due to its accessibility and its robust capabilities in handling linear and non-linear optimization problems. The Solver module facilitates the selection of system parameters that minimize costs while meeting the constraints provided by subsidy conditions, energy needs, and installation capabilities.

The decision-making model incorporates the following criteria and variables:

**Initial Investment Costs:** These are the upfront costs associated with the purchase and installation of the PV system and are amortized over the system's expected lifespan to reflect their impact on annual costs.

**Subsidies:** Calculations include potential financial support from the Nová zelená úsporám program 2022 [2] for family homes in the Czech Republic, optimizing the system size and configuration to maximize subsidy uptake.

**Operational Costs:** Yearly maintenance and operational costs are considered, including potential costs for energy purchases when solar production is insufficient.

**Energy Sales Revenue:** The model accounts for revenue generated from selling surplus energy produced by the PV system back to the electrical grid.

The model operates by first defining a range of possible PV system sizes and battery storage capacities. It then evaluates each configuration to determine the total cost across the system's lifespan, including maintenance, additional energy purchases, and depreciation of components. The Solver module optimizes these configurations by minimizing the total annual cost, which includes both the amortized investment and operational costs adjusted for subsidies and revenues.

The conditions of the subsidy program are directly integrated into the model, specifying constraints such as eligible system sizes, types of installations, and the extent of financial support. These conditions influence the optimization process by defining feasible boundaries within which the PV system must operate to qualify for financial incentives.

## Results

This chapter presents the multicriterial decision-making model developed to assess the feasibility and optimization of photovoltaic (PV) system installations in the Czech Republic. The model is designed to determine the annual costs associated with electricity generation from a PV system over its operational lifetime, while also considering the optimal size for both the PV installation and the necessary battery storage. The model consists of various inputs, variables, outputs and supporting calculations which are presented in Figure 1 and Figure 2 and described below.

kategorie	parametr	popis	jednotka	hodnota	min	max
účelová funkce	min. náklady za rok	optimalizace velikosti instalace FV panelů ku velikosti akumulace pro nejnižší roční náklady	Kč/rok	20 613,64		
proměnné	počet FV panelů - výpočet	rozměr panelu 1600 x 1000 mm	ks	25,22	0	50,00
	kapacita akumulace		kWh	19,96	0	30,00
výsledky	počet FV panelů - zaokrouhlený na celé číslo		ks	25,00	0	50,00
	návratnost s dotacemi		roky	1,98		
	návratnost bez dotací		roky	9,05		
omezující podmínky	cena za FV systém	FV panely + instalace + akumulace	Kč	434 385,92	0	500 000,00
	plocha FV panelů		m <sup>2</sup>	40,00	0	80,00
pevné parametry	velikost plochy pro FV panely (střechy)		m <sup>2</sup>	80,00		
	nominální výkon FV panelu	výkon jednoho panelu od 300 do 400 Wp	kWp	0,3992	0,30	0,40
	energie vyrobená FV panelem o 1 kWp	1 kWp instalovaného výkonu vyrobí za rok v Česku asi 1 MWh elektrické energie	kWh	1 000,00		
	roční spotřeba energie budovy		kWh	10 000,00		
	% energie vyrobené a spotřebované na místě			0,30		
	% využití akumulace během roku	50% kapacity průměrně za rok využito (uložení přetoků)		0,50		
	cena za 1 panel		Kč	3 000,00		
	cena akumulace	baterie	Kč/kWh	15 000,00		
	cena za nákup elektřiny ze sítě		Kč/kWh	4,80		
	cena za prodej elektřiny do sítě		Kč/kWh	0,50		
	životnost technologie		roky	30,00		

Figure 1: Inputs and Outputs for the Multicriterial Decision-Making Model for Photovoltaics Installation (source: author)

pomocné výpočty									
cena za panely		Kč	75 000,00						
cena instalace	do 5 kWp - 50 000 Kč, 5-10 kWp - 60 000 Kč	Kč	60 000,00	50 000	Kč do 5 kWp				
cena za servis a opravy instalace za rok	5% z ceny instalace	Kč	3 000,00	60 000	Kč do 5-10 kWp				
cena za akumulaci		Kč	299 385,92	100 000	Kč nad 10 kWp				
cena za prodanou elektřinu za rok		Kč	1 668,74						
cena koupené elektřiny za rok		Kč	16 115,86						
výkon FV elektrárny		kWp	9,98						
energie vyrobená FV elektrárnou		kWh	9 980,00						
spotřeba vyrobené energie v reálném čase		kWh	3 000,00						
uložená energie v akumulaci		kWh	3 642,53						
spotřeba vyrobené energie včetně akumulace		kWh	6 642,53						
spotřeba koupené energie		kWh	3 357,47						
prodané přebytek energie		kWh	3 337,47						
dotace za instalaci Nová zelená úsporám 2023	Základní instalace o výkonu 2 kWp s hybridním měničem – 60 000 Kč, max 10 kWp	Kč	60 000,00	2	10			60 000	Kč za instalaci 2 kWp
dotace za instalaci Nová zelená úsporám 2023	Za každý další 1 kWp instalovaného výkonu – 10 000 Kč, max 10kWp	Kč	79 800,00	0	8			10 000	Kč/1kWp instalace nad 2 kWp
dotace za akumulaci	Za 1 kWh el. akumulačního systému – 10 000 Kč	Kč	199 590,61	9,98	19,96			10 000	Kč/1kWh akumulace - mini
dotace celkem		Kč	339 390,61						

Figure 2: Supporting Calculations for the Multicriterial Decision-Making Model for Photovoltaics Installation (source: author)

## Model Inputs

### Fixed Parameters

- Area available for PV panels (velikost plochy pro FV panely (střechy)): Specifies the total roof area available for installing the PV panels.
- Nominal output of PV panel (nominální výkon FV panelu): Represents the energy output capacity of a single PV panel, typically ranging from 300 to 400 Watts peak (Wp).

- Energy produced by a 1 kWp PV panel system (energie vyrobená FV panelem o 1 kWp): Estimates the annual energy production of a 1 kWp system.
- Annual energy consumption of the building (roční spotřeba energie budovy): The total energy requirement for the building annually.
- Percentage of energy produced and used on-site (% energie vyrobená a spotřebovaná na místě): The proportion of produced energy that is consumed directly at the installation site.
- Percentage of battery utilization during the year (% využití akumulace během roku): This parameter estimates how much of the battery capacity is utilized annually, taking into account seasonal variations and consumption patterns.
- Cost per panel (cena za 1 panel) and Cost of battery storage (cena akumulace): These reflect the costs of individual components of the PV system.
- Electricity purchase and sale prices (cena za nákup elektřiny ze sítě/cena za prodej elektřiny do sítě): The cost of buying electricity from the grid and the revenue from selling excess electricity back to the grid.
- Technology lifespan (životnost technologie): Indicates the expected operational lifespan of the PV technology being used.
- Panel efficiency: Each panel is assumed to have a nominal output between 300 to 400 Wp. [3]
- Energy production: The model bases its calculations on the assumption that a 1 kWp system generates approximately 1 MWh of energy annually in the Czech context. [3]
- Building Energy Consumption: Annual energy consumption of the building is estimated at 10,000 kWh.

### Restrictive Conditions

- Cost of PV system (cena za FV systém): This constraint limits the total allowable expenditure on the PV system, including panels and installation costs.
- Area of PV panels (plocha FV panelů): This is the maximum area available for the installation of the PV panels, which can limit the number of panels installed.

### Model Outputs

#### Target Function

The model provides several key outputs that are essential for evaluating the viability and effectiveness of PV installations:

- Minimum annual costs (min. náklady za rok): This is the primary objective of the model, aimed at minimizing the total annual cost of the PV system over its lifetime. The optimization considers installation size and battery storage to achieve the lowest yearly expenses. The model optimizes for the lowest possible annual costs, which include the amortized initial investment, maintenance expenses, costs for any necessary additional energy purchases, and the revenues from selling excess energy back to the grid.

#### Variables

- Number of PV panels (počet PV panelů - výpočet): This variable determines the total number of PV panels required, calculated based on the installation's energy production goals and space constraints.
- Battery storage capacity (kapacita akumulace): The capacity of battery storage needed to store the excess energy produced by the PV panels, which can be utilized during low production periods.

### Results

- Rounded number of PV panels (počet PV panelů - zaokrouhlený na celé číslo): Adjusts the calculated number of PV panels to a whole number for practical implementation.

- **Payback period:** The model calculates payback period in two scenarios: with and without subsidies. With subsidies, the payback period is significantly reduced, enhancing the attractiveness of the investment.

The analysis of economic viability shows that with optimal configuration, the system not only reduces the dependency on grid electricity but also offers substantial cost savings over time. This is enhanced by strategic utilization of available subsidies, which can significantly alter the financial outcomes favoring the investor.

The model was tested for different scenarios and variations of PV installations for family houses. The scenario in Figure 1 is a family house has constraints such as a maximum PV system cost of CZK 500,000 and a maximum panel area of 80 square meters. The results of the model suggest using 25 PV panels and recommends a battery storage capacity of roughly 19.96 kWh. The payback period with subsidies is 1.98 years and the payback period 9.05 years. This corresponds to the limits of the subsidy Nová zelená úsporám and it optimizes the subsidy to the maximum.

## Conclusion and discussion

The multicriterial decision-making model for PV installation in Czechia is applicable to calculate the approximate size of PV installation and accumulation for family houses. It calculates the payback period including subsidy and without subsidy. The subsidy conditions affect the optimal results the most as the results of the scenario show. However, the model can also be used for optimizing the PV installation without the subsidy.

The model for optimizing photovoltaic installations operates under several assumptions that affect the accuracy of its results and its practical applicability. These limitations are as follows:

- **PV panel orientation and tilt:** The model assumes that all PV panels are optimally oriented towards the south with a tilt of 35 degrees. This ideal positioning is not always feasible in practical scenarios due to varying architectural features and site-specific limitations.
- **Panel performance data:** The performance metrics for the PV panels are derived from external sources rather than calculated directly within the model. This reliance on external data may introduce inaccuracies if the data is not updated or specific to the conditions at the installation site.
- **Annual and daily variations:** The model does not account for fluctuations in energy consumption and PV system performance throughout the year or the day. Instead, it uses a coefficient to estimate the percentage of energy produced that is consumed on-site, simplifying the model but potentially overlooking significant variations.
- **Battery utilization:** The use of battery storage is not calculated based on actual daily and yearly electricity production and consumption data. It is instead represented by an average utilization coefficient, which may not accurately reflect real-world usage patterns.

To enhance the accuracy of this model in future iterations, several improvements are suggested:

- **Panel performance calculations:** Incorporate calculations that adjust the performance of the panels based on their actual orientation and tilt. This could be achieved by importing data, as no simple formula currently exists to directly calculate this performance.
- **Solar irradiance and panel performance:** Integrate data on solar irradiance variations throughout the year and expected daily and yearly performance of the PV panels. This data could be sourced from the Czech Hydrometeorological Institute (ČHMÚ) to ensure accuracy and relevance.
- **Energy consumption patterns:** Include detailed data on the energy consumption patterns of residential buildings throughout the day and year. This would require gathering and standardizing data from various case studies and integrating them into the model to reflect more realistic energy usage.

These enhancements would address the current model's limitations by providing a more detailed and dynamic understanding of PV system performance and its interaction with real-world conditions. Implementing these changes would likely increase the model's complexity but significantly improve its utility and predictive accuracy for potential investors and homeowners considering PV installations.

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### 3. UTILIZATION OF ARTIFICIAL INTELLIGENCE IN THE CZECH REAL ESTATE MARKET

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#### Abstract

This paper provides a comprehensive overview of the potential and applications of artificial intelligence (AI), machine learning, and property technologies (PropTech) within real estate markets abroad and in the Czech Republic. It focuses on how these technologies optimize various processes in real estate transactions, from data collection and management to market analysis, property valuation, price forecasting, and automated property management. An analysis of academic and commercial articles reveals that while the advantages of AI are widely acknowledged, academic publications more frequently highlight its limitations, particularly economic, regulatory, technological, and ethical challenges. The paper suggests that future research should target these shortcomings to ensure that technologies are implemented effectively and safely in both the private and public sectors. Additionally, it offers a foundational literature review for further research and case studies focusing on real estate market trends and price forecasting in municipalities across the Czech Republic. The paper's research questions affirm the hypothesis that AI plays a crucial role in maintaining stability and enhancing the efficiency of the real estate market when properly implemented. Finally, the paper emphasizes the ethical implications of AI utilization, not only in the real estate sector. This is recognized as a critical topic for future expert discussions and further research in AI and PropTech.

#### Keywords

artificial intelligence; literature review; real estate

## Introduction

In research on factors influencing real estate prices, elements of artificial intelligence (AI) are more frequently utilized in international studies, across various stages of the real estate lifecycle and property types (land, industrial buildings, residential developments, etc.). AI-driven processes are implemented and technically refined at an academic level. AI is also employed by commercial entities within the real estate sector. The subject of this paper is an analysis of potential AI application methods within the real estate market in the Czech Republic. The main objective of this work is to create a comprehensive theoretical overview of AI applications in the real estate market, describing the benefits, drawbacks, and limitations of this sector. Another goal is to support further development in various stages of the real estate lifecycle, specific real estate market analyses, and research on price-influencing factors in the Czech Republic and specific localities. This article does not focus on AI functionality and programming.

Hypothesis: AI capabilities must be an integral part of the real estate market in the Czech Republic to ensure its functionality and stability.

Research questions: What are the possibilities of using AI and machine learning? In which phases of the real estate market can AI be employed?

The property lifecycle encompasses all real estate processes necessary for acquisition, development, property search, and property management [1]. For instance, in property search, the duration of listing until a property is sold is analyzed [2]. Various methods for property search are employed, including classical information filtering, searches based on image similarity, or identification of the property's physical or technical state from listing photographs [3]. Based on a photograph, certain model settings can assess features like the view from a window [4]. Furthermore, matching new buyer requirements with initial seller requirements is possible [5]. Acquiring property is associated with property valuation, with value assessments conducted by various market entities (brokers, mortgage advisors, banks, researchers, etc.) [6]. Property prices can be predicted using several methods, from basic statistical methods, classical and multiple regression analysis, Geographic Information Systems (GIS), decision trees, and random forest models, to artificial neural networks [7]. As noted, various tools are used for price prediction, but historical price trends in the given area (both local and national) remain fundamental for training models [8].

In most cases, data collection, mathematical formulas, and machine learning models are resource-intensive. However, these tools are essential for processing large datasets within a specific timeframe [1]. Regularly updating large data volumes is often impossible, as the model may not be trained on recent data [9]. Data volume examples include studies from Los Angeles (140,289 real estate transactions from 2012 to 2018 using AI to explain socioeconomic and demographic factors [10]) or 40,000 analyzed listing photographs in Rotterdam's real estate market [4]. In an experiment conducted in Shanghai, 16,560,228 property records and information were used, divided into a training dataset (11,592,160 records) and a test dataset (4,968,068 records) to validate a model based on a hybrid neural network [2].

Real estate market development and its attributes are vital for the socio-economic and dynamic development of cities [10] and urban economies, encompassing spatial planning and investment [7]. In the Czech Housing Concept 2021+ [11], the development of smart cities and homes, along with the support of new technologies, is highlighted as an opportunity and an aspect for improving quality of life. Thanks to new technologies, efficiency can be enhanced in the real estate market, costs reduced, and client services improved [12]. In the Czech context, the benefits and areas of potential AI use are highlighted, as real estate agents or companies lose a competitive advantage when AI is not utilized [12] and [13]. Technologies in the real estate market, often termed PropTech (Property Technologies), have their own markets and development, including national and international associations [14]. Increasing investments in real estate and real estate technologies are anticipated, which also supports the development of AI agents specifically for the real estate market, such as the advanced ChatGPT model [15]. This study [15] also focuses on developing a new real estate AI agent.

## Methodology

The topic of this article, utilization of artificial intelligence on the Czech real estate market, was selected due to the broader research on price-forming factors, where findings indicate a lower usage of new technologies compared to international studies. Initially, scholarly publications were identified in the ScienceDirect database from Elsevier (SCOPUS) using keywords and phrases such as: Artificial Intelligence, Machine Learning in Real Estate, PropTech, Big Data, Random Forest, Neural Networks, Neural Networks for Price Forecasting, Real Estate Price Models, AI and Property, Real Estate Property, Personalized Marketing in Real Estate, Real Estate Customer Segmentation AI, Real Estate Recommendation, Deep Learning. Upon locating academic publications and selecting relevant ones, i.e., those focusing on real estate markets, similar articles were suggested by the database. Further literature was searched based on literature reviews, notably these studies [1], [16], and [17]. Keywords were also entered into the Google Scholar database.

To ascertain the current state of the Czech real estate market, web links to articles on artificial intelligence were additionally retrieved. However, these were limited to Czech commercial entities [12] and [13]. From international commercial sources, a publication by Deloitte Global – Real Estate Prediction 2024 [18] was consulted. Within Czech publications, the Czech Technical University DSpace repository served as a source, where Jakub Nádraský's bachelor's thesis titled Application of Machine Learning in Real Estate was located [19].

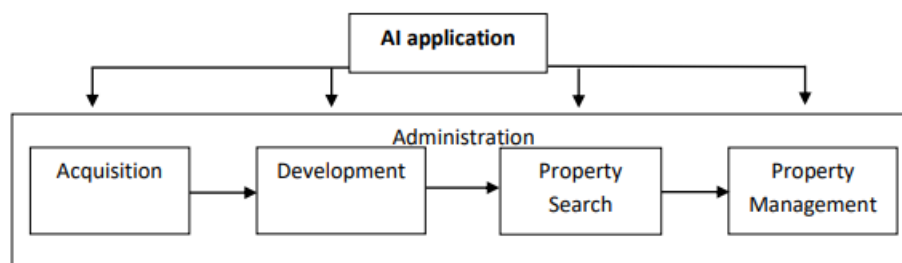
Additionally, responses from ChatGPT were used to demonstrate an analysis of property condition, specifically of a room, based on a photograph (response dated 30.09.2024).

Through a broader investigation of price-forming factors in the areas of Teplice and Mladá Boleslav, which included data collection and local surveys, the need for more complex systems was identified. This involves systems and applications for data collection from various data sources, applications for data sorting and verification, applications for data assessment and the creation of basic models, and potentially the creation of advanced and regularly updated models. Tools for data presentation or information utilization for critical decision-making at various levels, as described in the introduction, are also relevant. Existing tools and usage possibilities are presented in the Results details chapter.

## Results

Based on the analysis and survey of artificial intelligence applications in the real estate market, this chapter presents various components of AI and machine learning tools. Some of these components and applications are already in use by certain entities, while others remain in the research phase, with predictions for development and gradual implementation.

Real estate assets within the market undergo a lifecycle, during which AI elements can be applied in each stage, as shown in Figure 1 [1].



**Figure 1: Property Life Cycle and AI Application (source: own modification based on [1])**

In addition to the four stages of acquisition, development, property search, and property management, Figure 1 includes administrative tasks required across all phases of the real estate asset cycle.

The utilization of artificial intelligence is contingent upon the quality and, above all, the quantity of data entering the respective software or model, often referred to as Big Data [1]. Data availability is a fundamental prerequisite

for any analysis [7], which is why database systems such as SQL or Pinecone are employed [15]. In particular, data related to location and territory can be processed using Geographic Information System (GIS) techniques [7]. These techniques facilitate the creation of interactive maps containing information on factors influencing real estate prices [7], as well as direct pricing maps [20], which are updated based on actual prices and utilized for further detailed analyses. Pricing maps also serve current market analysis, price prediction, and monitoring the current status of specific properties [20].

An Australian study [14] addresses property technologies (PropTech) that are employed in the Australian rental housing market, specifically focusing on:

- Investment and data-driven decision-making (e.g., BuyCloud, Higher than Average Growth),
- Property visualization and virtual tours (e.g., RealAR),
- Platforms for property searches based on similarities (e.g., Ignite, Tenant, 2Apply),
- Short-term rentals (e.g., Airbnb),
- Contract signing and financial solutions (e.g., Docusign, Trustbond, RentBond),
- Applications for lease termination and moving (e.g., Happly, Move Me In),
- Research, collaboration, and legal advisory applications (e.g., NALA, Dear Landlord).

This is merely a basic overview of the possibilities within the Australian real estate market regarding the areas where digital technologies can be utilized, some of which are gradually evolving based on machine learning algorithms. Existing libraries for developing machine learning models can be employed for programming algorithms [19].

For price prediction, multiple regression models are utilized [19], which are compared in terms of advantages and disadvantages with the artificial neural network method in a Turkish study from 2009 [6]. Artificial neural networks have proven to be more accurate for price predictions [6], a claim further supported by study [1]. However, it is noted that there is no universal artificial intelligence model applicable to all real estate markets due to the vast amount of data and the numerous differences across individual local real estate markets [1]. Regression models are extended to random forest models, which are a form of ensemble machine learning where the result is obtained by averaging the outputs of individual decision tree models and their respective regressions [19]. As previously mentioned, it is essential to have training and testing data sets in such cases [2]. Additionally, Markov chains [21] and Multiple Criteria Decision Analysis (MCDA) [17] are also employed.

The information from available academic publications is further supported within the commercial sector, not only within the context of the Czech real estate market. The prediction of artificial intelligence utilization in the real estate market is described by Deloitte Global and elaborated into the following six points [18]:

- Flexible and efficient building designs and digital testing,
- Extensive data analysis for property valuation considering numerous factors (automatic valuation models, machine learning, risk analysis, decision-making),
- Personalized services to enhance interest among current and potential tenants or users of residential units or hotels (digital assistants, receptionists, chatbots, smart houses),
- Predictive building management and maintenance (using collected data about the building's condition to assess wear and tear and recommend maintenance, or automate daily tasks and communication with external entities),
- Automation of lease administration (deadline monitoring, invoicing, notifications of changes),
- Digital technologies as a new paid service (detailed information on energy consumption, monitoring of renewable resources, etc.).

In addition to increasing the efficiency of existing processes, enhancing competitiveness, enabling data-driven decision-making, facilitating effective communication between clients and real estate agents, and other advantages, Moravio (an IT company) presents the following use cases of AI in the real estate market [13]:

- Analysis of potential buyers' behavior and accelerated property sales (personalized evaluations),
- Chatbots (client inquiries, initial selection and filtering of listed properties, creation of advertisements and listings),
- Market analyses, specific property evaluations, including future price predictions,
- Assessment of potential buyers' preferences and subsequent recommendations of similar properties,
- Utilization in property management and interactions with tenants (chatbots, simple accounting tasks, contract checks),
- Virtual tours.

These use cases are also supported by an article from the real estate agency RE/MAX Delux, which discusses artificial intelligence in the real estate environment, highlighting faster and more accurate property valuation as a key success factor in sales [12]. The assessment of properties and their easier advertising, as well as the creation of descriptions for listings, are implemented within the Czech real estate website [3]. The use of precise multiple regression functions to track similar values of preferences between new buyers and sellers ensures a quicker match, thereby facilitating sales [5].

Within ChatGPT, AI assistants specifically designed for the real estate sector are also available (e.g., Real Estate, Real Estate Investment Advisor, Commercial Real Estate Guide, Real Estate Listings & Property Descriptions GPT), with their usability varying significantly among users, often by several thousand. In the context of this article, there is no known additional experience with these AI assistants from either foreign studies or the author themselves. When utilizing ChatGPT directly, rather than a specialized real estate AI assistant, a request for analysis of the technical condition of the property shown in Figure 2 was submitted on September 30, 2024. This represents a sample image from a property listing, which, unfortunately, is no longer active as of the publication date of this article, from the portal Sreality.cz [22].



**Figure 2: Photo from the Property Listing (source: own modification based on [22])**

The response containing an analysis of the technical condition of the room presented in the photograph (a kitchenette in its pre-renovation state, unfurnished, located in a panel building in Prague 4) is provided below [ChatGPT, September 30, 2024]:

*“Floor: The floor tiles appear to be in reasonable condition but may not be modern or of high quality. They may be functional, but aesthetically, they might require updating.*

*Walls: The walls are painted white and feature half-height cladding. The cladding is outdated, which may not appeal to those seeking a modern look. There may be signs of wear or discoloration, indicating that repainting or new tiling would be advisable.*

*Ceiling: The ceiling tiles appear relatively intact; however, they may be older and could benefit from modernization.*

*Plumbing and Electrical Wiring: Visible in the image are the plumbing installations and electrical outlets, which should be inspected to ensure functionality and compliance with standards.*

*Overall Space: The room appears narrow, limiting arrangement and design options. It is currently unfurnished and unoccupied, which may diminish its appeal for immediate occupancy."*

Since the photograph does not include a scale, the analysis cannot be considered technically precise and, therefore, cannot be utilized for further calculations. Furthermore, the presence of an older oven, for instance, is not mentioned. When evaluating such a response, it is crucial to consider the personal experiences of real estate agents and potential buyers. Nevertheless, this serves as a support for decision-making and further analysis necessary for deciding on the acquisition of such a property and any potential renovation execution and cost calculations. This analysis is more of a "what-if" scenario. It is also important to note that no supplementary information (additional photographs, a detailed property description, location, address, etc.) has been provided. In such cases, traditional property analysis techniques are still required.

Although the advantages and applications of artificial intelligence and machine learning elements in various areas and phases of the real estate cycle undoubtedly enhance efficiency, competitiveness, and facilitate decision-making, there are, however, drawbacks. No disadvantages were identified within the Czech real estate market. Conversely, studies [14] and [16] mention several disadvantages and limitations that must always be considered during any implementation (within enterprises, academia, the real estate market, and others) [16].

International studies have identified these barriers, based on questionnaire surveys and analyses of academic articles, to the implementation of digitalization and innovations in the Australian real estate market [16]: high costs of software and hardware, lack of information and access to data, insufficient legislative framework, low trust in the adoption of new technologies, inadequate communication and digital awareness, insufficient willingness to invest in digitalization, lack of government support, insufficient demand for these technologies, among others.

On the other hand, the previously mentioned study regarding potential applications highlights the impact of new digital technologies on tenants [14]: support for speculative land development, rising property prices, investment speculation, additional fees and costs for tenants, unprotected personal data, profiling of tenants, bias, utilization of private data for training other systems and models, legal interpretations of methods used, missing legislation, and charging for information, among other issues.

The use of large amounts of data and information correlates with data protection and the necessary adherence to ethical standards, particularly in academic environments. For this reason, the use of artificial intelligence in research is also included in the conditions of certain journals, wherein authors must declare that generative artificial intelligence has not been utilized for text creation [23]. However, this pertains only to text creation and not to the use of artificial intelligence for analytical purposes and as a tool within the research process [23].

## **Conclusion and discussion**

This paper addresses and provides a comprehensive overview of the utilization of artificial intelligence within international real estate markets and the real estate market in the Czech Republic. It presents potential applications of elements of artificial intelligence, machine learning, and other property technologies (PropTech) in optimizing various procedures and processes related to real estate transactions.

The objective of this article has been fulfilled through a comprehensive analysis of scholarly articles and commercial publications directly from companies engaged in real estate commerce. By comparing this information, similar advantages are attained. However, disadvantages are primarily highlighted in academic publications. It is these disadvantages that subsequent phases of research should focus on to eliminate these shortcomings. The

article also aims to explore potential applications for further research and studies in the real estate market and property pricing. This serves as a foundational analysis from which specific processes can be selected for more detailed examination on particular datasets within the Czech Republic. Additionally, this article provides an overview of the literature that can serve as a more detailed basis in selected cases.

Based on the responses to the research questions posed in the introduction (What are the possibilities for utilizing artificial intelligence and machine learning? In what phases of the real estate market can artificial intelligence be employed?), it is possible to accept the established hypothesis and thus conclude that the utilization of artificial intelligence must be an integral part of the real estate market in the Czech Republic to ensure the stability and functionality of this market. Artificial intelligence can be employed throughout the entire life cycle of a property, for the purposes of data collection, data administration, market analysis, property analysis, property valuation, and price prediction, extending to automated property management and legislative oversight.

The hypothesis is confirmed primarily because this represents, in contemporary times, a natural process of digitalization, not only in the real estate sector but also in other sectors of the economy. Given the interconnections and the number of entities within the real estate market, enhanced efficiency and process optimization are of paramount importance. However, it is essential to invest in testing individual models to ensure that correctly functioning systems are implemented in both the private and public sectors, preventing data breaches, outages, and distortion of data and realities. Further research on such topics is critical, including facilitating professional discussions on these matters. The author considers the ethical implications of employing elements of artificial intelligence to be the most significant limitation, and therefore, a statement from the author is included at the end of this article.

## Acknowledgement

In writing this paper, artificial intelligence was utilized solely and exclusively for analytical purposes (to assess the technical condition of a property based on a photograph, to search for AI assistants, to explain the principles of mathematical formulas from international studies, and to clarify technical and technological terms in the field of information technology). This research was not financially supported in any way.

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## 4. SMART READINESS INDICATOR

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### Abstract

The article on Smart readiness indicator deals with the results of pilot testing of the SRI tool on selected buildings in the Czech Republic and the possible benefits of the SRI tool for achieving savings in the operation of buildings and their technical equipment. The article discusses the setting of weighting factors and their impact on the maximum possible score in the Czech Republic. The use of the tool is demonstrated on two buildings, one with only basic control, the other building is a new building with advanced control of all systems. The evaluation showed that the objects will generally achieve a low score, regardless of the installation of advanced control systems, this is an important finding for the interpretation of the achieved score in the Czech Republic conditions. At the same time, it can be said that the objects with low scores offer significant potential for reducing the cost of operation.

### Keywords

EPBD, SRI-ENACT, smart readiness indicator

## Introduction

As part of the European target to achieve a zero-emission housing sector by 2050, a Directive on the energy performance of buildings (Directive (EU) 2024/1275 of the European Parliament and of the Council of 24 April 2024) has been adopted. The primary objective of the Directive is to minimize greenhouse gas production and achieve energy self-sufficiency in buildings. The Directive imposes requirements, inter alia, on the thermal technical condition of buildings, on the use of renewable energy sources and on the technical systems of buildings. The Directive newly introduces the concept of Smart Ready Buildings (Article 15, SRI). Thus, in addition to the actual efficiency of the equipment, the quality of the equipment control and other building functions are now also assessed.

The SRI concept was introduced in 2017, when the first proposed methodology was consulted. In 2018, the SRI tool was officially introduced for voluntary use. In 2019, after the first experiences, a second technical study of the SRI was carried out and the methodology was adapted. The following year, the EC Implementing Act was issued and pilot testing started.

The SRI assessment will be mandatory from 2027 for buildings with HVAC output above 290 kW, and a testing phase is currently underway in the Czech Republic.

HVAC efficiency is defined e.g. in the Ecodesign Regulation, where the obligation to use heat recovery in air handling units, minimum efficiency of heat sources, etc. is enshrined. The applied regulation and control of the HVAC system has not yet been addressed in detail in any legislation. There is currently significant potential for energy and operating cost savings in the way the HVAC system is operated. Energy audits repeatedly show that the HVAC system is set at inappropriate temperatures, attenuation is not set correctly, the simultaneity of operation is not addressed, the chain: source, distribution, final element is not set correctly (e.g. operation of pumps when the cold source is switched off), the building is not able to respond to solar heat gains, etc.

This text discusses the potential benefits of the SRI indicator for more effective deployment of "Smart" HVAC and building management solutions and its impact on the economics of energy saving HVAC measures and energy costs.

## Methodology details

The SRI is an indicator to assess the level of digitalization and technology integration within a building and expresses its readiness to use and optimize smart technologies to adapt building operations to the needs of users and the network and to improve the energy efficiency of the building and the energy chain (supply and demand optimization) (Zirngibl et al., 2020).

The research followed the different levels of functionality defined in the SRI methodology. The actual SRI methodology is being developed in the framework of the SRI-ENACT project, which develops tools and services for SRI calculation and provides recommendations for smart building retrofitting.

The evaluation within the methodology looked at quantitative and qualitative data on HVAC management, i.e. whether or not control is implemented and how "smart" the control is. In addition, the actual electricity generation and storage and energy flexibility were also assessed. The method was tested on selected representative buildings, on the one hand a building with virtually no control, on the other hand a sophisticated modern building, and the results were further assessed with respect to the author's auditing practice.

As part of the solution, a fact-finding survey was carried out on the buildings and available design documents or BIM data were considered.

## Results details

The SRI is a multi-criteria assessment of a building's regulatory and other functions. The indicator assesses 9 technical areas with seven impact criteria in three key functions. The technical areas are: heating, cooling, hot water,

ventilation, lighting, dynamic building envelope, electricity (RES), electric vehicle charging, and measurement and control. The impact criteria are: energy efficiency, maintenance and failure prediction, comfort, utility, living conditions and accessibility, user information and flexibility and energy storage. The impact criteria are classified into three key functions: energy performance and energy efficient operation, responsiveness to user needs and energy flexibility.

The assessment is then made by comparing it with the maximum of 'smart' features that can be achieved. Method A - limited number of features (for indicative quick self-assessment), Method B - all features (detailed assessment by a specialist, preferred in the Czech Republic) and Method C - self-selection (details not yet available).

The objects have different usage characteristics depending on the climate zone. Cooling dominates in southern Europe, heating in the north. The methodology is therefore divided into five climate zones. The assessment is carried out for 6 building types: house, small BD, large BD, office building, commercial building and educational building.

Results are presented from two "borderline" buildings, representing a currently conventional building with basic control (Building 1) and a modern building with advanced control and BIM in place (Building 2).

Technical areas	Description
Heating	non-condensing boilers, equithermal boiler control
Cooling	local cooling, SPLIT units
Domestic HW	stationary gas water heater, manual on/off
Ventiltion	no mechanical ventilation
Lighting	manual lighting on and off
Dynamic building envelop	no dynamic building envelop elements
Electricity (RES)	no RES
Eletrical vehicle charging	no charging
Monitoring and control	equithermal boiler control, set attenuation

**Figure 1 - Description of building 1**

Technical areas	Description
Heating	new condensing boilers and the use of waste compression heat
Cooling	new chillers with free cooling
Domestic HW	indirectly heated storage tank, charge pump control
Ventiltion	new HVAC units with complete air treatment (including recuperation and humidification), CO <sub>2</sub> measurement
Lighting	LED lights, DALI protocol
Dynamic building envelop	manually operated internal shading, in part of the building
Electricity (RES)	no RES
Eletrical vehicle charging	no charging
Monitoring and control	heating and cooling control according to building load, master control of all HVAC componets

**Figure 2 - Description of building 2**

## Achieved score, building 1:

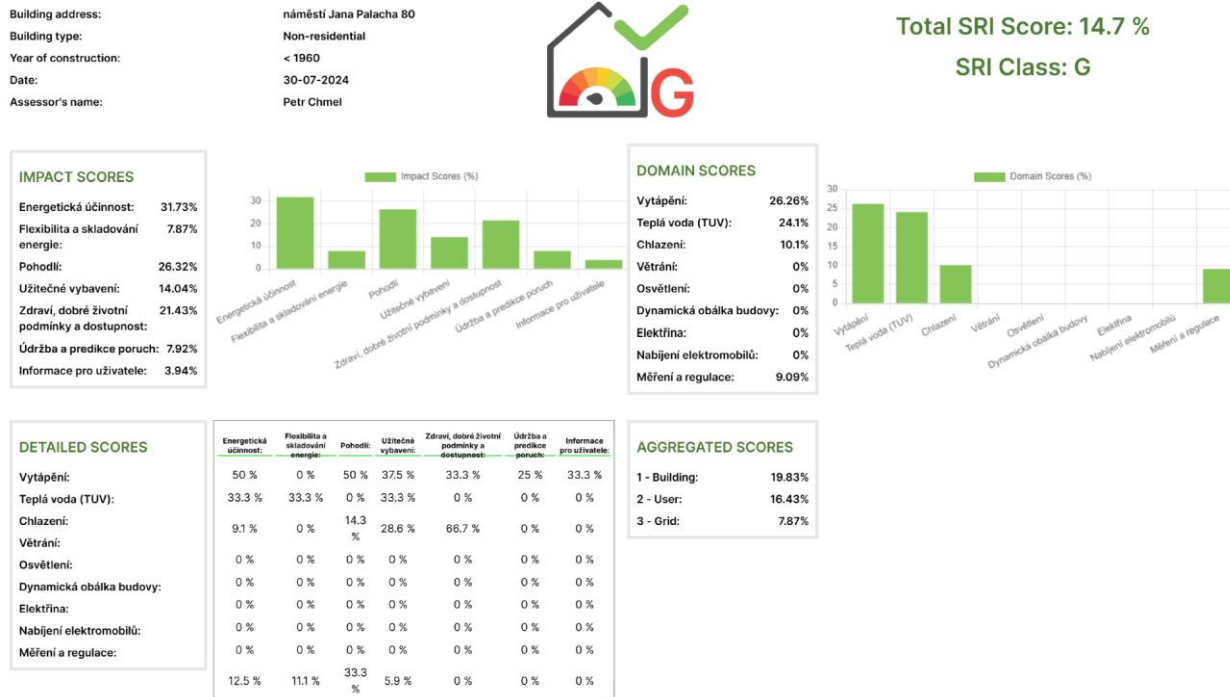


Figure 3: SRI score building 1 (source: author)

## Achieved score, building 2:

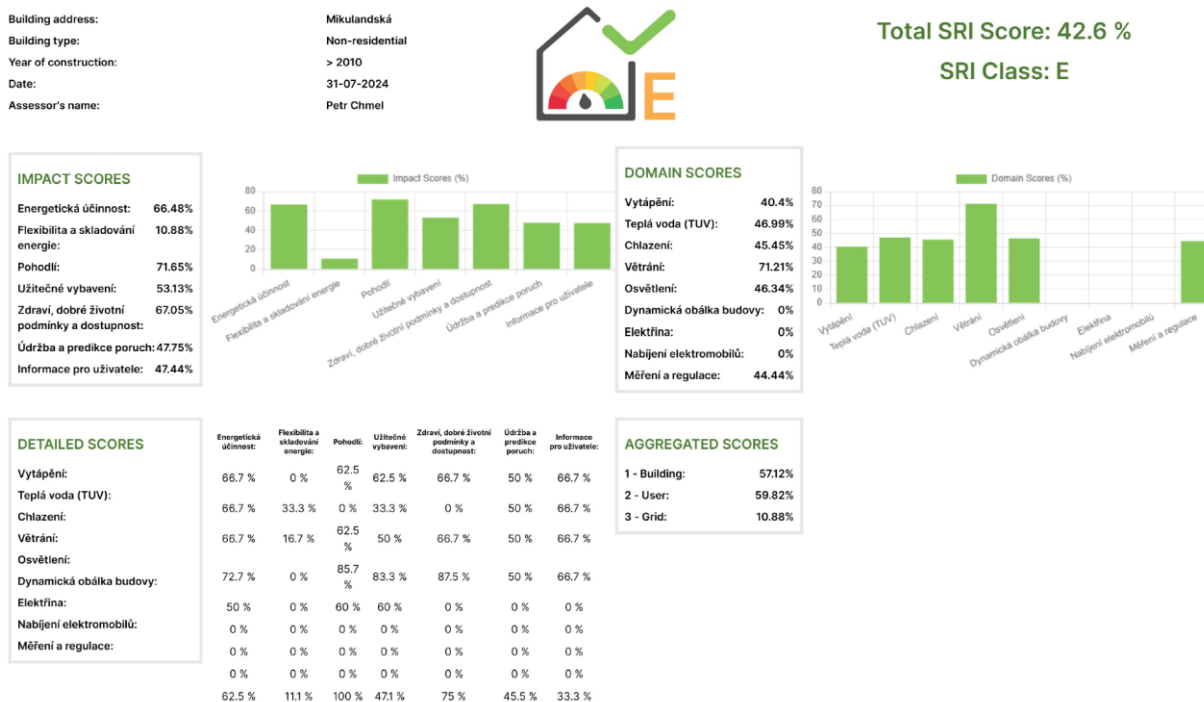


Figure 4: SRI score building 2 (source: author)

## Conclusion and discussion details

Module 3, a detailed assessment by a specialist, was tested. The weighting set for the individual impact criteria is clearly reflected in the scores. The impact criteria are classified into three key functions: energy performance and operation, responsiveness to user needs and energy flexibility. Each of these functionalities has a weighting factor of one third. Flexibility, as a function, is not widespread in the country and distribution networks are not ready for it. There are units of pilot projects in the Czech Republic focused on "price" flexibility. Usually these involve the control of heat pumps in relation to the spot (dynamic) price of electricity. The electricity distributor uses high and low tariffs to distribute consumption during the day, switching between these tariffs with the "HDO" signal, but without the possibility of user influence. Thus, the user cannot implement the demand side management (DSM), which is just included in the third key function of the SRI. Flexibility is not addressed in natural gas and heat energy supply systems. The maximum SRI score achievable in the country is thus limited to 66 %.

This score would be achievable on buildings where all 9 technical domains are present. This is another strict requirement, for example, the RES and dynamic envelope area is not usually possible in heritage areas, in general RES, most often photovoltaic or photothermal panels, are difficult to implement in city centers as parts of roof usability (slope, orientation, static load capacity).








Key functionalities	1/3		1/3				1/3
	Energy performance & operation		Responds to the needs of occupants				Energy flexibility
Impact criteria	1/2	1/2	1/4	1/4	1/4	1/4	1/1
							
	Energy efficiency	Maintenance & fault protection	Comfort	Convenience	Health, well-being & accessibility	Info to occupants	Energy flexibility & storage
	16,7 %	16,7 %	8,3 %	8,3 %	8,3 %	8,3 %	33,3 %

Figure 5: Weighting factors

In the area of Energy Performance and Operations, a higher score is already being achieved, the reason being the implementation of the Ecodesign Regulation, the Energy Management Act of 2000 and the savings actively addressed in the Czech Republic since then, which have focused mainly on the renovation of facilities.

Thus, the key function for the SRI score is Response to User Needs, and in this area, metering and control to achieve thermal comfort and optimal operation is of the greatest importance. As mentioned in the introduction, this is a promising area for addressing HVAC savings and SRI can be a beneficial tool.

The specific scoring results on Building 2 show and confirm that even a modern building from 2021 with good quality control, secondary metering, data archiving, BIM model and modern HVAC achieves a score of only 42.6%. The building lacked only state-of-the-art control features using predictive and learning models (e.g. fuzzy logic), the use of RES and a greater use of dynamic building envelope (could not be implemented here).

In Czech conditions, low scores in the range of about 15-25% can be expected for conventional buildings. Modern buildings will achieve values of 45-55%, while state-of-the-art buildings built or retrofitted with the aim of high energy efficiency (e.g. using the PD&B method) can achieve values of over 60%. The highest score achieved so far in the pilot phase is 48.8%.

Achieving the maximum score hits the cost optimum. Smart solutions are often also costly, and for buildings with, for example, low energy consumption, this solution may not be profitable. The installation of smart solutions must

also respect the capabilities of the building. For example, buildings with high thermal inertia do not emphasize immediate HVAC response, buildings with permanent use do not address attenuation, etc. The SRI scores must therefore be interpreted in the overall context of the building.

For the determination of SRI in the Czech Republic, an on-site inspection and discussion with the actual operator of the building is important. The basis for drawing up the report is not usually the content of an energy audit or energy performance certificate for buildings, the report cannot be drawn up from the documentation alone.

The score is influenced by the professional erudition of the preparer within units of percentages. The individual criteria are scored at level 0-4, the definition of each level is made in one sentence in the methodology, it is not a clear technical definition. Thus, individual preparers may differ in their interpretation of each level.

The SRI tool is a useful indicator for deciding on the use of 'smart' solutions for individual buildings. In the future, it would be useful to monitor the cost-effectiveness of smart solutions and the savings achieved by implementing them.

Low score buildings offers significant potential for energy savings in control of the building and of the HVAC components. For example by optimizing heat supply and distribution can by typically save around 5% of the heat, optimalization of mechanical ventilation and cooling can save 5-10% of electricity. These savings are typical in EPC projects, where the savings are guaranteed by energy service company.

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## 5. INNOVATIVE APPROACHES FOR THE SUSTAINABILITY OF TRANSPORT STRUCTURES AND THE REDUCTION OF THE CARBON FOOTPRINT

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### Abstract

This article presents a systematic review of current innovations in sustainable transport construction, with a particular focus on the use of recycled materials, renewable energy and other green technologies. The main question this chapter seeks to address is: To what extent can innovative approaches in construction contribute to reducing the environmental footprint of transport buildings? The research hypothesis is that the introduction of new materials and practices can significantly reduce the environmental footprint of transport projects while improving their long-term efficiency and sustainability.

### Keywords

Transport construction, sustainability, carbon footprint, LCA

## Introduction

Transportation infrastructure is one of the key elements of modern society, enabling the mobility of people and goods and supporting economic growth. However, traditional methods of constructing and maintaining transport structures place significant demands on natural resources and lead to high greenhouse gas emissions, which negatively impact the environment and contribute to climate change. With the growing emphasis on conserving natural resources and sustainability, there is a need for new approaches and technologies to reduce the environmental impacts of these construction projects and promote their energy efficiency.

The aim of this research is to evaluate and optimize sustainable construction options for transportation infrastructure through innovative methods and technologies. This chapter focuses on developing approaches that enable more efficient use of materials, minimize emissions, and ensure the long-term sustainability of infrastructure.

This chapter presents a systematic review of current innovations in sustainable transportation infrastructure construction, with particular emphasis on the use of recycled materials, renewable energy sources, and other ecological technologies. The primary question this chapter seeks to address is: "To what extent can innovative approaches in construction help reduce the ecological footprint of transportation infrastructure?" The research hypothesis is that the introduction of new materials and procedures can significantly reduce the environmental burden of transportation projects while improving their long-term efficiency and sustainability.

Reducing the carbon footprint is a highly relevant topic, addressed by the European Green Deal. Through the Green Deal, the European Union has set a target of achieving climate neutrality by 2050. This initiative includes a range of measures aimed at dramatically reducing greenhouse gas emissions, with sustainable investments in infrastructure, energy, and construction playing a key role. The emphasis is on supporting renewable energy sources, material recycling, and reducing emissions in industrial sectors [24].

As an EU member, the Czech Republic has joined the goals of the European Green Deal and set emission reduction targets for 2030. The Czech National Energy and Climate Plan (NECP) outlines specific steps for reducing the carbon footprint, particularly through transforming the energy sector, increasing energy efficiency, and developing low-emission infrastructure. Emphasis is also placed on developing transportation infrastructure that reduces emissions using recycled materials and renewable resources [25].

It is also essential to mention the EU Fit for 55 legislative package, which aims to reduce greenhouse gas emissions by 55% by 2030 (compared to 1990 levels). The Fit for 55 initiative includes measures targeting emissions reduction across all sectors, including transportation and construction. This package emphasizes higher energy efficiency and increasing the proportion of recycled and renewable materials in infrastructure projects, including transport structures [26].

## Methodology

The first task was to find suitable materials or studies that address the topic. This chapter describes innovative approaches and technologies used to minimize the carbon footprint in the construction of transportation infrastructure, including methods for assessing their environmental impacts and ways to ensure the reproducibility of these methods in other projects. The goal is to develop a systematic approach that not only reduces CO<sub>2</sub> emissions but also provides a practical framework for sustainability in transport construction.

Reducing the carbon footprint involves measures and strategies that lead to a reduction in greenhouse gas emissions, particularly carbon dioxide (CO<sub>2</sub>), released into the atmosphere due to human activity. This process is crucial for mitigating climate change, as CO<sub>2</sub> and other greenhouse gases like methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O) contribute to global warming [18].

In terms of sustainable transportation construction, reducing the carbon footprint focuses on implementing environmentally friendly technologies, materials, and practices that minimize emissions throughout the infrastructure's life cycle.



## Standard Methods in Transport Construction

Traditional transport construction methods often rely on primary (new) materials, fossil fuels to operate construction equipment, and standard maintenance practices that have limited attention to sustainability.

Standard transportation structures, such as roads and bridges, typically use concrete and asphalt, which require high energy and produce CO<sub>2</sub> emissions. The production of these materials, especially cement and asphalt, has a high carbon footprint, contributing to the negative environmental impacts of construction [10].

Common practices in construction involve using fossil fuels to power heavy machinery, leading to high greenhouse gas emissions and an increased carbon footprint of the entire project. Without incorporating renewable energy sources, these methods continue to rely on unsustainable energy consumption [11].

Standard maintenance practices are often reactive, involving energy-intensive repairs or reconstructions that increase costs and carbon footprint. This maintenance focuses on damage response rather than prevention, which can lead to higher intervention needs over the structure's lifetime [12].

Standard methods often avoid recycled materials due to concerns over quality and durability, increasing demand for natural resources and leaving a higher carbon footprint [13].

These methods remain widely used due to their established nature, lower initial costs, and technology availability. However, compared to innovative practices using recycled materials, renewable energy sources, and advanced monitoring methods, standard methods have a higher carbon footprint and lower sustainability.

## Innovative Approaches and Technologies

The main goal is to identify technologies and materials that reduce the carbon footprint throughout the transportation infrastructure's life cycle.

**Use of Recycled Materials:** Recycled building materials, like concrete or asphalt, significantly reduce emissions by reducing the need for new materials and decreasing landfill waste. Studies have shown that using recycled materials can reduce CO<sub>2</sub> emissions by up to 30% compared to traditional materials. These materials also reduce overall waste and the need for new raw materials, positively impacting the sustainability of the entire lifecycle of structures [1, 2]. This also reduces CO<sub>2</sub> emissions associated with material transport [19].

**Renewable Energy Sources:** Solar panels and other renewables can be integrated into construction to meet energy demands. For example, installing solar panels along transportation corridors can significantly reduce emissions during both construction and operation. In some cases, they cover up to 40% of construction energy needs, contributing to overall energy efficiency [3] [20].

**Smart Monitoring and Maintenance:** Advanced monitoring technologies, such as sensors and digital twins, enable predictive and optimized maintenance, extending the lifespan of structures and minimizing the need for high-carbon repairs [4]. Digital twins provide accurate insights into material performance and condition, allowing timely interventions and maintenance with reduced energy and material consumption.

**Optimization of Construction Processes and Maintenance:** Technologies like digital twins or sensors for predictive maintenance improve the efficiency of construction processes and reduce energy demands for repairs and maintenance. More efficient processes reduce repetitive construction work, minimizing material and energy consumption [21].

**Minimizing Emissions during Transport:** Efficient logistics, which optimizes material transport to construction sites, or the use of low-emission vehicles for transport, helps reduce overall CO<sub>2</sub> emissions during construction [22].

## Impact Analysis

Each of the approaches above was evaluated through the Life Cycle Assessment (LCA) methodology, allowing quantification of the environmental impacts of individual technologies and materials. LCA includes the following steps:

**Defining System Boundaries:** For transportation infrastructure, system boundaries encompass all relevant life cycle stages, allowing a detailed evaluation of environmental impacts at each step, from material extraction to final disposal [14]. In the LCA, impacts were analyzed from raw material extraction to the final disposal of construction materials, covering both the production and maintenance phases [5].

**Inventorying Inputs and Outputs:** This step involves collecting data on all materials, energy, and emissions associated with processes within the infrastructure life cycle. For transport projects, inventorying is crucial as it allows precise tracking of the impact of new materials, such as recycled materials or renewable energy sources [15]. CO<sub>2</sub> emissions, water, and energy consumption were quantified, with each innovative technology or material assessed based on emissions over its lifetime [6].

**Impact Assessment:** This phase analyzes the environmental impacts of each step, including CO<sub>2</sub> emissions, energy consumption, and renewability potential. Impact assessment is key to verifying the hypothesis about reducing environmental burden, as it quantifies the benefits of innovative practices compared to traditional methods [16]. For example, specific environmental impacts of each technology were analyzed using software tools (e.g., GaBi, SimaPro). Results showed that recycled materials and renewable energy sources could reduce CO<sub>2</sub> emissions by over 25%, while using digital technologies contributes to extending infrastructure lifespan by up to 15% [7].

**Interpretation of Results:** The final LCA phase evaluates whether results align with project goals, such as reducing the carbon footprint and ensuring sustainability. LCA provides data that can confirm that implementing recycled materials, energy-efficient technologies, and monitoring systems contributes to fulfilling the sustainability hypothesis [17].

## Reproducibility

Ensuring the reproducibility of these approaches requires setting standardized procedures and creating accessible resources for applying these technologies in various geographic and climatic conditions.

**Standardization of Procedures:** Environmental impact assessment methods, such as LCA, can be widely applied across different projects, allowing for comparison of results between different construction projects. By setting uniform metrics, it is easier to identify projects where innovative technologies have the greatest potential to reduce the carbon footprint [8].

**Adaptation for Different Conditions:** Different climatic and geographic conditions require the adaptation of certain technologies (e.g., solar panel efficiency varies across climates). By introducing flexible modular solutions, effective emission reduction can be ensured regardless of local conditions.

**Knowledge Dissemination and Awareness:** Implementing these approaches on a larger scale requires raising awareness among professionals and collaborating with academic institutions. Organizing professional seminars and publishing best practices can significantly help introduce these technologies into practice [9].

## Results

The result is a comparison with standard methods. Innovative approaches have proven to be more efficient and sustainable compared to traditional construction methods. While traditional practices often use primary materials with a high carbon footprint and rely on conventional energy sources, innovative methods offer advantages in terms

of economic efficiency. Although initial costs for implementing renewable resources and digital technologies may be higher, long-term savings from reduced energy and maintenance costs ensure a faster return on investment [5].

Another advantage is the reduced environmental burden. Compared to conventional methods, innovative approaches lead to significantly lower emissions due to the use of recycled materials and energy-efficient technologies. This helps reduce the environmental impact of structures over their life cycle [6]. Finally, there is also an increase in the longevity of structures thanks to advanced monitoring and maintenance methods, which reduces the need for intensive reconstructions. This more efficient approach brings sustainable benefits in terms of both emissions and costs [4].

### **Hypothesis Evaluation**

The results confirm the hypothesis that the introduction of innovative materials and practices leads to a significant reduction in the environmental burden of transportation structures and improves their long-term efficiency and sustainability. Specifically, the use of recycled materials, renewable energy sources, and advanced monitoring technologies demonstrated the ability to reduce CO<sub>2</sub> emissions, improve energy efficiency, and optimize maintenance. These findings suggest that innovative approaches could be widely implemented as standards for future transport projects focused on sustainability.

### **Conclusion and discussion**

The research confirmed that the implementation of innovative methods in transportation infrastructure construction can significantly reduce the environmental impact of these projects. The main benefits were found in the use of recycled materials, which reduce CO<sub>2</sub> emissions and raw material consumption, and in the integration of renewable energy sources that help meet some of the energy demands of the construction process. Furthermore, the implementation of digital technologies for monitoring and predictive maintenance extends the lifespan of structures and reduces the need for intensive repairs. These factors contribute to the long-term sustainability and lower carbon footprint of transportation projects.

The findings of this research are particularly significant for construction companies, public institutions, and policymakers seeking ways to reduce the environmental impact of infrastructure projects. Recycled materials represent a sustainable alternative to traditional materials, and their wider use could be a significant step toward reducing dependency on primary resources. Renewable energy sources offer a way to lower operational and maintenance costs, providing economic benefits as well. Digital technologies, such as sensors and digital twins, are emerging as key tools for predictive maintenance and can also be applied beyond construction, such as in logistics and other areas where sustainability is essential.

Reducing the carbon footprint in transportation infrastructure is crucial for achieving sustainable development goals, as these infrastructures have a long lifespan and a significant environmental impact. Efforts to reduce the carbon footprint not only contribute to environmental protection but also ensure long-term economic efficiency and responsible use of natural resources [23].

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## 6. ISSUES OF ECONOMIC ASSESSMENT OF THE RENEWABLE ENERGY SOURCES IMPLEMENTATION IN THE CZECH REPUBLIC

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### Abstract

The European Union's climate and energy policy has set up a series of objectives, for which increasing the share of renewable energy in final energy consumption plays a key role. Together with the decarbonization target and the revised directives on the energy performance of buildings, which promotes greater use of solar energy, and the directive on the promotion of renewable energy, and in relation to ensuring energy security, there is an increasing emphasis on the implementation of renewable energy sources.

The aim of this work is to analyze key aspects in quantification the main economic costs of the implementation of renewable energy sources in the Czech Republic regarding meeting the EU targets.

The calculation is based on the analysis of available statistical data, the Czech National energy and climate plan and studies of the renewable energy potential in the Czech Republic. Data from the main Czech subsidy programs and market research are used to determine the cost component. The work primarily focuses on the main renewable sources intended for electricity production, i.e. solar and wind energy.

The study results show the potential gross costs of implementing renewable energy sources to meet the RES share of final consumption commitment. Renewable energy implementation offers significant potential for reducing dependence on fossil fuels, reducing greenhouse gas emissions and reducing final energy costs, but there are several barriers, not least of which is the sheer cost of RES deployment, which represents a major challenge on the path to decarbonization.

### Keywords

cost assessment; decarbonization; EU directives requirements, renewable energy cost

## Introduction

The European Union's climate and energy policy has set a number of specific targets, among which reduction of greenhouse gas emissions, e.g. for example through greater implementation of renewable energy sources, plays one of the key roles. Renewable sources are also important in strengthening the resilience of the European energy system and its independence from Russian energy imports.

Based on the Green Deal strategy and its implementation package Fit for 55 [1], between 2023 and 2024 the key energy directives were revised. These are the Directive 2024/1275 on the Energy Performance of Buildings (EPBD IV) and the Directive 2023/2413 on the promotion of energy from renewable sources (RED III).

The Energy Performance of Buildings Directive [2] aims to minimise the production of greenhouse gases and achieve energy self-sufficiency in buildings. To meet these objectives, the Directive introduces a number of requirements and measures. It introduces a new energy standard, the so-called zero-emission building, whose requirements include that the zero-emission building must not generate any carbon emissions from fossil fuels on site and that the total annual primary energy consumption must be fully covered by renewable energy annually. From 2028, all new buildings owned by public bodies should be zero-emission buildings and from 2030 all new buildings should be zero-emission buildings. The directive also encourages greater use of solar energy in buildings, making it mandatory to install solar systems on selected existing buildings and eventually new buildings. The introduction of appropriate solar energy installations for all new public and non-residential buildings will be in place from the end of 2026, for existing public buildings gradually decreasing in size of useful floor area (over 2000 m<sup>2</sup> by the end of 2027, over 750 m<sup>2</sup> by the end of 2028 and over 250 m<sup>2</sup> by the end of 2030). For non-residential buildings over 500 m<sup>2</sup> undergoing major renovation by the end of 2027 and for new residential buildings and adjacent covered car parks by the end of 2029. The Directive also calls for greater support for renewable energy storage.

Last but not least, the Revised Renewable Energy Directive (RED III) [3] calls for a gradual increase in the share of renewable energy and waste heat and cooling in district heating and cooling and a general increase in renewable energy in the heating and cooling sector, taking into account the use of waste heat and cooling as well as renewable electricity.

Alongside these directives, the EU's headline targets for 2030 for increasing the share of renewable energy in final energy consumption and reducing greenhouse gas emissions have been increased. By 2030, the share of renewable energy sources in EU energy consumption should reach the binding target of 42.5% [4]. Similarly, net greenhouse gas emissions should be reduced by 55% by 2030 compared to 1990 levels. Subsequently, a climate neutrality target has been set for 2050.

**Table 1: Development of key objectives (source: author, based on the European Union official website)**

Indicator / target	2020	2030
Greenhouse gas emissions reduction	20.0 %	
2018 – Directive 2018/844		40.0 %
2023 – based on the Fit for 55 Package		<b>55.0 %</b>
Share of RES in total final consumption	20.0 %	
2018 – Renewable Energy Directive 2018/2001/EU		32.0 %
2021 – Proposal for amending the Renewable Energy Directive		40.0 %
2022 – Proposal of the REPowerEU Plan		45.0 %
2023 – Amended Renewable Energy Directive EU/2023/2413		<b>42.5 %</b>
Share of RES in transport	10.0 %	
2018 – Renewable Energy Directive 2018/2001/EU		14.0 %
2023 – Amended Renewable Energy Directive EU/2023/2413		<b>29.0 %</b>

The European target is a common one and therefore not all countries have to achieve the stated share of RES in their final energy consumption, if the value is put together from nationally determined contributions (NDC). The Czech Republic had to reach a national contribution of 13% by 2020, which it has accomplished. The National energy

and climate plan (NECP) from 2019 subsequently set a target of 22% by 2030 and its last revision (draft version) from 2023 envisages an achievable RES share of 30% (compared to the EU target of 32%). The latter target of 42.5% has not yet been considered.

As of the year 2022, the share of renewables in EU gross final energy consumption was 23%, respectively 18.2% in the Czech Republic and the progress over the last years is shown in the figure below, divided into electricity, heating and cooling and transport [6].

In any case, according to the draft 2023 NECP update [5], the Czech Republic plans to meet most of this target mainly by using solar energy, as well as wind energy, biomass and natural gas substitutes (e.g. hydrogen) for electricity generation, biofuels and hydrogen for transport and biomass, hydrogen and heat pumps for heating. Based on the above, it can be considered that most renewable energy will support electricity production. However, a more detailed plan is lacking, partly due to the lack of an updated State Energy Policy (the latest version is from 2015), which should set out the long-term energy mix and energy strategy in view of the EU's new objectives (the NECP rather addresses how to achieve the set plan).

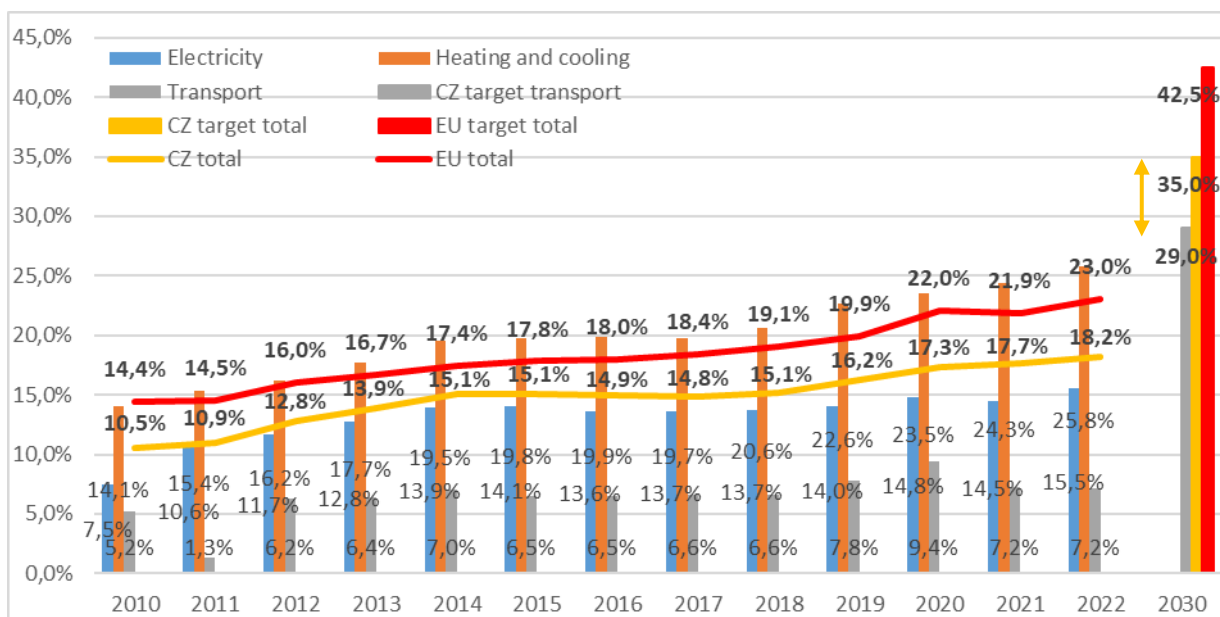


Figure 1: Development of the share of renewables according to Eurostat SHARES (source: author)

## Goals of the study

The main goal of this work is to analyze the key aspects in quantification the main economic costs of the implementation of renewable energy sources in the Czech Republic. Secondly the work calculates possible economic cost of renewable energy implementation by 2030 in the Czech Republic for the electricity sector, considering the minimum requirements under European legislation and the targets under the European Green Deal and Czech National Energy and Climate Plan.

## Methodology and results

Work on this document was carried out in three sequential steps, with all steps involving analysis to identify key aspects affecting the cost of renewable energy implementation:

- First, an analysis of legislation, both EU and national, key strategic documents and relevant expert studies was carried out.
- Subsequently, statistical data - Energy balance of the Czech Republic 2010-2022 [7] and Eurostat SHARES [6] - were analyzed to determine trends in energy consumption and the share of RES in final energy consumption and to determine target (absolute) values of energy consumption in energy units for 2030. This value was used to

calculate the share of renewable electricity, or how much electricity production from renewable sources will need to increase by 2030.

- Finally, based on available data from subsidy programs, projects containing renewables and market research, the unit costs for implementation selected renewable energy sources were analyzed and the total gross cost of implementing RES to meet the 2030 targets was calculated.

### Determination of total RES values for 2030

The share of renewable energy sources is calculated based on the SHARES methodology and expresses the share of gross final energy consumption from RES in total gross final energy consumption. It is not a simple ratio of the real value of RES to total final consumption, which could be determined directly from a commonly used energy balance. Data for SHARES are collected separately.

According to the Renewable Energy Directive, the *“gross final consumption of energy means the energy commodities delivered for energy purposes to industry, transport, households, services including public services, agriculture, forestry and fisheries, the consumption of electricity and heat by the energy branch for electricity and heat production, and losses of electricity and heat in distribution and transmission.”*[3] The gross final consumption of renewable energy is calculated as the sum of:

- gross final consumption of electricity from renewable sources;
- gross final consumption of energy from renewable sources in the heating and cooling sector; and
- the final consumption of renewable energy in the transport sector.

The analysis found that if the Final Energy Consumption in the FEC2020-2030 methodology is used from the energy balance and the Distribution Losses (A) and Own Consumption in Electricity and Heat Generation (B) are added to it, sum very close to the SHARES gross total final consumption values is obtained. The difference between the values is a maximum of 1.71%, with less than 1% between 2019 and 2022, therefore values (A) and (B) from energy balance can be used for further calculations for renewable energy balance. The exponential trend function was used to determine how much the values of (A) and (B) could be in 2030 based on the trends from 2010-2030.

Based on the Energy Efficiency Directive and the NECP of the Czech Republic, the value of final energy consumption to be achieved is known. The target value for the Czech Republic is 846 PJ (the value in 2022 is 1019 PJ), however, for the time being the planned achievable value according to the draft NECP update of 2023 is considered to reach 945 PJ. The extrapolated values (A) and (B) were added to these values to obtain the gross final energy consumption in 2030 (in two variants, first in line with the EU target – C1 – and the second one according to a feasible scenario in the NECP CZ – C2).

**Table 2: Trend values and extrapolated values (source: author according to [6],[7])**

Type of consumption	Identifier	Unit	2020	2021	2022	2030
Distribution losses	A	TJ	25,223	24,342	23,107	21,869
Own consumption in electricity and heat production	B	TJ	41,561	42,892	42,601	33,711
Total gross final consumption	SHARES	TJ	1,090,668	1,161,537	1,113,563	
	C1	TJ				901,580
	C2	TJ				1,000,580

Subsequently, the shares of total gross renewable energy consumption were determined (D). The draft NECP update planned to achieve a 30% share, the analytical thinktank Facts on Climate and the professional association Voice of renewables in Czechia consider a range of 32% to 35% achievable, the target ideal value is 42.5% (this is however valid for the whole EU, while there are countries that already achieve a higher share, so not all countries have to reach the 42.5%, but even lower is sufficient if the target is met as a whole - this is also the approach of the Czech Republic).



**Table 3: Shares of total gross renewable energy consumption (source: author)**

Type of consumption	Identifier	Unit	Share	Total renewable gross final consumption	
				C1	C2
Total renewable energy consumption	D	TJ	30.0%	270,474	300,174
		TJ	35.0%	315,553	350,203
		TJ	42.5%	383,172	425,247

**Determination of partial RES values for 2030**

The following approach was used to determine the share of renewables in the sub-sectors (electricity, heating and cooling and transport) of total renewable energy consumption (D). The baseline total consumption values (E1-E3) for the sub-sectors for 2030 were determined by extrapolation using exponential regression based on the SHARES consumption trends from 2004 to 2022. The following assumptions were then applied:

- In the case of transport, the Renewable Energy Directive requires EU Member States to ensure that the amount of renewable fuels and renewable electricity supplied to the transport sector leads to a share of renewable energy within the final consumption of energy in the transport sector of at least 29 % by 2030 or greenhouse gas intensity reduction of at least 14,5 % by 2030.
- Draft NECP update considers the share of RES in electricity production at the level of up to 37%, expert studies consider a value of 35%. Conservatively, the lower of the two values is used.
- The Energy Efficiency Directive set the goal of reducing EU final energy consumption by 11.7% by 2030, compared to the projected energy use for 2030 (based on the 2020 reference scenario).
- According to the Renewable Energy Directive the share of renewable energy in the heating and cooling sector should increase by 1.1 to 1.3% per year.

Based on the total consumption values (E1-E3) for 2030 and in accordance with the SHARES methodology (for electricity and transport sectors correction multipliers are applied), the renewable energy values attributable to the transport and electricity generation sectors were calculated (F1-F3), with the share for the heating and cooling sector calculated as a residual to the total gross RES consumption (D). In the case of option C1, which is fully in line with the EU targets, the 2030 sub-consumptions were further as a reduction 11.7% from 2020 values before the share of renewable energy was calculated. The resulting new renewable energy production by sector is then calculated as the difference between the known shares in 2022 and the calculated shares in 2030. The resulting values are further verified against the assumptions above and share and balance sheet adjusted, if necessary, based on further calculations.

**Table 4: Extrapolated gross total final consumption per sector (source: author)**

Gross total final consumption	Identifier	Unit	2020	2021	2022	2030 - C2	2030 - C1
Electricity	E1	TJ	252,256	261,824	253,187	262,198	222,742
Heating and cooling	E2	TJ	583,796	628,311	574,393	535,550	515,492
Transport	E3	TJ	257,589	279,713	286,868	295,720	227,451

**Table 5: Share of renewables per sector (source: author)**

Total RES consumption	ID	Unit	Year	Variant C2 – year 2030			Variant C1 – year 2030		
			2022	30.0%	35.0%	42.5%	30.0%	35.0%	42.5%
		TJ	202,609	300,174	350,203	425,247	270,474	315,553	383,172
Electricity	F1	TJ	38,299	89,568	89,568	89,568	76,090	76,090	76,090
Heating and cooling	F2	TJ	148,207	143,714	193,743	268,787	142,935	188,014	255,633
Transport	F3	TJ	16,103	66,892	66,892	66,892	51,449	51,449	51,449

Finally, it was necessary to split the new renewable production in the electricity sector into the different types of sources that would cover the production. First, there was an adjustment where electricity from the transport sector was added to the electricity sector (according to SHARES, electricity from electromobility is counted in transport). At the same time, the development of electromobility until 2030 was estimated.

The NECP draft update, which lists the Installed Electricity Generation Capacity of new sources, was used to do this. Based on these values, the shares for electricity production were determined for individual source types (F1-F3). The planned use of hydrogen was determined to be unattainable after closer examination and distributed among the remaining three main sources - biomass (i.e. CHP), solar and wind.

**Table 6: Distribution of new renewable electricity production between types of sources (source: author)**

Type of energy source	Share	Unit	Variant C2	Variant C1
Solar energy	77%	TJ	39 477	29 099
Wind energy	10%	TJ	5 127	3 779
Biomass energy	13%	TJ	6 665	4 913

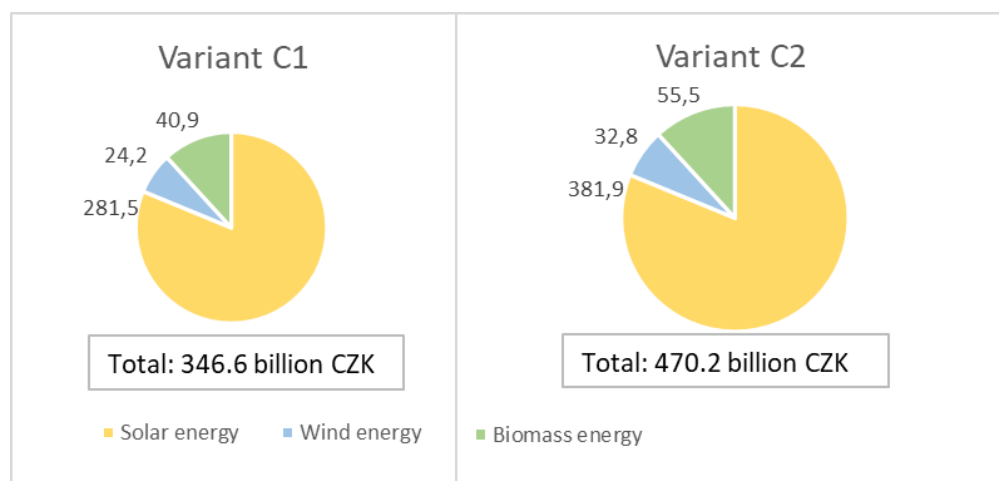
### Calculation of RES implementation costs

First, unit costs per unit of energy production were determined. To obtain them, reports on the evaluation of subsidy programs for energy efficiency and renewable energy were analyzed. These were the programs OP PI, OP TAK, New Green Savings and the Modernization Fund. Unfortunately, mostly only aggregated values were found for the whole specific calls (i.e. all renewables together) and thus insufficient relevant data was obtained. Therefore, a secondary approach was taken to market research and professional publications and articles to determine the gross unit prices. The cost survey was complemented by an analysis of energy production from individual sources (costs were often given per whole unit or per installed capacity).

The average prices for RES utilization were identified as follows:

- Solar energy: 34,840 CZK/kWp, i.e. approx. 34,840 CZK/MWh per year (production ranges from 800 to 1200 kWh/kWp, cost varies depending on the size of the installation).
- Wind energy: 47 169 506 CZK/MW, i.e. 23 025 CZK/MWh per year (production ranges from 1800 to 2600 MWh/MW, existing wind power plants in CZ in 2022 produced electricity with effectivity of 2049 MWh/MW of installed performance).
- Biomass energy (mainly cogeneration): approx. 30 000 CZK/MWh (cost varies depending on the size of the installation and annual operating time, best to assessed individually).

Based on unit prices and known production shares by source (G1-G3), the total gross cost of implementing renewables for electricity generation with respect to meeting EU targets in 2030 is calculated.



**Figure 1: Comparison of costs of renewable energy sources for electricity generation for options C1 and C2 (source: author)**

## Conclusion and discussion

Renewable energy sources are an important element in reducing greenhouse gas emissions, increasing energy security and overall achieving the goal of decarbonizing the economy. However, quantifying the total cost of implementing renewable energy has proven to be a very challenging and quite complex task. This is not only because of the need to know the specifics and principles of different types of renewable energy technologies, but also because of the lack of appropriate data. Based on the calculation approach described above, the analysis of the cost items and the technical [9][10][11][12][13] and strategic documents [5][8], the following aspects and barriers to the calculation were identified.

The first barrier is the actual determination of the possible future energy consumption, and particularly the distribution of energy consumption among the different sectors assessed. Especially when compared to the target value and considering current trends. By 2030, the total final energy consumption in the Czech Republic should decrease significantly, while it does not look like it will decrease in the transport (road transport is increasing) or electricity sectors (due to the introduction of smart technologies and electrification of heating - heat pumps - electricity consumption will rather increase)). This leaves the heating and cooling sector, which, however, is calculated to account for a very significant reduction in overall energy consumption, where in some scenarios there may even be a decrease in the current absolute production of energy from renewable sources (because of increasing energy efficiency and thus reducing the demand for thermal energy).

The distribution itself, at least roughly, must be based on the State Energy Policy [8]. However, in the case of the Czech Republic, it has not yet been updated and therefore does not consider new approaches, technologies, trends or new EU energy and climate protection objectives, in particular the increased renewable energy sources implementation and the simultaneous increased shift away from fossil energy sources.

Another barrier is the incomplete renewable energy legislation, which does not yet fully cover modern approaches, technologies and trends of recent years. Similarly, in the case of the Czech Republic, there is a delay in the transposition of some European directives and requirements, which may affect the proper implementation of renewable energy sources (e.g. energy communities, energy flexibility, accumulation, permitting processes, simplification of local production, etc.).

A separate chapter in the case of the distribution of resource types is the resource adequacy assessment, which shows the possible development trajectories of the Czech electricity sector, and. The design of resources must consider their generating capacity and availability in relation to energy demand. A significant problem with renewable energy sources, in the case of wind and solar, is their intermittent production during the day, so that not all demand can be covered by photovoltaic plants alone, for example, but a suitable combination of several types of sources must be chosen. This already requires the use of more complex simulation models.

There are several sub-obstacles in terms of calculating the total cost. The first is the lack of free information on the cost of implementing renewables, particularly other than PV (these are less numerous and so there is less data on them). The second point is the induced investments that are needed to properly implement RES. This can be investments in electrical infrastructure to increase its capacity for development needs, especially for PV, or costs for associated civil and technological works (e.g. improving the statics of the roof for PV). These costs are generally difficult to quantify.

Another point to consider is considering the operating costs of maintaining the resources in question. In such a case, it would be appropriate to evaluate the implementation of RES by means of a cost-benefit analysis, considering the benefits, which may consist in reducing emissions, reducing the burden on fossil energy sources, the impact on emission allowances and the impact on the price for the final consumer. This is a challenge for further study in the field of renewable energy.

## Acknowledgements details

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## **7. KNOWLEDGE AND TECHNOLOGY TRANSFER OF MEDICAL DEVICES: A CASE STUDY OF A PEDIATRIC MOBILITY AID**

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### **Abstract**

This study explores the Knowledge and Technology Transfer (KTT) process in the pediatric medical device sector through a case study on the collaborative development of a pediatric mobility aid. Pediatric medical devices have particular design, market, and regulatory obstacles that hinder innovation in this field. A University-Industry Collaboration (UIC) between an industrial design firm and a university civil engineering faculty developed a multifunctional medical device to improve mobility and ergonomic support for children with complex physical needs. Key findings reveal obstacles such as mismatched project schedules, a lack of business incentives for ongoing academic involvement, and knowledge gaps in medical device laws. The study highlights the necessity of flexible finance methods, standardized KTT frameworks, and early regulatory expertise involvement to meet the intricate requirements of pediatric medical device innovation. These observations provide a framework for enhancing cooperation and creativity in the creation of pediatric devices with ramifications for players in specialized healthcare sectors as well as legislators.

### **Keywords**

knowledge and technology transfer (KTT), pediatric wheelchair, medical device class 1

## Introduction

In the healthcare industry, Knowledge and Technology Transfer (KTT) is essential for developing medical technologies and making sure they are successfully incorporated into clinical practice. In the meantime, University-Industry Collaboration (UIC), which is becoming a crucial KTT mechanism, has accelerated significantly throughout Europe. A growing number of funding programs, mostly spearheaded by the European Union (EU) through strategic funding programs, support this collaborative paradigm. Individual member states have therefore created regional and national funding programs aimed at a range of industrial sectors, including healthcare.

The medical device industry, which has experienced significant legislative changes since the switch from the Medical Device Directive 93/42/EEC to the Medical Device Regulation (MDR) (EU) 2017/745, is one specific area of the European healthcare sector that is undergoing dynamic transformation. Medical devices and medical device makers have left the market as a result of the more stringent regulatory environment and increased conformance costs [1, 2]. This regulatory shift has significantly impacted the availability of niche medical devices, particularly in the pediatric market, where innovation is noticeably lacking [2, 3]. Stakeholders have found that stricter rules result in higher medical device costs [4].

Despite this, the medical devices industry is a thriving global market, accounting for 82.18% of the medical technology sector as a whole, with projected total revenues of \$467.9 billion in 2022 [5]. Nonetheless, there appears to be a gap between the adult and pediatric device sectors. This is based on the creation of pediatric medical devices, which have particular difficulties because of the small population and the particular medical requirements of children [4, 6]. Pediatric devices require careful adjustments to accommodate different subpopulations based on age, growth, and development, which complicates both design and regulation [7].

Implemented in 2007, the EU Paediatric Regulation aimed to address these gaps by ensuring that medicines for children aged 0 to 17 years are properly researched and authorized. Although the 10- year evaluation of the regulation highlights improvements in pediatric research, it also identifies unmet needs, especially in rare diseases and neonatal care, where device innovation remains limited. [8]. This scarcity is particularly evident in areas such as pediatric mobility aids, where the materials, production processes, and devices' functionality are often outdated to meet the specific needs of young patients and their caregiving environment [3].

Notwithstanding the acknowledged value of innovation, there are still barriers to the widespread adoption of new technology in pediatric medical devices, particularly in specialized sectors with potentially weak commercial incentives. According to Medtech (2024), 90% of the 37,000 medical technology businesses in Europe are SMEs [9]. Research indicates that strict MDR regulations significantly impact SMEs, leading to heightened financial and procedural difficulties [10]. Addressing these barriers and providing incentives for these SMEs is crucial to ensuring that pediatric patients and their caregiving environment receive the medical devices they need for safe and effective care.

The UIC project, a collaboration between a Czech industrial design firm and the Experimental Centre of a Czech Technical University, aims to develop a multifunctional mobility device for children with special needs. Initiated by a local charity and funded by a national agency, the device combines sitting, lying, and standing positions with adjustable height for ergonomic interaction, promoting mobility while easing caregiver effort. The project addresses challenges in collaborative medical device development, regulatory compliance, and commercialization, resulting in a therapy chair prototype after a four-year development cycle.

## Literature review

### Collaborative Knowledge and Technology Transfer (KTT) in healthcare

As highlighted in a review by Marques et al. [11], knowledge transfer (KT) and knowledge exchange (KE) are most successful when researchers and practitioners collaborate based on mutual trust and clearly defined roles, leading to more practical and applicable outcomes. This underscores the importance of fostering strategic research partnerships, such as UICs, to drive innovation and impact in health care. "The translational gap: bridging basic

research, clinical practices, and society“ also addresses the efforts required to transfer scientific results from the lab into marketable applications by fostering networking and education [12].

Klemme et al. emphasize the importance of a multi-directional, agile knowledge transfer strategy for healthcare technology [13]. Essential findings indicate that effective knowledge transfer depends on trust, consistent communication, and equitable collaboration between academic and healthcare sectors. The research indicated that inflexible models obstruct advancement, but a dynamic, customized strategy facilitates the deployment of technology. This highlights the necessity for more dynamic partnership approaches in the medical technology sector to realize the benefit of transfer.

Facilitating collaborative development in technology-driven breakthroughs is essential. Research indicates that "healthcare organizations primarily promote knowledge creation and acquisition processes that significantly influence non-technological innovations" [14]. This underscores the necessity for a balanced strategy, ensuring that technical breakthroughs are acknowledged while also recognizing the significant impact of non-technological innovations on enhancing healthcare procedures.

### **Dissemination of pediatric medical devices**

The urgent necessity to fulfill the unaddressed requirements for pediatric medical devices is thoroughly reported in the literature [1, 2, 6, 10, 15, 16, 17, 18]. The stagnation of innovation in this area is ascribed to multiple factors, including the limited pediatric population [16], significant regulatory obstacles [1], and the considerable expenses related to attaining regulatory compliance [8, 39]. Pediatric mobility aids necessitate enhanced flexibility compared to adult devices to facilitate growth and development, resulting in increased design complexity. Moreover, the literature underscores a deficiency in innovation with pediatric mobility aids, especially in material selection, design, and weight factors [3]. Addressing the shortage and lack of innovation in the pediatric medical device market requires the development of strategic initiatives, such as offering incentives to foster UICs. The commercialization of their outcomes follows strategic research contracts or start-ups. According to Rose et al.'s review of commercial outcomes from collaborative academic medical product development, the best way for people to work together is through three main parts: mentoring with scientific and regulatory guidance, gap funding for preclinical proof-of-concept studies, and help with market research [6]. Sun et al. further emphasize the critical role of non-dilutive grant funding in the pediatric medical device sector, given the limited funding availability and the small market size [16]. Initiatives in Europe and the USA were formed to address this deficit [6, 8, 16, 18, 19].

Warty et al. criticize Roger's Diffusion of Innovation theory, asserting that it requires revision due to the inadequate pace of product application in the healthcare sector [20]. In their study, "Barriers to the Diffusion of Medical Technologies Within Healthcare," the authors identify six principal barriers to the diffusion of innovation in healthcare: technology-specific challenges, clinical evidence, regulatory assessments, health technology assessments, reimbursement, and adoption, among others. These establish the foundation for this case study examination.

Pietzsch et al. examine early evaluation processes for medical devices to guide decisions on risks, benefits, and economic viability [21]. These assessments help developers, regulators, and providers identify challenges and market feasibility early, integrating clinical, regulatory, and market data to balance innovation with safety and cost-effectiveness. The importance of pediatric postural support.

Literature highlights the importance of anthropometric wheelchair design influencing the comfort and health outcomes of diverse user groups [22]. Initiatives are undertaken to enhance ergonomics in the positioning and mobility of youngsters. Torres-Pérez and Caballero-Reyes emphasize the deficiencies of current pediatric wheelchairs, which frequently lack adjustable features to match children's growth, resulting in problems with posture and comfort [23]. Employing ergonomic principles and specific anthropometric measurements of prospective users, the resultant wheelchair design accommodates children's growth, enhances comfort, and improves posture, rendering it a functional, customizable, and economically feasible solution for pediatric users across diverse environments.

Ning et al. also highlight the importance of postural support in wheelchairs through adjustments in the back, seat, and leg positions to relieve pressure [24]. In addition, they bring attention to the need to overcome obstacles both indoors and outdoors while maintaining static stability.

## Methodology

This study is based on a KTT case involving UIC for the development of a pediatric medical device. The case outlines a UIC project structured as follows: The tasks of project management, engineering, and design were carried out by the industrial partner. The industrial partner was also responsible for market research, product development, and materials research. Field research, market testing, and consultations with subject matter experts were conducted collaboratively with the university partner. The university partner additionally took on the role of validating the mechanical and statical outcomes involving the development of specific testing tools and processes.

Advancing the development of medical devices iteratively includes the involvement of all stakeholders in the process [15]. In this case, neither partner is experienced in medical devices, so professional feedback from physiotherapists, orthopedic technicians, pediatricians, and nurses, but also the daily caregiving environment, such as parents, teachers, and personal assistants, was regularly consulted.

Past the prototype stage, a proof of concept stage is taking place, validating not only the commercialization potential but also involving accredited testing required for MDR conformity. The goal of the industrial partner is to start a new line of business in the form of a medical device manufacturer start-up.

The case study approach used in this research follows the framework proposed by Crowe et al., who distinguish between intrinsic, collective, and instrumental case study methods [25]. The instrumental technique was chosen to extract insights from this general case, offering a comprehensive grasp of theoretical KTT within the pediatric medical device business through joint research. This approach utilizes the case as a means to explore and explain a wider issue, specifically the processes and obstacles faced in the creation of a medical device, with a focus on collaborative development efforts. The following steps, as suggested by Crowe et al. were taken.

### Definition of the case:

The case is defined as a collaborative applied research project in the field of pediatric medical devices, serving as a foundation for understanding the processes, challenges, and barriers associated with KTT activities. The development of a pediatric medical device provides insights into the dynamics of collaboration between academic and industrial partners in this specialized sector while highlighting steps necessary till the commercialization phase.

### Selection of the case:

This case was chosen for its comprehensive development cycle from Technology Readiness Level (TRL) 0 to 9, covering prototype completion, proof-of-concept (POC), new business formation, regulatory compliance, production planning, and commercialization. Funded through a mix of public and partner resources, with potential additional financing, it exemplifies collaborative research with multiple stakeholders. This project innovates pediatric mobility by integrating multifunctional positioning at various heights, incorporating ergonomic principles for both the child and caregiver. It's ideal for studying KTT in pediatric medical devices.

### Data collection

Over four years, data was gathered on challenges and barriers categorized by the Warty et al. framework, adapted here to focus on collaboration dynamics and funding. This approach structured the analysis of obstacles from research through commercialization. As Warty et al. do not consider UIC challenges, the categories collaboration dynamics and funding have been replaced by their category "others."

### Analysis, interpretation, and reporting

The case was analyzed through KTT theory, examining collaboration, funding, innovation, regulatory requirements, and commercialization. Findings were organized by barriers, with emphasis on the unique challenges



in pediatric medical devices. The report offers insights on success factors, challenges, and lessons for future KTT activities.

## Results

Throughout a four-year UIC project cycle, various aspects concerning KTT have been monitored and key challenges and barriers documented. These challenges provide valuable insights into the factors that influence the efficient transfer among the project partners. This review will help to identify areas in need of improvement for more successful collaboration and innovation. The results are as follows:

### Collaboration challenges

University-industry collaborations in medical device research face challenges due to sector knowledge gaps, mismatched expectations, and the human factor. Insufficient medical device knowhow hinders project planning and feasibility evaluations, resulting in alterations to budgets and time frames. Addressing this knowledge gap requires investment in consultation to synchronize project requirements, particularly for the industry partner that emphasizes market applicability.

A common barrier in UIC is the expectation mismatch between industry and university partners. The university partner aims for scientific contributions, while the industry partner focuses on market applicability. This disparity can lead to frustration if outcomes don't meet both parties' aspirations.

In long-term collaboration projects, motivation can diminish over time, and maintaining momentum requires ongoing involvement. Diversity in organizational culture and role conflicts are common barriers. Designating a dedicated part-time coordinator within each team facilitated regular updates and collaboration among teams but faced obstacles such as role conflicts and issues in bridging organizational cultures.

Sharing intellectual property (IP) rights often challenges UICs, as both partners may lack experience and consistent practices for managing IP in joint agreements, leading to early conflicts and distrust [26,27]. Universities' fragmented KTT structure leads to inconsistent IP management, complicating collaboration agreements and increasing friction with industry partners. Centralizing and standardizing KTT at the university level is advisable to create easily applied frameworks, clarify expectations, and streamline IP negotiations while addressing the perception of initial contributions as sufficient.

The human factor plays an important role in any kind of relationship. Research confirms that the human factor, trust, and commitment also play a key role in collaborative research [28]. UICs are often triggered by interpersonal relationships and common professional goals. Despite the initial trust and commitment in the relationship, there is a strong need to formalize UICs as business relationships and, therefore, go beyond the individual relationships among people. To ensure a smooth collaboration among the team members, a clear project management plan is proposed. Defining goals, setting milestones, assigning responsibilities, and facilitating communication [26] helps avoid conflict in critical situations. Regularity in exchange of progress and results is vital for the continuous trust and commitment among the team members.

### Funding

Funding the development and commercialization of a medical device can be challenging due to many unknowns, especially for new entrants. Public funding offers initial support but requires a defined and rigid time and budget plan despite the difficulty in projecting a complete timing and financial overview for each development stage. As a result, project phases are often individually funded, with public funds covering initial stages and third-party funding or personal investment supporting subsequent ones.

Research indicates that public funding in this sector enhances long-term employment impacts [29], underscoring its benefits as a non-dilutive resource. Venture Capital (VC) funding may be less suitable for non-breakthrough devices with limited niche markets, but private funding with strategic interests may be more appropriate. In niche markets, such as pediatric therapeutic devices, proof-of-concept (POC) stages often rely on a mix of public funding,

strategic partnerships, or private investment. Nonetheless, the inflexible deadlines and established periods of grant submissions can interrupt project continuity, potentially obstructing seamless advancement. In this instance, POC financing has been requested, although confirmation of the funds is anticipated to arrive less than one month before the expiration of the existing funding. Therefore, the continuation of the project is critical, as it ensures the retention of trained personnel. Any disruption at this stage risks undermining the project's success and may lead to its failure.

In this case, the industrial partner has provided initial development funding, but additional support for the POC and market entry stages will likely involve a blend of public, private, and third-party funding. University funding is not anticipated, given legal and financial limitations on their part. Selecting the appropriate funding type, whether government grants, private investors, angel investors, or venture capital, remains essential due to each source's unique needs and conditions [30].

### **Technology-specific challenges**

Technology-specific challenges refer to issues related to the technological characteristics of a device that influence its diffusion [20]. Challenges within the control of the research team include usability. Those beyond the team's control involve stigmas associated with certain materials or functions.

In the presented case, challenges within the team's control include the choice of alternative materials and production processes, as well as the functionality of the device. Specifically, the multifunctionality of the device may pose a challenge for inexperienced users, as the various functions can be perceived as overwhelming. Typically, the market offers one device per function, such as an indoor therapy chair, an indoor standing trainer, or an outdoor buggy. In the presented case, the integration of functions within a single device provides the user with enhanced capabilities but also introduces a greater need for small adjustments. For instance, repositioning the child from sitting to standing requires securing the child with restraint systems, adjusting the footrest and leg rest, and then, by means of a manual pump, repositioning the child from a sitting position to laying and, finally, to a vertical position. A mechanical adjustment system was intentionally chosen to avoid the dependency on electricity. Clear manuals and training must be part of the product's communication strategy.

Challenges beyond the team's control include the market's inexperience and inacceptance of materials other than the typically used aluminum and injection molded plastics. Composite materials and 3D-printed components have yet to gain widespread applications in this sector, mainly due to a lack of innovation in this segment [3]. These new materials and production processes face potential rejection due to market concerns regarding the perceived lack of stability and durability. Market feedback indicates that structural plastic components tend to be perceived as unstable, potentially leading to a lack of acceptance and subsequent market rejection. Despite these concerns, 3D printing, for instance, offers promising solutions for prototyping and small-scale production. Their advantages lay in the design flexibility and absence of expensive tooling costs, particularly for small series production. Despite structural testing and proof of regulatory conformity, user perception may lead to rejection of the product.

### **Clinical evidence**

Clinical evidence aims to address uncertainties regarding a device's performance, safety, and effectiveness, as well as the dissemination of data to mitigate these uncertainties [20]. Throughout the development cycle of the therapy chair, subject matter experts were regularly consulted. Through invaluable connections to key stakeholders, clinical evidence could be gathered within the Czech Republic and Germany, providing multifaceted feedback.

Small groups of experts consisting of parents and teachers, physiotherapists, assistants, pediatricians, and orthopedic technicians from the Czech Republic and Germany were given demonstrations of the device's functions, either at their workplaces or at the development team's premises, typically for one to two hours. Due to stringent regulations on formal testing with children, demonstration and testing were conducted using a dummy. While the feedback provided was detailed and critical, the development team acknowledges that short testing cycles and the use of a dummy may have impacted the accuracy of the feedback and show some insufficiencies in conclusively demonstrating the device's performance, efficiency, and safety.

Additionally, the voluntary participation of subject matter experts may have limited the quality of the feedback, as some participants were hesitant or reserved in sharing their open opinions and knowledge. Full-scale clinical testing in a real-world environment will be necessary to evaluate further the usability once the POC stage commences. Furthermore, accredited laboratory tests are required to formally prove static strength, stability, material fatigue, and biocompatibility. Challenges acknowledged include the involvement of stakeholders and their conclusive feedback during development, which must lead to regulatory conformity and market acceptance.

### **Regulatory affairs**

Regulatory affairs play a critical role in the development and commercialization of medical technology [20]. Regulatory requirements must be understood early in the development process to avoid costly redevelopment. In the therapy chair case, the team faced challenges due to lack of expertise in medical device regulations. To overcome these issues, they considered involving a qualified regulatory expert, but this was underestimated during the grant application process.

The therapy chair falls under Medical Device Class 1, which is the least restrictive category and allows for self-certification. With this classification in mind, the team incorporated basic MDR requirements related to design and development from the start. Only in later stages did the team consult MDR experts for support with documentation and process preparation for certification. A significant challenge was the limited availability of experienced professionals in the Czech Republic, which highlights the underdevelopment of this market segment.

When it comes to accredited physical testing of the device, it became clear that there is little to no local capacity for testing relevant standards, including DIN EN 12183, ISO 7176, and ISO 16840. This forced the team to seek out laboratories in Germany, adding further costs due to travel and higher service fees. In addition, software-specific systems concerning MDR require Quality Management Systems (QMS) further require the acquisition of new skills and further investments, which greatly impact the project budget.

### **Health Technology Assessment (HTA)**

The World Health Organization (WHO) defines Health Technology Assessment (HTA) as “a systematic and multidisciplinary evaluation of the properties of health technologies and interventions,” assessing their value by considering health impacts and implications for health systems, such as medical devices [31]. Despite the rising healthcare costs in the Czech Republic and other European countries, HTA can help optimize spending in the medical device sector but remains underutilized [32]. Conducting HTA presents additional financial limitations and reporting challenges for medical device innovators [33]. Bridges and Jones propose a more visionary approach to HTA by introducing a patient-centered model where patient perspectives and experiences shape the assessment process, ensuring that healthcare technologies align more closely with patients's needs and values [34]. Kubatova and Rogalewicz criticize the lack of HTA standardization and adaptation for medical devices [35]. The therapy chair doesn't introduce any groundbreaking innovations; instead, it combines and optimizes the functions of existing devices. This results in a limited and informal approach to HTA. Based on a suggested HTA framework [36], the therapy chair's HTA approach is summarized as follows:

**Definition of the medical goal and decision problem:** Caring for children with complex needs requires significant physical effort from caregivers. The therapy chair aims to consolidate multiple mobility devices into one, enhancing the comfort of both the occupant and the caregiver, incl. less lifting in and out of the device, while providing several micro- and macro-positioning tools. It addresses not only the medical needs of the child but also the ergonomic demands placed on caregivers, including lowering the weight of the device, a new concept not covered in the market.

**Assessment of consequences using clinical evidence:** Current clinical evidence suggests that the multifunctional therapy chair is an efficient tool. However, further data is necessary to confirm the device's structural integrity and assess the functionality of its features during daily use, based on both the child's clinical use and the caregiver's ergonomic evaluation.

Resource assessment using cost analysis: As a publicly funded UIC project, the economic principles differ from those of fully commercially funded developments, where budget constraints typically dictate the development timeline. The industrial partner benefits from increased financial flexibility, with 60% of the funding coming from public sources and the university partner up to 90%. In this case, the project timeline is governed by the grant's timeframe rather than by budgetary limits.

Analysis of incremental costs versus consequences: While the device is expected to have higher upfront costs, it is projected to offer long-term savings when compared to the costs associated with purchasing, maintaining, and storing one versus two or three separate devices.

## **Reimbursement**

Following obtaining the MDR conformity, additional steps are necessary to facilitate the dissemination and reimbursement of the device. Reimbursement involves collaboration with thirdparty funding agencies, such as public and private health insurers. The development of a reimbursement strategy is crucial for the successful diffusion of medical devices in Europe, where prescriptions for mandatory health insurance programs typically acquire medical devices [20].

Coding: Reimbursement for medical device manufacturers is secured through contractual agreements with health insurance companies responsible for covering the costs of medical devices for their clients. Registering the device with insurers can be a complex, regionally variable process, often involving significant administrative effort due to the need for multiple contracts. Reimbursement is based on predefined billing codes, which assign prices to specific product groups. Often, these prices remain fixed or rely on the least expensive option, which hinders the spread of high-end products that provide superior quality to users and caregivers.

Coverage and Payment: High-end medical devices may require significant out-of-pocket contributions from end users, limiting commercial sales and accessibility. National regulations and the income levels of users can present serious barriers to the commercialization of such devices. In many cases, the clinical and economic evidence supporting the product may not be strong enough to justify reimbursement, further complicating market access [20].

Policies: Reimbursement systems vary significantly across countries. For instance, the Czech Republic only renews wheelchair support every five years, which poses a challenge for small children seeking appropriately sized mobility devices as they grow. In contrast, a pediatrician's recommendation in Germany allows children to receive new devices and even prescribe multiple devices for different environments like home and school. If a new medical device does not fit into an existing product group, the creation of a new group may be necessary, which can be a highly restrictive and time-consuming process.

For the multifunctional therapy chair, the reimbursement challenge is particularly relevant, as it is considered a high-end product. The goal, following MDR certification, is to position the chair in a new product group to establish a new price standard for its category, though the outcome remains uncertain. The strategy for the therapy chair is to provide sufficient clinical evidence to prove the clinical and, hence, economic benefit. This is expected to be performed in cooperation with a renowned university hospital in the Czech Republic. It is yet uncertain whether this needs to be performed again in leading markets like Germany to achieve a stronger positioning for clinical use and adoption in the market.

## **Adoption:**

The adoption of medical devices introduces a range of complex challenges, particularly in achieving widespread acceptance. Warty et al. emphasize two critical factors influencing the adoption or rejection of innovations: the absence of opinion leaders and the characteristics of potential adopters. Opinion leaders play a pivotal role in establishing confidence among potential buyers, attracting an initial group of early adopters who help to validate the product.

This dynamic aligns with Rogers's Diffusion of Innovation model, which outlines five stages of technology adoption [37]. In this model, innovators initially adopt and champion the technology, encouraging early adopters, who subsequently influence the early majority, followed by the late majority. The success of a medical device, therefore, hinges on the breadth and pace of its adoption. Effective strategies to engage opinion leaders and early adopters can accelerate this process, significantly enhancing the device's market penetration and impact.

Lastly, the device's country of origin influences market perception. Western European countries may perceive products from Central or Eastern Europe as lower quality, especially in the business-to-consumer (B2C) sector, although this perception is less common in business-to-business (B2B) interactions, according to the project's stakeholder feedback and literature [38]. To address this, partnering with a reputable Western European distributor is expected to enhance market confidence and mitigate these perceptions. Table 1 summarizes the KTT challenges in the diffusion of medical devices specific to the presented case.

**Table 1: Case-specific summary of KTT challenges in the diffusion of medical devices**

Categories	Challenges
Collaboration challenges	Insufficient expert knowledge Expectation mismatch Motivation in long-term projects Role conflicts and organizational culture Sharing IP rights Human factor
Funding	Budgeting for medical device innovation proves complex Public funding suitable for non-breakthrough research A university partner is not a funding partner
Technology-specific challenges	Within the team's control Choice of materials and production processes Functionality Beyond the team's control Inexperience in using functions Rejection of materials
Clinical evidence	Access to use cases Testing in real-world settings Obtaining honest feedback
Regulatory affairs	The team's knowledge gap of MDR High costs associated with the access to material High costs and lack of skills for MDR compliant software Lack of accredited testing capacity Lack of professional advisors for medical device regulation Listing with health insurances
Health technology assessment	Definition of the medical goal and decision problem Assessment of consequences using clinical evidence Resource assessment using cost analysis Analysis of incremental cost versus consequences
Reimbursement	Coding Coverage and Payment Policy
Adoption	Lack of Opinion Leaders Adopter Characteristics:

## Discussion & Conclusion

This study highlights the complexities of KTT in connection with collaborative research and diffusion of innovation within the pediatric medical device sector. A case study on the development of pediatric mobility serves to analyze

collaborative challenges. One of the main barriers identified is the knowledge gap between both partners about the regulatory requirements for medical devices, particularly in the field of MDR. This knowledge gap leads to a dependence on external contributions during prototype development, regulatory compliance, and contractual relationships with insurers. Furthermore, the case demonstrates the importance of flexible, agile funding mechanisms that allow the inclusion of new partners or services as the project evolves, avoiding interruptions that can arise from fixed funding timelines.

The research collaboration culminated in a mid-term university-industry relationship, wherein the industrial partner addressed a particular technological deficiency in material and structural testing with the university's expertise. The team currently does not anticipate a continuation of this collaboration, given the strong reliance of the SME's (industrial partner) innovation efforts on public funding. This dependency often limits collaborations to the duration of the funded project, aiming for competitive market advantages or entry into new business segments within that timeframe. In contrast, larger companies, with less reliance on grant funding, tend to establish strategic, long-term alliances with universities to support sustained research and development (R&D) and access a pipeline of skilled professionals.

The project originated from a genuine commitment to improve mobility for children with special needs and enhance their caregiving environment. Nevertheless, it quickly became apparent that achieving a successful outcome also required a commercial mindset. The team underestimated the complexities of bringing a medical product to market during the team formation and initial grant application phase. Securing grants proves challenging since it necessitates precise timing, project focus, and team composition alignment. Often, this process begins only after the announcement of funding programs. This often results in hurried, last-minute planning rather than a strategic and planned approach.

With better foresight and the involvement of medical devices and special materials experts from the outset, the team could have accelerated development, reducing delays caused by trial and error. Enhanced knowledge transfer from these experts would have significantly benefited the project. Despite these challenges, both partners gained valuable expertise, such as in 3D printing technologies, the use of composite materials, and others. These applications extend beyond this project to other fields.

Interaction between science and industry in the medical device sector can vary significantly depending on whether the initial drive comes from scientific research or industry demand. When the industry initiates a collaboration, companies often identify specific technological needs or market gaps and turn to academic partners for innovative solutions or advanced research capabilities. This pull approach allows companies to leverage academic expertise for product development, often with a clear commercial objective.

On the other hand, a push approach, in which science seeks to contribute to research, is more prevalent in emerging research areas, where academic discoveries serve as inspiration for new applications or entire product lines within the industry. Researchers may uncover novel materials, processes, or mechanisms in the lab, gaining interest from industry partners to explore potential applications. This approach is typical of more groundbreaking discoveries.

The motivation for developing medical devices, especially in the pediatric space, extends well beyond commercial considerations. Unlike many consumer products, medical devices often emerge from a need to address urgent health challenges, improve patient quality of life, and fulfill unmet medical needs. Ethical and compassionate motivations frequently drive the development of devices tailored to pediatric patients, as this user group has specific physiological needs that differ from adults and typically has fewer device options tailored to them. Moreover, pediatric device development often faces unique regulatory, technical, and financial barriers, reinforcing the need for a mission-driven approach.

Recommendations to improve the pediatric device sector focus on easing regulatory barriers and costs to ensure timely approvals and market access for essential devices. For instance, streamlining regulatory pathways, establishing pediatric-specific standards, and encouraging early-stage funding are among the suggested measures

to facilitate a commercially viable entry of devices into the market. The goal is to encourage the innovation of pediatric devices that not only meet commercial demands but also fulfill critical healthcare needs, ensuring that pediatric patients can access necessary, highquality medical technologies.

In conclusion, this case study provides valuable insights into the processes, barriers, and enablers of KTT in pediatric medical devices, demonstrating that successful university-industry collaboration requires realistic timelines, flexible funding structures, and proactive regulatory planning. Future UICs in the pediatric device sector would benefit from dynamic funding structures, fostering long-term collaboration and offering incentives for SMEs to invest in niche healthcare innovations. Optimizing these elements can drive impactful advancements in pediatric care, making specialized devices more accessible for underserved populations.

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## 8. HOW 3D PRINTERS FOR HOUSES CAN REDUCE CO2 EMISSIONS

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### Abstract

3D printers for building construction are emerging as an innovative technology. One of the advantages that could be leveraged is their potential to reduce CO2 emissions in the construction sector, which is one of the major contributors to global emissions. Adopting this technology allows for greater precision in construction, reducing material consumption and minimizing waste, which traditionally plays a significant role in the sector's ecological footprint. Automation and digitalization of the construction process also offer benefits such as shorter building completion times and reduced transportation needed for material delivery, leading to decreased emissions related to site logistics. The proposed research aims to analyze the potential of 3D printing for construction, assessing how this technology could represent a significant innovation in reducing CO2 emissions in the construction sector. The author will use the results for future research.

### Keywords

Contour crafting; CO2 Emission; Raw concrete; 3D printing, 3D Technology

## Introduction

3D printers for the construction industry represent one of the most promising technological innovations of recent years, with potentially wide-reaching impacts in various sectors, including construction, architecture, and environmental sustainability. The construction sector has historically been among the most significant contributors to global CO<sub>2</sub> emissions, significantly driving climate change and environmental pollution. The introduction of technologies such as 3D printing offers new opportunities to rethink traditional construction methods, resulting in greater efficiency in production and a reduction of the environmental impact associated with creating new buildings.

One of the main advantages of using 3D printers in construction is the precision with which structures can be built, allowing for optimized material consumption and a significant waste reduction. In traditional construction, a large portion of the materials used ends up unused or in the form of waste, which must then be disposed of, contributing to pollution and increasing the environmental impact of the entire construction process. Conversely, 3D printing allows for the exact amount of material needed to create each structural element to be used, eliminating waste and improving the overall efficiency of the process.

Another crucial aspect is the possibility of using alternative and more sustainable materials than traditional ones. Additionally, 3D printers can utilize recycled materials, reducing the environmental impact of new constructions. This feature promotes a more ecological approach to construction and opens new possibilities for integrating sustainable solutions into building design.

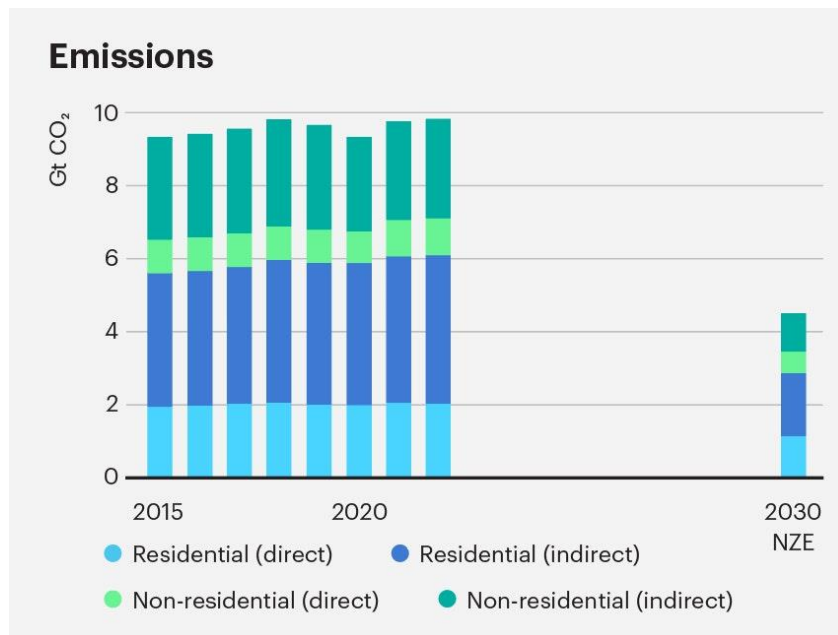
Beyond the reduction in material waste, 3D printing offers significant advantages in terms of automation in the construction process. Automation allows for shorter construction times, improving overall site efficiency and reducing the need for intensive labor. This leads to a reduction in costs, as well as lower energy and resource consumption during the construction phases.

Logistics related to the transportation of building materials is one of the significant contributors to CO<sub>2</sub> emissions associated with the construction of new homes. 3D printers make it possible to produce components directly on-site or in the immediate vicinity, limiting the need for transportation and reducing emissions related to this process phase.

The potential of this technology in reducing CO<sub>2</sub> emissions and optimizing the resources used during the construction phase highlights that the benefits are not only direct from using this tool but also indirect.

## CO<sub>2</sub> emissions in construction:

The construction sector is one of the largest sources of CO<sub>2</sub> emissions globally, significantly contributing to climate change and environmental pollution. According to the International Energy Agency (IEA), in 2022, the construction and building sector was responsible for about 37% of global energy-related CO<sub>2</sub> emissions, divided between operational emissions and those embedded in construction materials such as cement, steel, and aluminum. Operational emissions come from the energy consumed for heating, cooling, lighting, and other daily building functions. With the growing use of renewable energy and increased energy efficiency, these emissions are expected to decrease in the coming decades. However, embedded emissions, which result from the production and processing of building materials, pose a growing challenge as the demand for construction materials continues to rise due to population growth and urban expansion.

**Graphic: CO<sub>2</sub> emission trends compare with the Net Zero Emissions scenario by 2030**

Source: IEA (2023), Tracking Clean Energy Progress 2023

A 2022 United Nations report highlighted that, despite efforts to improve the energy efficiency of buildings, the growth in built-up areas has outpaced these improvements, leading to an overall increase in CO<sub>2</sub> emissions.

Another critical factor to consider is the impact of construction materials.

Traditional materials like cement and steel significantly contribute to global emissions. Cement alone is estimated to be responsible for about 7% of global CO<sub>2</sub> emissions. Adopting more sustainable approaches, such as using recycled or alternative materials, could significantly reduce these emissions.

To meet the goals of the Paris Agreement, all new constructions must include low-impact and zero-emission buildings by 2030. However, less than 5% of new constructions currently fall into this category.

The greatest challenge remains the decarbonization of existing construction materials and the introduction of circular solutions. Reusing existing buildings, improving cement and steel production processes, and adopting innovative technologies like 3D printing can help reduce CO<sub>2</sub> emissions while promoting sustainability in the construction sector.

### **Analysis of the construction phase with 3D printer:**

The analysis of construction phases using 3D printers highlights their significant potential in reducing CO<sub>2</sub> emissions. Although 3D printers, as technological tools, do not directly affect emissions, adopting this technology can represent a revolutionary method of optimizing the construction process and eliminating factors that traditionally contribute to environmental impact.

First, one of the key differences between conventional construction and 3D printing is materials management. The precision of 3D printers allows only the exact amount of material needed to build each component of the building to be used. This approach to reducing material consumption leads to two primary considerations:

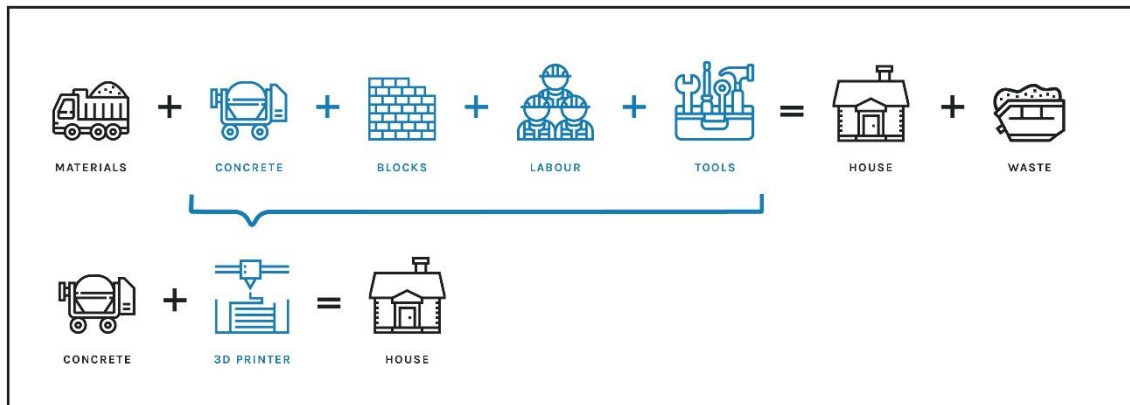
#### **1. Reduction in material consumption:**

If the machine uses only the strictly necessary material, the demand for construction materials decreases, which can result in lower market demand for resources. Less cement, bricks, or steel means fewer emissions associated with producing and transporting these materials.

## 2. Reduction in construction waste:

The printer's precision generates less waste on the construction site, thus reducing the amount of waste to be disposed of in landfills. In traditional construction, construction waste constitutes a significant percentage of global waste, and its disposal is a relevant source of emissions.

### Scheme: traditional methodology Vs. 3D printers



Source: Andrea Palazzo

In addition to these characteristics, another important advantage of this technology is seen in the execution phase. The 3D printer can simultaneously construct both the interior and exterior walls, creating a cavity between the two layers where we can install the thermal insulation materials and technological systems, such as:

- Electrical
- Hydraulic
- Drainage

The installation of the systems takes place simultaneously with the construction of the walls as they are built.

This means that all the necessary systems are integrated during the wall construction. In traditional construction, after the walls are built, they must be subsequently drilled or partially demolished to install the systems, increasing construction waste and additional labor. In contrast, 3D printing eliminates this destructive phase.

### Photos: electrical and water installations in printed walls





Source: Peri Group, Germany's first 3D-printed residential building

Consequently, we can make further considerations on the role of 3D printers in reducing CO2 emissions thanks to their different execution method:

**1. No additional waste to dispose of for the systems:**

Removing and disposing demolished materials to install the systems will not be necessary.

**2. Lower consumption of repair materials:**

There will be no need for additional materials to repair the demolitions, thus reducing both resource consumption and the emissions related to their production.

**3. Energy savings:**

Reducing demolition and repair operations also entails a lower energy demand for powering heavy tools such as pneumatic hammers and cutters.

**4. Reduction in material transportation:**

Since the walls are built completely and integrated, there will be no need to transport additional materials for repairs, further reducing transportation-related emissions.

**5. Reduction in site traffic:**

Fewer subsequent interventions also reduce the number of workers who need to return to the site, resulting in decreased vehicle traffic and emissions associated with worker transport.

**Analysis of construction technology with 3D printer:**

Introducing 3D printing into the construction sector brings changes in the construction phases and significant shifts in the methodologies used. These changes lead to numerous environmental and efficiency benefits.

- The way thermal insulation of the walls is executed
- The way walls can be finished
- The way walls can be painted

This technology can revolutionize not only the construction phases but also the methodologies themselves, bringing significant environmental benefits. Three main differences are observed in the execution of thermal insulation for walls, surface finishing, and the painting process. These innovations make the process more efficient and contribute substantially to reducing CO2 emissions and the overall environmental impact.

## Thermal Insulation

Traditionally, thermal insulation for buildings requires specialized teams and additional equipment, such as scaffolding and machinery, to install insulating panels. This increases the transportation of qualified personnel and equipment to the construction site and leads to more vehicles and associated emissions.

With 3D printing, however, thermal insulation can be integrated directly into the construction process. The printer creates walls with cavities that can accommodate insulation, eliminating the need for specialized teams and reducing the execution time. The workers can handle the work already on-site, thereby reducing the number of necessary transports and the use of heavy equipment, such as scaffolding or cranes. This minimizes fuel consumption from transport vehicles and lowers the overall environmental impact associated with site logistics.

## Wall Finishing

In traditional construction, wall finishing requires plaster and similar materials to make the surfaces smooth and ready for painting. This process generates material waste and requires further resources for the purchase of plaster and qualified labor for its application, which results in additional transportation needs and an increase in emissions.

With 3D printing, walls can be created with already-finished surfaces, completely eliminating the need for manual plastering or smoothing. This greatly reduces the use of additional materials and minimizes the waste produced. Furthermore, since finishing is an integral part of the printing process, there is no need for additional teams to carry out the finishing work.

From an environmental perspective, this reduction in steps and required resources translates into decreased emissions related to the production and transportation of additional materials. By reducing the number of workers needed, the emissions associated with their daily commuting also decrease, contributing to an overall lower environmental impact.

## Wall Painting

Wall painting is an important phase of traditional construction. It involves the use of chemical paints, often containing volatile organic compounds (VOCs). These substances are harmful to the environment, contribute to indoor air pollution, and may require multiple coats to achieve an even finish.

With 3D printing, however, it is possible to integrate colour directly into the construction materials used. During the printing process, coloured pigments can be added to the material mix, resulting in walls that do not need to be painted. This eliminates the need for chemical paints and related tools such as brushes and rollers, reducing emissions associated with the production, transportation, and application of paints.

The absence of paint also reduces the number of workers and the time needed on the construction site, further lowering the associated environmental impact. Fewer workers mean fewer vehicles and less energy consumption on-site, contributing to a more sustainable overall construction process.

3D printers not only innovate the way buildings are constructed but also offer concrete solutions to reduce the environmental impact of the building process. Integrating thermal insulation, creating finished walls without plaster, and eliminating the need for painting helps reduce CO2 emissions at every phase of construction.

## Materials for 3D Printers for Houses: Flexibility and Sustainability

3D printers for construction not only change the way of building but also give the possibility to change the material used to make the construction, resulting in the ability to reduce CO2 emissions. Its flexibility allows it to use various materials, adapting to different design needs. This not only allows for more efficient construction of houses but also reduces the overall environmental impact through the use of innovative and sustainable materials.

The use of innovative and sustainable materials in the 3D printer industry has developed solutions using alternative materials to traditional concrete, making environmentally friendly construction possible. These innovative materials include geopolymers, a class of cementitious materials that emit much less CO2 than

conventional concrete. Geopolymers are typically obtained by reacting an aluminosilicate powder with an alkaline silicate solution. They represent a step towards reducing emissions from cement production and are potentially usable materials in many sectors.

An interesting example of using completely organic materials comes from the Italian company WASP (World's Advanced Saving Project), which has developed a 3D printer capable of building houses using a mix of clay and natural, completely biodegradable materials. The TECLA project, realized by WASP, has built a house composed of local clay and agricultural waste, offering a sustainable and low-cost housing solution without compromising solidity and thermal efficiency.

**Photo: TECLA project, eco-sustainable habitat printed by WASP Italia and designed and Mario Cucinella Architects**

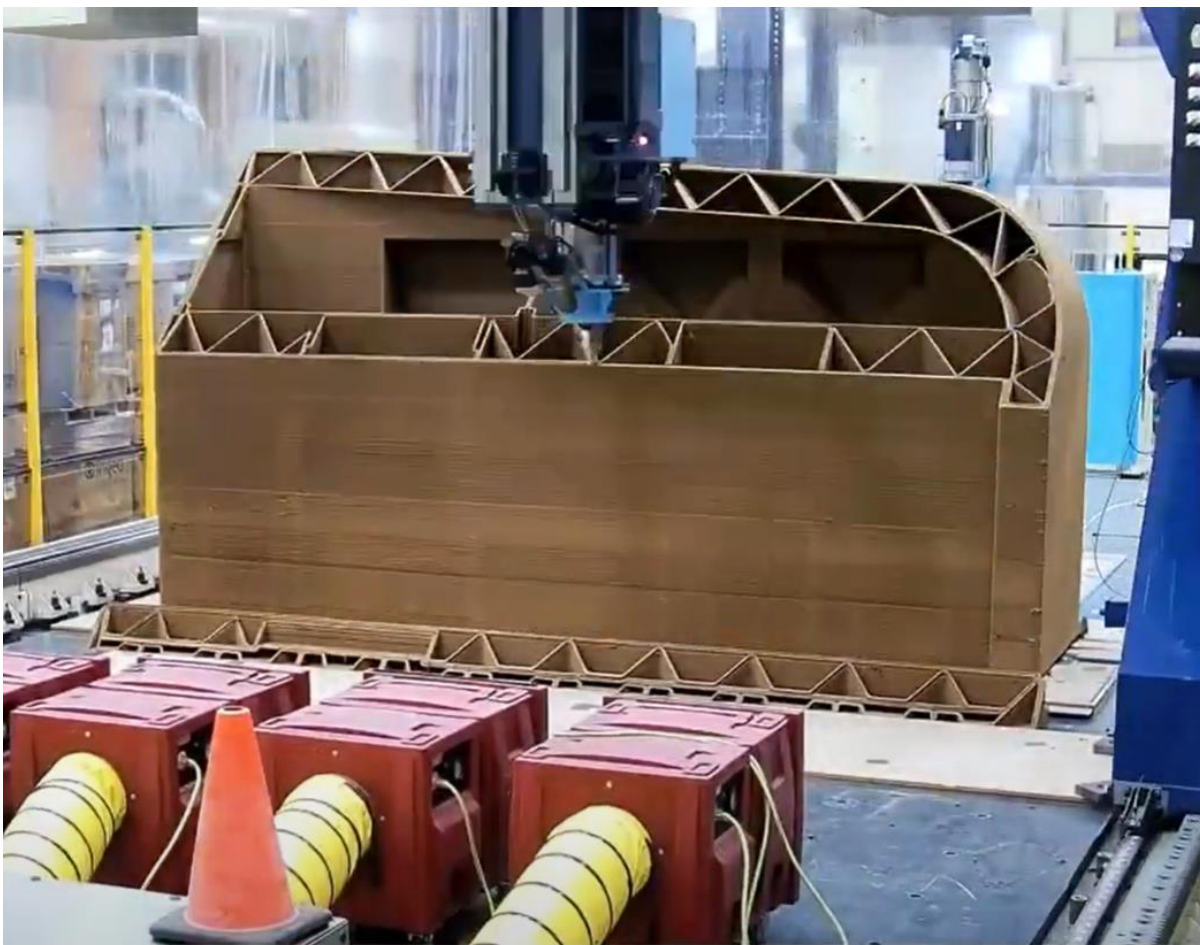


Source: MC A (Mario Cucinella Architects)

The University of Maine's project is also a significant step forward regarding sustainability. BioHome3D is the world's first 3D-printed house made entirely from bio-based materials, including wood fibers and bio-resins. Walls, floors, and roofs were printed using this wood-based mixture. Wood is not only renewable but also absorbs CO<sub>2</sub> from the atmosphere during its life cycle. This project opens up new possibilities for sustainable buildings.



Photo: BioHome3D

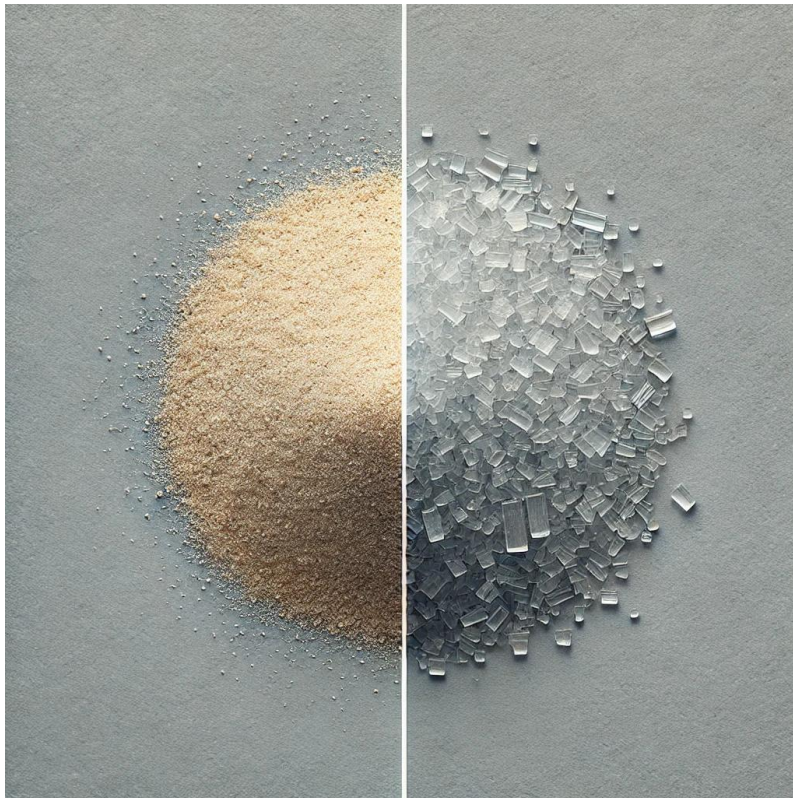


Source: The university of Maine

Another alternative approach for using materials in 3D printers is to employ well-known materials, such as cement, but substitute their traditional components with more sustainable materials. A study conducted by Brunel University of London explored the use of recycled glass as a substitute for sand in the cement mix for 3D printing. Replacing sand with recycled glass in cement mixtures is possible due to the similar properties between these materials. Sand and glass are composed primarily of silica. This allows the glass to perform similarly to sand in the cement matrix without compromising the cement's structural integrity, strength, and durability.

Additionally, recycled glass can be ground into fine particles that mimic sand's texture and size distribution. This allows it to blend effectively with cement and water, forming a strong, cohesive mixture. The glass particles provide a similar bonding effect to sand in the cement mix, contributing to the overall strength and durability of the material and increasing the insulation properties of the concrete.

**Photo: Sand and Glass**



Source: APA

This innovation reduces cement's environmental impact by utilizing a widely available waste material like glass. Using recycled glass not only helps reduce the consumption of sand, a natural resource that is becoming increasingly scarce but also decreases cement's overall environmental footprint.

### **Cement and Sustainability: A Matter of Quantity**

Although cement cannot be considered an eco-friendly material due to the high CO<sub>2</sub> emissions produced during manufacture, 3D printing can make its use more sustainable. Thanks to the precision of 3D printers, we can reduce waste, as only the strictly necessary amount of material is employed. Additionally, the walls built are not made of solid cement but feature cavities, as previously discussed, which allows for a reduction of material usage by about 20%.

Combined, these two factors make clear how 3D printing reduces the overall environmental impact of buildings, making it a viable solution for cutting CO2 emissions in the construction sector, even with less eco-friendly materials like cement.

This technology offers a range of solutions that, thanks to its flexibility in material use, allow for significant CO2 emission reductions becoming one of the most promising technologies for addressing the challenges of reducing CO2 emissions in the construction sector. It provides a sustainable alternative to traditional methods, enabling us to look toward the future of construction with a more sustainable approach, reducing environmental impact.

## Conclusion

This research has demonstrated how 3D printing technology in the construction industry can significantly reduce CO2 emissions, addressing both traditional construction methods' direct and indirect environmental impacts. One of the primary ways 3D printing achieves this is by optimizing material usage. The precision of 3D printers minimizes waste, ensuring that only the required amount of material is used. This alone results in a lower demand for raw materials, which are traditionally responsible for substantial CO2 emissions during their production and transportation.

Additionally, 3D printing's ability to incorporate sustainable materials further strengthens its potential to lower emissions. As demonstrated, the flexibility to use alternative materials such as geopolymers, recycled glass, and even renewable resources like wood presents a clear path towards more sustainable building practices. Even when traditional materials such as cement are used, 3D printing offers more sustainable options. These innovations in materials not only reduce the construction process's carbon footprint but also help in the circular economy by repurposing waste products.

Moreover, 3D printing technology streamlines the construction process, reducing the need for extensive labor and reducing emissions from transportation, a significant contributor to the overall environmental impact of the construction sector.

One key challenge is that, currently, 3D printing technology is primarily applicable to small-scale residential projects, such as single-family homes and villas with a maximum height of three floors. The technology has not yet evolved to be widely usable for large-scale or multi-story buildings, such as skyscrapers or complex commercial structures, which limits its potential impact on reducing global CO2 emissions on a larger scale.

However, despite this limitation, 3D printing still offers a promising starting point for significantly reducing emissions in the construction of single-family homes. As one of the most resource-intensive sectors, even small advancements in efficiency for more minor projects can contribute meaningfully to environmental sustainability. The success of printing smaller buildings paves the way for innovation, providing valuable insights and data that will guide future developments.

It is likely a matter of time before the technology can be adapted for larger projects. One possibility is prefabricated components—3D-printed off-site and then assembled on-site—which may allow larger, more complex structures to benefit from the precision and material efficiency of 3D printing. This hybrid approach could open new opportunities for 3D printing in large-scale construction while maintaining its material reduction and sustainability advantages.

As the construction industry continues to grow to meet the demands of a rising global population, the evolution of 3D printing could play a pivotal role in achieving the sustainability goals outlined in the Paris Agreement. Whether through direct application to large-scale projects or by producing prefabricated components, 3D printing remains crucial in the ongoing transition towards a low-carbon future.

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## 9. LIFE CYCLE COST ANALYSIS OF SIDEWALKS BASED ON SELECTED PAVEMENT TYPES

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### Abstract

Sidewalks can have various surfaces that facilitate their function for pedestrian movement and extend their lifespan; however, in the design phase, the cheapest construction options are often chosen in terms of implementation costs, which can subsequently lead to higher repair costs. This paper compares several types of sidewalk surfaces from the perspective of life cycle costs..

### Keywords

Sidewalks; life cycle costs; Urban

## Life Cycle Costs of Buildings

Life cycle costs represent the total expenses incurred over the lifespan of a building. From a phase perspective, this includes acquisition costs, maintenance, or renewal costs, as well as expenses related to operation and end-of-life processes. This analysis primarily focuses on evaluating the costs incurred over the building's economic lifespan. [1]

It is essential to conduct a life cycle cost analysis already in the pre-investment phase of a project to enable the selection of the most economically efficient building solution. The lower the life cycle cost indicator, the more advantageous it is for the investor. Crucial factors include information about cost development across the various project phases, the ability to influence these costs, and the lifespan of structures and equipment. [1]

In choosing an optimal variant, we often mistakenly evaluate only acquisition costs, while operational, maintenance, and renewal costs are overlooked—even though usage-phase costs constitute a significant portion of life cycle expenses. Many of these future costs can be significantly influenced during the pre-investment phase of the project, where material and construction choices are considered. [1]

Beyond acquisition, operational, and disposal costs, a building's life cycle can also encompass externalities and social benefits or costs, which impact the building's surroundings.

## Pedestrian Pathways

Pedestrian pathways are segments of adjacent traffic spaces designated primarily for pedestrian movement. A sidewalk may be separated from the main traffic area either vertically with posts or railings or horizontally with a dividing green belt or a bike lane. These separation methods can be used independently or in combination. Pedestrian pathways should ensure a high level of operational safety, including a sense of security, as well as smooth traffic flow, sufficient freedom of movement, and barrier-free accessibility.

Sidewalks, like other types of roadways, require appropriately designed types and thicknesses of structural layers. When properly maintained, these layers remain functional throughout the intended lifespan of the sidewalk, optimizing financial expenditure on both construction and maintenance. An incorrect design of these structural layers can result in under-dimensioning, leading to frequent damage, or over-dimensioning, which causes unnecessary costs.

In general, roadway layers are divided as follows: the subgrade layer, often compacted soil; followed by the base layers, typically consisting of an upper and lower layer made from mechanically stabilized aggregate or aggregate bound with hydraulic binders and crushed stone in the lower base layers. The top part of the roadway construction consists of surface layers—the wearing and base layers. These layers vary based on the chosen surfacing material, with asphalt and cement concrete surfacing being the most common options. [2] [4] [5]

## Asphalt Pavement

Asphalt is a flexible material under standard weather conditions, allowing it to absorb a certain degree of movement and pressure without cracking. For urban pedestrian pathways, this flexibility is advantageous, especially in cases where partial parking on sidewalks is necessary. However, asphalt surfaces are sensitive to high temperatures, which can lead to softening and deformation. This can significantly damage the sidewalk surface and impair its functionality. [3]

Asphalt surfaces are relatively easy to maintain, and repairs are generally less expensive compared to other materials, such as concrete. Cracks or potholes can be quickly and efficiently repaired using asphalt patches. However, these patched areas may again create a higher risk of deformations and limit the usability of the pedestrian pathway. [3]

One advantage of asphalt is its noise-reducing capability due to its smooth surface, which is beneficial in residential areas or near sensitive areas such as hospitals or schools.



On the downside, asphalt has environmental drawbacks. The production and installation of asphalt can negatively impact the environment, releasing harmful emissions during asphalt mixing and volatile organic compounds during installation. Additionally, recycling old asphalt after reconstruction or demolition can be challenging. Another disadvantage is asphalt's high absorption of solar radiation, which contributes to the urban heat island effect. Asphalt surfaces heat up quickly in hot weather, which can raise ambient temperatures and affect pedestrian comfort.

For this study, a commonly used asphalt pavement composition was selected:

- Asphalt concrete for the wearing layer: ACO 8, thickness of 4 cm
- Asphalt concrete for the base layer: ACL 16, thickness of 6 cm
- Cement-stabilized aggregate base layer: KSC I, thickness of 10 cm
- Crushed stone base layer: ŠD 0-32, thickness of 5 cm

## Interlocking Pavers

Interlocking pavers are made from concrete or aggregate, providing high resistance to wear, mechanical damage, and weather effects—even under severe frost or high temperatures. The segmented surface of interlocking pavers allows for easier maintenance, as individual pavers can be replaced without disturbing the entire surface. However, the initial installation of this surface is more complex than asphalt. Aesthetic variety is another advantage, as interlocking pavers come in numerous styles and can be arranged to match the surrounding environment. [3]

One major drawback is the joints between the individual pavers, which can complicate maintenance, especially due to weed and moss growth, potentially reducing functionality. For sidewalk installation with interlocking pavers, it is essential to carefully follow the technical installation process. Proper compaction of the base layers is particularly crucial; otherwise, local surface depressions can occur. Interlocking pavers can also be noisier than asphalt surfaces due to these joints.

For this study, a commonly used interlocking paver composition was chosen:

- Interlocking paver surface: ZD, thickness of 4 cm
- Aggregate bedding layer: CM, thickness of 4 cm
- Cement-stabilized aggregate base layer: C8/10, thickness of 10 cm
- Crushed stone base layer: ŠD 0-32, thickness of 15 cm

## Prague Mosaic

Sidewalks made from Prague mosaic have high aesthetic value and durability, making them suitable for historic city centres in the Czech Republic. This pavement consists of concrete paving stones in various shapes and sizes, often with inserts of natural stone or ceramic to create decorative patterns. Like other concrete pavements, Prague mosaic is highly resistant to wear, damage, and extreme weather conditions, making it ideal for high-foot-traffic areas. It is a low-maintenance surface, requiring only regular cleaning and debris removal. Damaged segments can be replaced without reconstructing the entire section. With proper installation and maintenance, Prague mosaic has a long lifespan, often lasting several decades. [3]

Proper installation is essential, requiring skilled professionals, as laying paving stones is labour-intensive. Failure to follow the technical procedure can reduce the surface's functionality and longevity, necessitating more frequent maintenance.

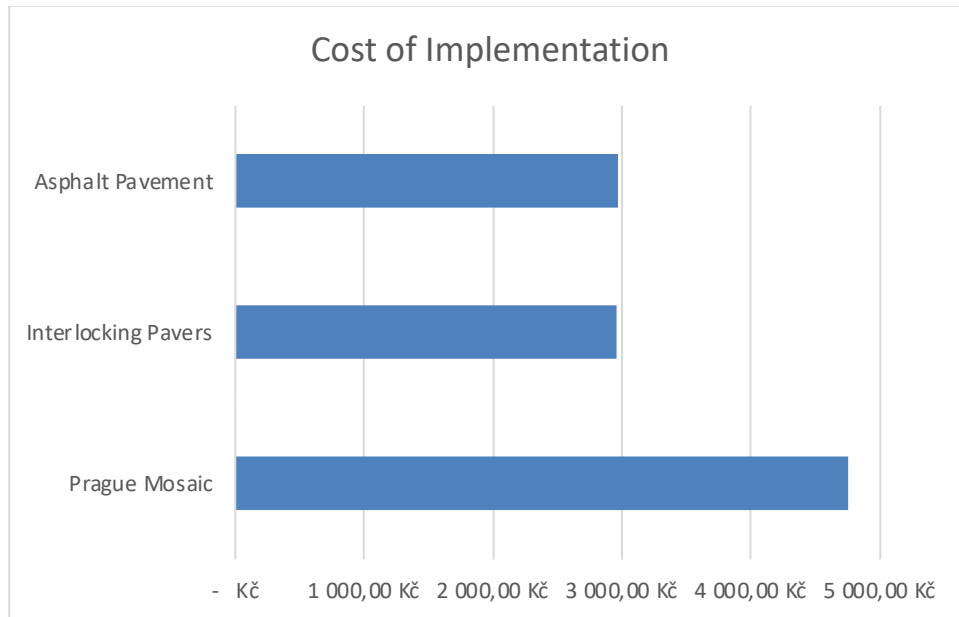
For this study, a commonly used Prague mosaic composition was selected:

- Prague mosaic surface: ZD, thickness of 4 cm
- Aggregate bedding layer: CM, thickness of 4 cm
- Cement-stabilized aggregate base layer: C8/10, thickness of 10 cm

- Crushed stone base layer: ŠD 0-32, thickness of 15 cm

## Lifecycle Costs of Sidewalks

The analysis of sidewalk lifecycle costs focuses on the cost evolution associated with selected sidewalk surface materials. For the purposes of this analysis, a model example was created for a sidewalk 50 meters long and 3 meters wide. The calculated costs focus solely on work performed on the individual layers. Labor and materials were priced according to the URS 24/II cost system.

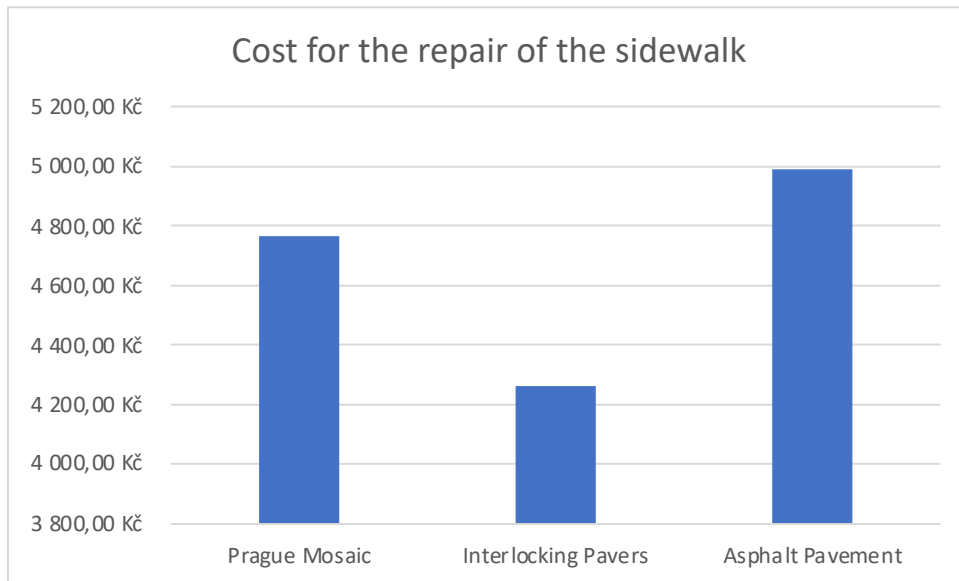


**Figure 1 The Costs for the construction of 1 m² of sidewalk**

The construction costs cover the expenses of building a fully functional sidewalk in an urban area, including earthworks, roadway installation according to the selected layers, and material transport. In comparing implementation costs, the most expensive option was found to be the sidewalk made from Prague mosaic pavers. The price increase in this case is due to the manual installation of the final surface layer, which requires small pavers and is more costly than the other two surface materials selected for sidewalks.

Repair costs include the expenses incurred when partial or full restoration of the sidewalk surface is necessary due to maintenance or replacement of technical infrastructure, often placed below sidewalks in urban areas. Repair costs may also arise when the sidewalk surface reaches the end of its service life. These costs recur throughout the operation and demolition phases of the sidewalk lifecycle.

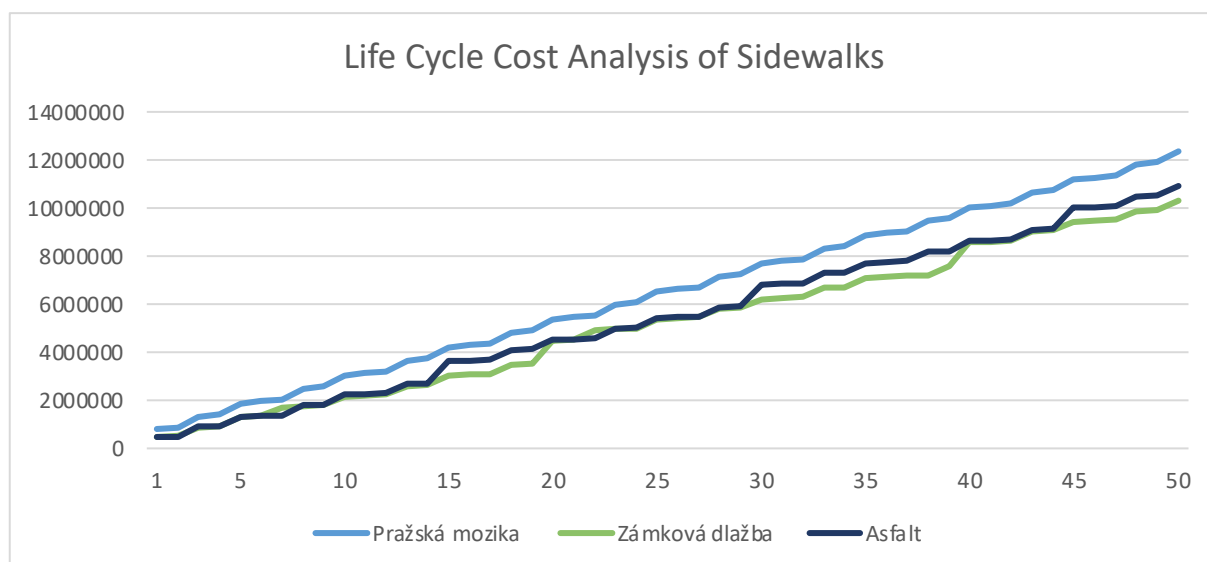




**Figure 2 The Cost for the repair of 1 m² of sidewalk**

For repairs, costs are approximately 5% higher for asphalt surfaces compared to Prague mosaic, and the least expensive option is interlocking pavers, which are around 12% cheaper than mosaic repairs. A significant advantage of surfaces made from Prague mosaic and interlocking pavers, compared to asphalt, is that the original surface material can often be reused. This analysis assumes a 100% reuse rate for the original material. Asphalt surfaces, however, cannot be recycled on-site, necessitating new material delivery and disposal of asphalt debris.

Aside from phase-specific costs, the URS 24/II cost system data also allows for comparison of sidewalk construction time in labour hours. The graph indicates that asphalt installation is the quickest, though its repair is time-intensive. Overall, interlocking pavers perform best, being only slightly slower to install than asphalt but faster in combined construction and repair time.



**Figure 3 Life Cycle Cost Analysis over Time with Minimum Surface Durability**

The figure 3 illustrates the cost evolution for the model sidewalk. In this example, the lifespan of Prague mosaic was set to 50 years. Over this period, the interlocking paver surface was fully replaced twice, based on a lifespan of

20 years, and the asphalt surface three times, with a lifespan of 15 years. Additionally, partial repairs were modeled to occur approximately every five years over one-third of the surface, due to technical infrastructure maintenance.

## Conclusion

Sidewalks primarily serve public rather than commercial interests, thus acting as a positive externality with no expectation of lifecycle cost recovery. Realization costs are often part of larger investment projects, both public and private. Maintenance and reconstruction costs typically fall to the managers or owners of technical infrastructure. Thus, lifecycle costs are shared among several parties, but their scope is determined by the project investor during the pre-project phase.

For construction costs, interlocking pavers and asphalt surfaces are almost identical. However, for reconstruction, interlocking pavers offer a cost advantage, primarily due to the reuse of surface material. The cost analysis included only one major infrastructure repair under the sidewalk; however, the extent of technical infrastructure below pedestrian pathways increases the likelihood of repairs following incidents or inspections, further favoring interlocking pavers.

It is worth noting that this analysis was conducted theoretically using a model example. To continue this work, it would be beneficial to conduct a practical analysis by comparing lifecycle costs of selected sidewalks in urban areas, using source data from contract registries and other.

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## 10. OPTIMIZING ENVIRONMENTAL IMPACT IN CONSTRUCTION: THE CONTRIBUTION OF BIM-BASED APPROACHES

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### Abstract

This paper presents the work of a PhD student in their first year, focusing on a literature review of Building Information Modeling (BIM) applications in sustainable construction. The study evaluates BIM's role across five key areas: Modular and Offsite Construction, Life Cycle Sustainability Evaluation, Building Energy Management, End-of-Life Decision Strategies, and Building Waste and Recycling. Concentrated research efforts in Europe, America, and Asia underscore a global push towards sustainable practices, although challenges such as data inconsistencies, interoperability barriers, and a lack of skilled professionals persist. Findings indicate that while BIM's integration with Industry 4.0 technologies like IoT and blockchain has the potential to enhance sustainability, advancements are needed to address existing gaps. This review provides a foundation for future research, emphasizing the importance of standardized data protocols and skills development for improved BIM utilization in sustainable construction practices.

### Keywords

building information modeling; construction; sustainability

## Introduction

The construction industry plays a pivotal role in economic growth globally but is a significant consumer of resources and a source of environmental impacts. Construction activities consume about 40% of the world's stone, gravel, and sand, 25% of all virgin wood, approximately 40% of global energy, and around 16% of water usage annually [1]. Besides material consumption, the industry generates substantial construction and demolition waste, and steel and concrete are especially intensive due to their widespread use. Cement production alone, necessary for concrete, contributes around 8% of global carbon emissions, with roughly 4.4 billion tons produced worldwide in 2019 [2].

As awareness of these environmental impacts grows, the principles of sustainable development are increasingly emphasized within the construction sector. Sustainable development encourages practices that improve economic, social, and environmental quality to benefit both current and future generations. This balance requires the industry to address not only resource efficiency but also energy conservation and pollution reduction strategies [3].

Moreover, construction is an essential component of social and economic frameworks, especially in regions like Europe, where it represents 7% of total employment and over 50% of Gross Fixed Capital Formation [4]. Nonetheless, the environmental impacts—including high energy consumption, substantial greenhouse gas emissions, waste generation, and resource depletion—underline the need for transformation within the industry. Consequently, the integration of sustainable practices, particularly through digital tools such as Building Information Modeling (BIM), is vital for minimizing these impacts, supporting the construction sector's transition toward environmentally responsible development [5]. This review identifies key opportunities, challenges, and research gaps in BIM utilization for sustainable construction, serving as a foundation for further exploration into innovative strategies for sustainable development in the built environment.

## Results

This review highlights the distribution of BIM research activity across various countries, with the United Kingdom, China, and the United States leading in publications. This concentration of research reflects a strong interest in sustainable construction practices within these nations, which often serve as benchmarks for emerging markets due to their advancements in regulatory policies, technological frameworks, and sustainability goals.

Key challenges were identified across each of the five main areas examined:

- **Data Quality and Availability:** Lifecycle Assessment (LCA) and End-of-Lifecycle Decision Making are critical for evaluating the environmental impact of materials over a project's entire lifespan. However, these processes are often restricted by data inconsistencies, frequently due to the lack of standardized data formats. This inconsistency can lead to incomplete assessments, reducing the reliability of environmental performance predictions and complicating data comparison across projects.
- **Interoperability Issues:** Effective waste management and Offsite Construction depend on seamless data exchange across different platforms. Unfortunately, software incompatibility and inconsistent data-sharing mechanisms within BIM frameworks complicate integration. This lack of interoperability disrupts the efficient transfer of information, creating delays, miscommunication, and missed opportunities for resource optimization, particularly in projects involving multiple stakeholders using various software systems.
- **Industry Reluctance and Skill Gaps:** While BIM adoption has been proven to aid sustainable practices, a significant portion of the industry remains hesitant to adopt these technologies. The shortage of skilled users familiar with BIM-enabled tools for Construction and Demolition Waste (CDW) management and Environmental Performance Monitoring (EPM) contributes to this reluctance. Many professionals are either untrained in BIM software or unfamiliar with the advanced analytical tools needed for assessing environmental impacts, resulting in suboptimal outcomes and underutilization of BIM potential.

These challenges on Figure 1 highlight the necessity for further research and targeted improvements to enhance BIM adaptability and relevance in addressing sustainability goals.

Figure 1 Challenges identified based on their frequency in the studies (author's source)

In recent years, BIM has evolved beyond its original purpose as a 3D modeling tool, establishing itself as a vital resource for driving sustainability within the construction sector. Initially developed to improve project visualization and design coordination, BIM's applications now support a range of integrated project delivery methods that enable better planning, efficient resource allocation, and optimized material use. Additionally, BIM's increasing compatibility with Industry 4.0 technologies such as IoT, machine learning, and blockchain facilitates comprehensive data-sharing across the supply chain. This integration enhances material tracking, enables energy optimization, and supports lifecycle assessments, providing a data-rich foundation for sustainable construction practices. In this review, BIM's applications were examined across five critical areas in sustainable construction, revealing unique opportunities and specific challenges associated with each area.

#### Modular and Offsite Construction

Offsite construction (OSC) involves prefabricating components such as panels, walls, or entire rooms in controlled environments, which BIM facilitates by enhancing design accuracy and material planning. This approach, often utilized in modular and prefabricated construction, is supported by BIM's precise quantity estimations and design simulations, improving resource efficiency and reducing onsite waste. The primary challenges in OSC involve ensuring logistical accuracy during transportation and maintaining interoperability between software used by various stakeholders.

#### Life Cycle Sustainability Evaluation

In sustainable construction, Lifecycle Assessment (LCA) assesses environmental impacts across a building's entire lifespan, from material extraction to eventual demolition. BIM has improved LCA's accuracy by providing precise quantity data, allowing integration with environmental databases to better estimate lifecycle impacts. Standards like ISO guide LCA processes, yet challenges persist, particularly in the availability of quality data during early project stages. Overcoming these limitations could enhance LCA integration, improving lifecycle sustainability in construction projects.

#### Building Energy Management

Energy Performance Management (EPM) within BIM utilizes IoT sensors to enable real-time energy tracking and efficiency analyses. By continuously monitoring energy usage and identifying inefficiencies, EPM provides a data-driven approach for reducing energy consumption throughout a building's operational life. Emerging AI tools, including machine learning, enhance predictive energy modeling based on historical and real-time data. Despite this potential, barriers remain in data integration and managing varied data formats across platforms, complicating ability of BIM to fully optimize energy performance of buildings.

#### End-of-Life Decision Strategies

BIM facilitates sustainable end-of-lifecycle strategies by documenting materials in a detailed material passport that promotes reuse in line with circular economy principles. This data-rich approach enables deconstruction planning that systematically safe reusable components, assisting with resource conservation. Despite the benefits, barriers as limited data availability, low demand for recycled materials, and a lack of guidelines for deconstruction processes persist. Enhanced material recovery planning within BIM could significantly improve end-of-life sustainability and resource retention.

#### Building Waste and Recycling

With its real-time material tracking and data management capabilities, BIM plays an instrumental role in managing construction and demolition waste (CDW). It can also help to minimize material wastage and improve recycling rates. By automating waste calculation and supporting prefabrication processes, BIM assists in reducing CDW. However, difficulties in data integration and regional inconsistencies in CDW standards limit broader adoption.

Studies also reveal a general reluctance toward adopting BIM in CDW management due to interoperability concerns and lack of user familiarity with waste management software.

## Conclusion and discussion

This paper discuss a findings from systematic literature review conducted on the topic of the extensive opportunities BIM provides for enhancing sustainable construction practices. By leveraging its capabilities in real-time tracking, precise material assessments, and lifecycle planning, BIM addresses critical environmental concerns across the construction process. Each area reviewed illustrates the potential of BIM to mitigate resource consumption, enhance material recovery, and improve energy performance.

Despite these benefits, BIM implementation in sustainable construction encounters substantial challenges, particularly in data quality, standardization, and industry acceptance. A significant barrier involves the lack of standardized BIM processes across projects and regions, complicating the uniform application of BIM tools. The interoperability of BIM with various software platforms is also a primary concern, especially for managing energy performance data and waste management processes. Addressing these barriers will be crucial in advancing BIM's integration into sustainable construction.

Based on these findings, author's future research will focus on BIM's integration with IoT and sensor technologies for comprehensive energy and facility management utilization. Given the industry's trajectory toward sustainable development, the research will support data-driven resource optimization and predictive management, enhancing BIM's role in sustainable construction. With continued advancements, BIM could play an instrumental role in shaping a more sustainable and efficient construction industry, contributing to a reduced environmental impact..

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## 11. ESG AND ITS ENVIRONMENTAL PILLAR

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### Abstract

The aim of this paper is to provide a comprehensive overview of the ESG (Environmental, Social, and Governance) framework, with a focus on its environmental pillar. Readers will be introduced to all three sustainability pillars, which have been the subject of non-financial reporting since 2025. Attention is given to carbon footprint analysis and its assignment to specific sources, differentiated by the so-called scopes 1-3. Furthermore, the context of ESG - energy (pathways to decarbonization), economic, and legislative aspects - will be addressed. With the cooperation of the gas company GasNet, the method for calculating the carbon footprint is outlined, and a list of measures by which companies can reduce their ecological footprint related to building and vehicle usage is compiled, which can play a significant role in the overall sustainability assessment of a company expressed through its ESG rating.

### Keywords

decarbonization; ESG; scope; carbon footprint

## Introduction

Over the past few years, the concept of ESG has steadily climbed the priority list for many companies. While this is partly due to legislation, which requires large corporations to report their performance according to specific guidelines, the more likely reason for increased interest in ESG is the business's reputation represented by the ESG score. This score characterizes the company's level of sustainable behavior and opens the door to numerous advantages-from financial incentives to privileges in public tenders, as well as enhancing the company's image in the eyes of employees, suppliers, and customers.

The three letters in the ESG acronym represent the three pillars of sustainability: E (Environmental), S (Social), and G (Governance). In this doctoral research, the primary focus has been on the environmental pillar of sustainability (E). However, the success of a company cannot rely solely on a sound environmental strategy; the S and G pillars are equally important. Therefore, future research will focus on these additional aspects of sustainability.

The following sections will provide a brief overview of the environmental aspects of ESG...

## Environmental Pillar of ESG - Emissions

Heatwaves, droughts, hurricanes, floods, glacier melting, and the subsequent rise in sea levels, along with the extinction of various species of flora and fauna and the collapse of ecosystems, are all examples that have led to increased concern about “natural” sustainability. This concern is due to the continuous rise in greenhouse gas emissions, which, because of the greenhouse effect, result in higher global temperatures-both in the air and oceans-leading to increased risks of these adverse events.

The growing concentration of greenhouse gases is caused by various sectors (Czech Republic 2021 data):

- Energy (33% - power plants and heating plants)
- Industry (28% - extraction, processing, and combustion of fossil fuels, industrial processes, etc.)
- Transport (16% - road, air, and rail transport)
- Buildings (10% - heating, gas cooking, water heating; all buildings except industrial)
- Agriculture (8% - livestock farming, land cultivation, combustion of fuels) • Waste Management (5% - methane emissions from landfills) [1]

## Carbon Footprint Calculation

One of the most well-known greenhouse gases, from which the term “carbon footprint” is derived, is carbon dioxide (CO<sub>2</sub>). However, despite its name, the term does not refer solely to CO<sub>2</sub> emissions; it also includes other greenhouse gases.

Specifically, the greenhouse gases considered in carbon footprint calculations (collectively referred to as GHG) include CO<sub>2</sub>, methane (CH<sub>4</sub>), and nitrous oxide (N<sub>2</sub>O). Additionally, fluorinated hydrocarbons (HFCs), perfluorocarbons (PFCs), sulfur hexafluoride (SF<sub>6</sub>), and nitrogen trifluoride (NF<sub>3</sub>) are also greenhouse gases, though they are often excluded from calculations.

Greenhouse gas emissions are commonly expressed in metric tons of carbon dioxide equivalent (tCO<sub>2</sub>e), which is determined by converting different gases based on their Global Warming Potential (GWP). The GWP compares the warming effect of a given gas to that of CO<sub>2</sub>, which has a GWP of 1.

Depending on whether emissions come from electricity consumption, natural gas use, or vehicle fuels, additional factors such as the emission factor, which indicates the mass of emissions per energy unit, are used in the calculations.



## Emission Scopes

To clarify the exact sources of emissions from company activities and to assess their environmental impact, emissions are categorized into three groups, known as scopes (Scope 1 - direct emissions, Scope 2 and Scope 3 - indirect emissions).

In a podcast with Ekonews, Daniel Heuer explained this concept clearly: „Scope 1 includes emissions from what the company directly consumes on-site. For example, they buy gasoline or coal, which they burn to power their vehicles or heat their buildings. These emissions are released from their chimneys or exhausts and are thus considered direct emissions.“ [2]

In the practical part of this research, emission calculations were carried out based on data from the gas company GasNet. Some examples of GasNet's Scope 1 emission sources include natural gas consumption in buildings and fuel consumption in company vehicles. Moreover, GasNet experiences specific challenges with fugitive emissions (from old pipelines) and technological losses (from repairs and maintenance of gas infrastructure), which account for over 90% of their emissions.

Scope 2 refers solely to electricity consumption in buildings and operations, as well as the consumption of heat and cooling.

Finally, Scope 3 includes the remaining emissions that are not covered by Scopes 1 and 2. These emissions result from activities closely related to the company but not directly owned or controlled by it (e.g., employee commuting). This scope often involves a wide range of emission sources, such as emissions generated throughout the supply chain, including waste management, and the production, sale, and transport of materials and products. Obtaining data for Scope 3 emissions is typically challenging, as suppliers may not track or provide the necessary information. Therefore, it is crucial to inform suppliers of ESG expectations early on and ensure they are aware of the reporting requirements.

## Decarbonization

The measures a company can take to reduce its carbon footprint from building and vehicle usage are summarized in the following section.

One of the approaches for reducing a company's carbon footprint is through offsets. This solution is often appealing due to its simplicity and lower cost compared to investments in energy-saving technologies, though the results of offsets are temporary, whereas technological investments offer long-term and lasting benefits. [2]

When fossil fuels are burned, emissions are released into the atmosphere, but natural or technological processes can capture these emissions back. Offsets are tradable units that partially reduce a company's carbon footprint and are categorized based on whether they actively remove carbon from the atmosphere or prevent its release. The most well-known natural process for this is tree growth. Through photosynthesis, trees absorb carbon, store it in wood, and partially in the soil. By purchasing carbon offsets, a company essentially finances tree planting and, as a result, can deduct a portion of its carbon footprint based on the amount of carbon the trees will absorb as they grow. [2],

[3]

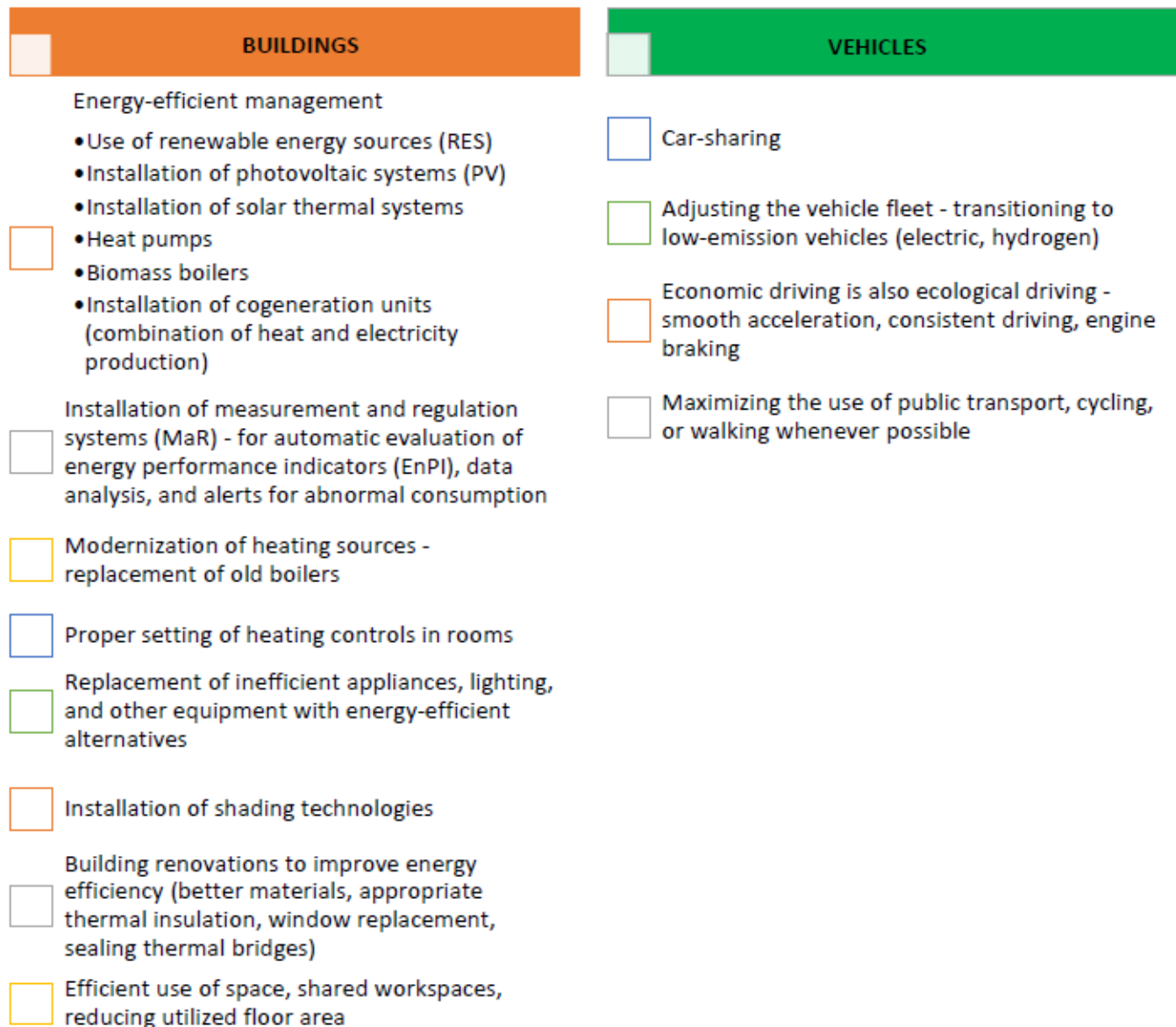
As mentioned in the podcast Between Two Worlds with Ladislav Tyll, tree planting is somewhat controversial. While it looks good and creates a positive image, according to Bill Gates' book, even if the entire United States were planted with trees, the impact would still be limited (it takes decades for trees to grow, and they do not absorb enough carbon in the short term). [4]

There are other ways to "offset" emissions as well, such as protecting ecosystems that naturally absorb carbon, funding gas stoves (in developing countries, gas usage is more efficient than wood burning), or investing in renewable energy sources like nuclear power or solar energy. [2], [3]

However, the environmental aspect of ESG should not be limited solely to carbon footprint mitigation. The "E" section of ESG also includes data on waste management, biodiversity, water usage, and circular economy practices.

Reusing greywater and rainwater (for toilet flushing, laundry, or watering plants) helps conserve both natural resources and company funds. In general, it is essential to prevent waste (whether energy, water, food, or materials) and to carefully separate waste for potential recycling.

Typically, the rule is: "When you save money, you also reduce your carbon footprint." For instance, a manufacturing process innovation may require an initial investment, but it ultimately leads to cost savings and lower emissions, benefiting both the company's bottom line and the planet. [5]



**Figure 1: Measures for Buildings and Vehicles**

Sources: Own processing based on source no. [6]

## Decarbonization in Construction

The construction sector consumes up to 50% of the world's total energy. After emissions from coal-fired power plants and vehicles, the third-largest source of CO<sub>2</sub> emissions is concrete, which also accounts for the largest share of demolition waste, occupying up to one-third of landfill waste. [7]

“Cement production accounts for 7-8% of global CO<sub>2</sub> emissions. Cement is a key component of concrete, which is the second most consumed substance in the world after water. Each person on Earth consumes about half a ton of cement annually. Roughly half of all cement is used in building construction, while the rest is needed for various infrastructure projects, such as roads, railways, or energy facilities like power plants.” [8]

For every ton of cement produced, approximately 0.6 tons of CO<sub>2</sub> are emitted. As a result, CCS technology (Carbon Capture and Storage) is increasingly being used to capture and store carbon (either underground, mixed into concrete, or incorporated during the curing process). By 2050, emissions reductions from CCS technology are expected to be up to 50% greater compared to current cement production emissions. [8]

Another highly emission-intensive material is steel, with approximately two tons of CO<sub>2</sub> emitted for each ton of steel produced. Steel is manufactured using two methods - 75% of production occurs in blast furnaces where coal and coke are burned, while the remaining 25% is produced through electric arc furnaces or direct reduction from iron. [9]

“Three technologies play a dominant role in steel decarbonization: the use of green or low-emission hydrogen, CCS, and recycling. Each of these technologies could contribute 20-30% to emission reductions. Decarbonized steel will be more expensive, with the cost of green steel expected to rise by 25-50%. However, this price increase will have only a minor impact on the final prices of products. A car or house using low-emission steel will cost about 1% more than one made with steel produced using conventional technologies, as steel typically accounts for only a small fraction of the total product cost.”

[9]

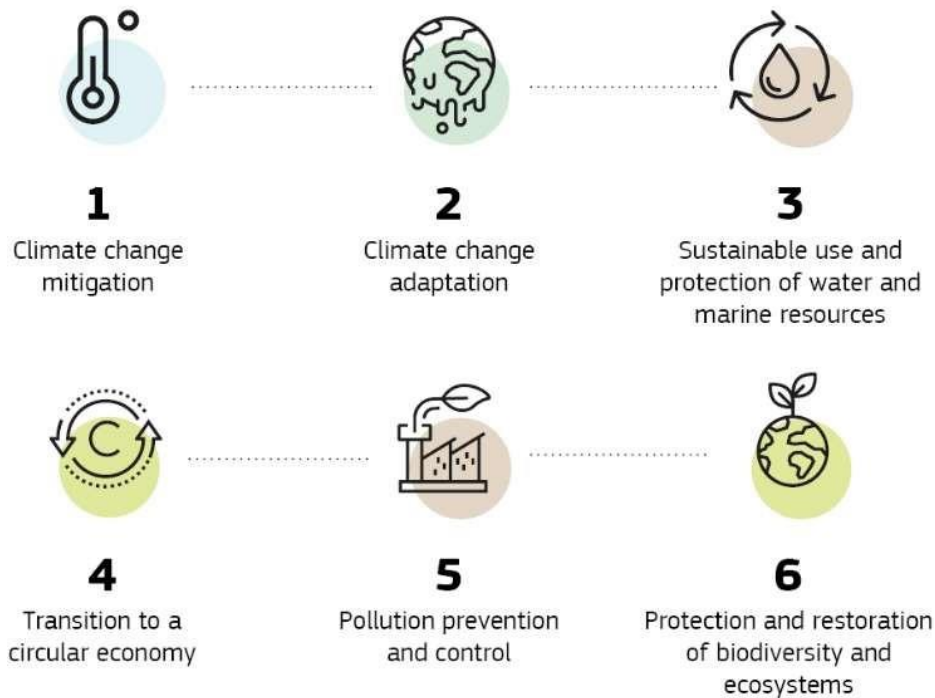
#### Economic Context of ESG

Achieving climate neutrality by 2050, a commitment made by the EU under the Green Deal, and limiting global warming to below 2°C or ideally 1.5°C, as stipulated by the Paris Agreement, requires substantial changes. It is not enough to simply reduce greenhouse gas emissions; we must actively remove them from the atmosphere.

The steps toward climate neutrality demand significant investments, many of which can be supported by funds such as the European Regional Development Fund, the Cohesion Fund, or the Green Climate Fund (for the implementation of measures in developing countries).

“In recent months, the European Union has adopted (and continues to adopt) several regulations that impose obligations on companies to monitor and assess the impact of their activities on the environment and society, and to inform the public about the results. These rules aim to make ESG measurable and allow companies to be compared with one another.” [10]

The EU taxonomy, a classification system for sustainable activities, determines what is and is not sustainable. It defines six environmental objectives. A company must meet the following conditions: it must significantly contribute to at least one of the objectives while not harming the others, and it must comply with various other business requirements (e.g., non-discrimination, anti-corruption, fair employee compensation). [11]



**Figure 2: 6 Goals of the EU Taxonomy Sources: [12]**

The EU taxonomy helps companies identify sustainable activities, which form the basis for making sustainable investment decisions. By increasing investments in sustainable programs, the European Union can more easily move toward achieving the Green Deal goal of climate neutrality. [12]

## Legislation and Reporting

“ESG is a tool for non-financial reporting, but it is closely linked to a company’s financial indicators. Reports are most meaningful when their indicators allow for comparisons, which can be achieved through standardization, ensuring consistency in the form of reported metrics.” [6]

In addition to the EU Taxonomy, companies must be aware of several other directives, regulations, and standards related to sustainability reporting, including CSRD, ESRS, and SFDR, as well as protocols for calculating carbon footprints such as the GHG Protocol, ISO 14000, and GRI. These are outlined below:

- CSRD - Corporate Sustainability Reporting Directive
  - A framework for disclosing sustainability information
  - Expands on the existing Non-Financial Reporting Directive (NFRD)
  - Aims to protect investors, prevent greenwashing, and ensure reliable and comparable reporting
- ESRS - European Sustainability Reporting Standards
  - Integrates all requirements for ESG reporting for non-financial organizations
  - Includes 82 requirements, with several qualitative and quantitative data demands
- SFDR - Sustainable Finance Disclosure Regulation
  - Applies specifically to the financial sector
- GHG Protocol - Greenhouse Gas Protocol
  - A partnership between businesses, NGOs, governments, etc.
  - A globally recognized approach for calculating carbon footprints
  - Purpose: to develop international standards and tools for GHG accounting and reporting
  - Goal: to achieve a global low-emissions economy

- ISO 14 064 - Environmental Management Systems Standard (ISO 14000)
  - Focuses specifically on greenhouse gas emissions
  - Companies that implement an EMS commit to preventing pollution, promoting sustainable development, and continually improving their environmental performance
- GRI - Global Reporting Initiative
  - The most widely used method for non-financial reporting
  - Provides a framework for what and how to disclose, ensuring comparability and credibility of reports

[11], [13]

It is essential to be prepared for legislative obligations that may affect your company, or for requests from the supply and demand chain. Companies aiming for success must integrate ESG principles into their operations. ESG is an effective management tool that helps assess risks and opportunities. Most companies already utilize ESG principles in some form, even if they call them by different names. Therefore, it can be said that every company is already employing strategies that fit within the ESG framework, even before mandatory reporting. [5]

“As part of the approved CSRD regulation, EFRAG (European Financial Reporting Advisory Group) has published the first set of European standards for sustainability reporting (ESRS). These standards are significantly more stringent in scope and disclosure depth compared to the current NFRD.” [14]

The first wave of mandatory sustainability reports (based on 2024 data and published in 2025) will affect organizations that were already required to report non-financial information under the NFRD. This includes listed companies and all large enterprises with over 500 employees. In the following year, the reporting requirement will extend to companies meeting one of the following criteria:

- At least 250 employees
- Balance sheet total over EUR 20 million
- Annual revenue of EUR 40 million or more [14]

In the subsequent years, small and medium-sized enterprises listed on stock exchanges and companies beyond the EU will also be subject to reporting requirements.

A sustainability report typically includes the company's profile, followed by issues categorized according to the ESG pillars. It covers governance structures (including board members), market position, ESG-related commitments, financial impacts of sustainability, key performance indicators (KPIs), and future trends (objectives, strategies, progress, risks, and potential impacts on the company and the environment).

Based on articles from the Examples from Practice section on the ESG in Practice web portal, founded by Veronika Doubnerová to raise awareness about sustainability and offer a comprehensive overview of important ESG information, the following list of topics was compiled, which companies frequently encounter in practice.

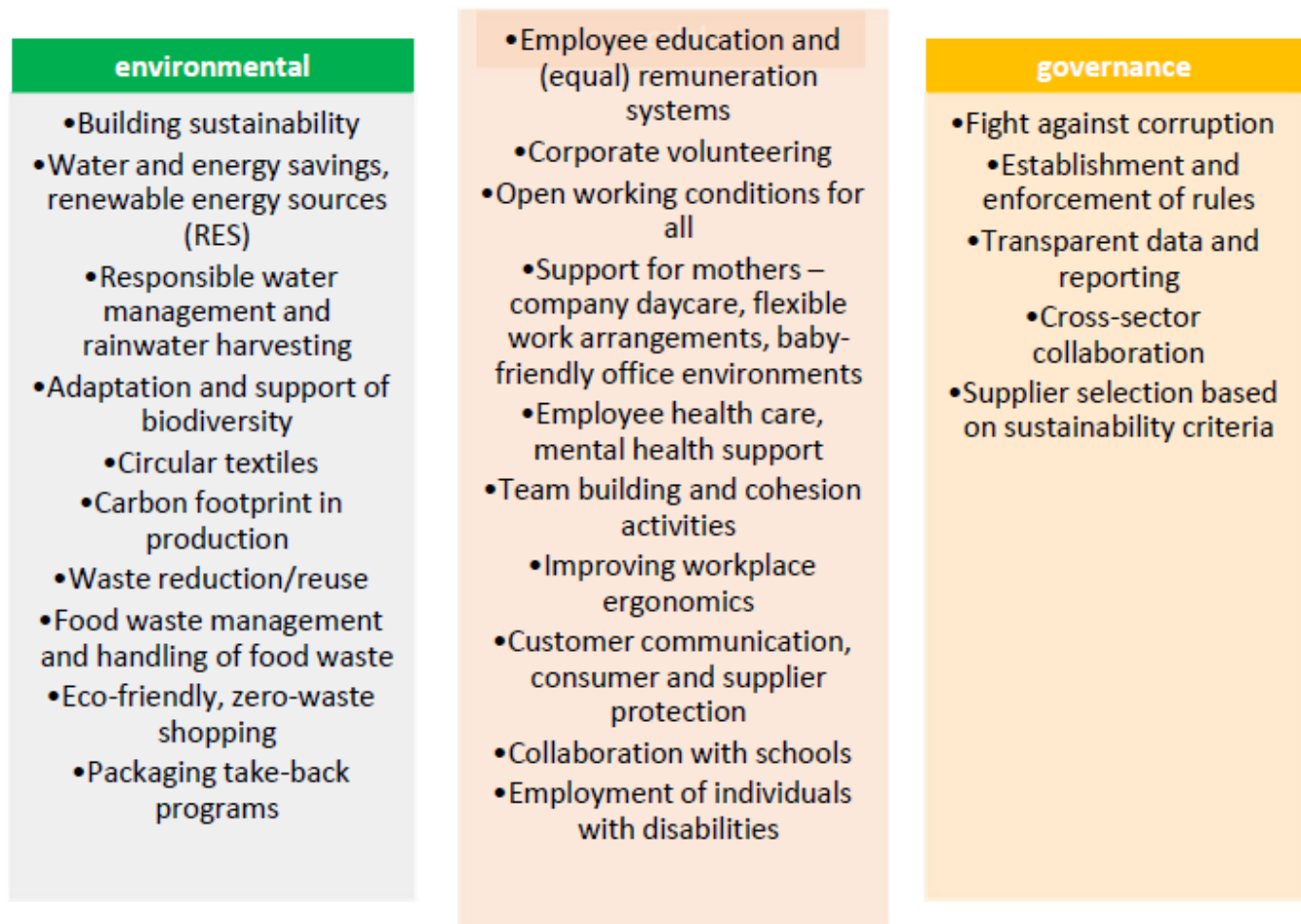


Figure 3: Areas Covered by the 3 Pillars of ESG

Sources: Own processing based on source no. [15]

## Conclusion

This chapter briefly summarizes the key insights regarding sustainability. ESG approaches sustainability from three perspectives - responsibility towards the environment, society, and adherence to governance and compliance rules. The reasons for integrating ESG into a company are numerous, including environmental, economic, energy-related, and legislative factors, which compel companies to report their non-financial data.

The aim of this research was to present the topic of ESG in a concise, clear, and comprehensive manner, assisting organizations that have struggled to navigate this often complex issue. ESG is a wellstrategized concept, targeting humanity's return to a more considerate and sustainable approach to natural resources, the environment, and mutual respect.

Since the Industrial Revolution (18th–19th century), human activity has significantly disrupted the planet's balance. Fossil fuel combustion, a major energy source, has resulted in high concentrations of greenhouse gases, leading to global warming, rising air and ocean temperatures, and changing water pH levels from alkaline to acidic. This has contributed to unpredictable extreme weather conditions, rising sea levels due to melting glaciers, and the extinction of species.

The sectors with the largest shares of greenhouse gas emissions in the EU (according to the most recent 2021 data from the Climate Facts portal) are threefold: energy, industry, and transport. Buildings and agriculture account for almost 13% of total emissions, with waste management following behind.

By transforming the energy mix - namely, by utilizing renewable energy sources whose potential remains largely untapped - climate neutrality can be achieved. Additional steps include decarbonization measures, which have been illustrated in previous diagrams, as well as proactive actions such as afforestation or implementing technologies that remove CO<sub>2</sub> from the atmosphere. It is important to adhere to energy-saving measures, minimize waste (whether energy, water, or materials), and carefully separate waste for recycling. Public transportation, cycling, or walking should be used whenever possible.

The common goal of achieving net-zero emissions and preventing global warming is enshrined in the Green Deal and the Paris Agreement. Company sustainability reporting is guided by precise legislative requirements at both the national and international levels. Although it may seem that these reports only apply to large companies, this is not the case. Apart from legislative requirements, smaller businesses will also face pressure from banks (when applying for loans), larger companies (which need to account for Scope 3 emissions from their supply chains), and customers who care about product origins and responsible business practices.

ESG does not focus solely on environmental issues but is built on three pillars: environmental, social, and governance responsibility. In addition to the environmental impact of business activities, ESG also addresses equal opportunities within the company, working conditions, occupational safety, consumer and supplier protection, board independence, business ethics, and rule compliance. As mentioned earlier, the social and governance pillars will be the subject of further investigation.

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## 12. DIGITALIZATION OF CONSTRUCTION MANAGEMENT

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### **Abstract**

Digitization of the monitoring of construction economics enables effective cost management thanks to the use of modern technologies and digital tools, but in contrast to the benefits, it also brings new challenges and obstacles to companies during implementation.

### **Keywords**

construction company, economy, digitization, process



## Introduction

Digitalization represents a revolutionary change in many industries, and construction is no exception. Monitoring the economy of construction projects, which includes cost management, scheduling, and resource allocation, is becoming more efficient through the use of modern technologies. Digitalization of economic monitoring in construction is a key element of modernizing the sector, enabling effective cost management, performance tracking, and resource optimization. This process involves utilizing modern technologies and digital tools that bring numerous advantages and improvements by integrating management processes. This study focuses on the trends, benefits, and challenges associated with digitalization in economic monitoring in construction, based on current research and studies.

## Methodology

The aim of this paper is to research the trend of digitalization in managing the economy of construction projects, the benefits of implementing digitalization, and defining the challenges that digitalization brings. Based on online research, the benefits and challenges of digitalization when implemented in construction companies were identified

## Trends in Construction Digitalization

Digitalization in construction encompasses various technologies, such as BIM (Building Information Modeling), IoT (Internet of Things), and cloud computing. These technologies enable real-time performance monitoring of projects and improve decision-making processes.

In recent years, the influence of IoT on construction has deepened significantly, where the collection of real data and its storage in repositories has proven to be an effective tool for reducing errors and delays. [1]

## IoT

IoT refers to devices equipped with sensors, GPS, and new technologies that ensure real-time data connectivity and exchange between various devices via the internet. One example is monitoring the curing of concrete using sensors placed in the concrete during pouring, which then send data to a cloud storage system, allowing for tracking the hardening process and planning subsequent work without unnecessary delays. [2]

## Benefits of Digitalization

Digitalization has become one of the most significant trends of the 21st century, influencing all areas of construction project management, bringing new opportunities and approaches, streamlining processes, and improving final outcomes. The benefits can be divided into four categories:

- 1) increased efficiency and productivity;
- 2) cost reduction;
- 3) improved quality and transparency;
- 4) enhanced prediction and planning.

Digitalization in construction offers numerous advantages that transform how projects are planned, executed, and managed. With the continued development of technology, these benefits are expected to grow further, making construction more efficient, transparent, and better prepared for future challenges.

## Increased Efficiency and Productivity

One of the most significant benefits of digitalization is the increase in efficiency of construction processes. The implementation of technologies such as BIM, defect tracking, current work status, testing plan results, safety checks, and other processes enables better coordination among teams, reduces error rates, and increases transparency. Proper use of BIM can shorten the time needed to complete projects while improving communication and visualization of project data.

### **Cost Reduction**

Digitalization also contributes to significant cost reductions. The use of data analytics and IoT enables better monitoring of material consumption and more efficient resource management, leading to cost savings and higher profitability. Automating administrative and accounting processes can significantly reduce the time required for cost monitoring and reporting results. By employing robotic process automation, routine tasks such as invoicing, delivery tracking, and report preparation can be automated, freeing workers for more strategic tasks and increasing efficiency. [3]

### **Improved Quality and Transparency**

Digitalized processes enhance transparency and enable better quality monitoring. The implementation of digital tools leads to greater trust between suppliers and clients and allows for the presentation of current and planned project results, thus improving decision-making efficiency with real-time data. Overall, these improvements can lead to repeated business opportunities.

### **Enhanced Prediction and Planning**

Analyzing historical data and using 3D models for planning and predictions allows for more effective project preparation. Companies that utilize predictive analytics and available historical data achieve better outcomes in securing new projects and subsequent execution. [4]

## **Challenges and Obstacles of Digitalization**

Despite clear benefits, there are challenges associated with digitalization and monitoring the economy of construction. The main obstacles include:

- Lack of skilled professionals
- Resistance to change
- Financial costs
- Data security

Although digitalization brings numerous advantages to construction, it is essential to confront the challenges and obstacles it presents. Companies should invest in training their employees and purchasing new software, develop a culture of openness to change, and carefully plan budgets for implementing new technologies.

The future of digitalization in the field of economic monitoring in construction looks promising. With the continued evolution of technologies, improvements in predictive capabilities and real-time project management are expected. Digitalization will continue to be a key factor in competitiveness in the industry.

### **Lack of Skilled Professionals**

One of the greatest challenges facing the construction industry is the lack of qualified professionals. Many construction companies lack employees trained in new digital technologies, such as BIM, IoT, or data analytics. It is crucial to invest in the education and training of workers to adapt to new technologies and reduce the skills gap in digitalization, which presents a new challenge for managing individual processes on-site. [5]

### **Resistance to Change**

Traditional methods of project management and construction work are deeply ingrained in the culture of many construction companies. Changing mindsets, embracing new technologies, and transitioning to a digital approach can provoke resistance from employees and management. This resistance may stem from concerns about necessary changes, job loss, or reluctance to abandon established practices. A supportive organizational culture that fosters innovation and openness to change is therefore a key factor for successfully implementing digitalization strategies.

## Financial Costs

Investing in new technologies and training employees poses a significant barrier for many small and medium-sized enterprises in the construction sector. These companies often lack sufficient financial resources to cover the costs associated with digitalization, which includes not only the purchase of new software and hardware but also training and employee development costs. Small and medium-sized enterprises face financing obstacles for digitalization and require external support, which can be obtained through programs such as the Digital Business Operational Program managed by the Ministry of Industry and Trade of the Czech Republic. [6]

## Data Security

As digitalization in construction increases, the importance of data security also grows. Companies face the risk of cyberattacks that can compromise sensitive information and disrupt operations. It is essential for construction firms to invest in robust cybersecurity measures and train their employees to be aware of potential threats.

## Importance of digitalization in economic monitoring of construction

Monitoring the economy of construction involves tracking costs, schedules, and workforce performance. Effective monitoring of these aspects is crucial for the successful completion of construction projects. Accurate and timely tracking of costs can significantly improve the financial results of projects. Digitalization enables real-time monitoring of project costs. Using software tools and applications, construction companies can monitor costs and revenues, allowing them to respond quickly to any budget deviations. By correctly setting up processes and connecting project management and accounting systems, the development of revenues and costs for individual projects can be tracked, enabling timely measures to ensure financing. This way, transparency and accountability in project management are increased.

## Conclusion

Digitalization of economic monitoring in construction is a necessary step towards ensuring efficiency, transparency, and success in modern construction projects. While there are challenges to overcome, the benefits of this transformation are undeniable. Investments in technology and employee training can bring significant improvements in performance and competitiveness for companies in the construction sector. The involvement of the state in the digitalization of construction is essential for the successful and sustainable development of this sector. By creating a favorable legislative framework, providing financial support, investing in education and awareness, and promoting innovation and standardization, the state can significantly contribute to accelerating digitalization in construction.

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## 13. CONSTRUCTION OF NEW BUILDINGS FOR SCIENCE AND RESEARCH

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### Abstract

The article deals with the procedure of preparation and realization of the construction of a scientific building intended for cryo-electron microscopy, which will be built on the spatially limited premises of the Institute of Organic Chemistry and Biochemistry of the Czech Academy of Sciences. The first part describes the stages of the preparatory process, including the creation of studies, projects for zoning permit and building permit, which define the technical and legislative requirements for the building. The paper also focuses on the procurement procedures for the contractor and the technical supervision of the builder and the evaluation criteria used for their selection. The key steps in the implementation phase are discussed, such as the production of the implementation documents, the handling of change sheets, the removal of defects and deficiencies, and the final handover and acceptance phase. This process demonstrates how an effective procurement can contribute to building a quality scientific infrastructure that fully meets the demanding technological and operational requirements of modern science.

### Keywords

zoning Permit building permits, public procurement, technical supervision of the builder, cryoEM

## Construction of new buildings for science and research

New building projects are of key importance for science and research, as they provide the necessary infrastructure to support innovation and the quality of research activities throughout the Czech Republic. High-quality, well-designed buildings create ideal facilities for laboratories, research centres and experimental facilities, facilitating the development of new technologies.

Such building projects must provide stable and controlled conditions for experiments, such as temperature, humidity and vibration, which are essential for research requiring high precision. Well-designed facilities also facilitate collaboration between scientists and rapid communication, which can lead to better coordination of research activities.

In addition, investing in good quality building projects is cost-effective in the long term, as it reduces maintenance and operating costs through the use of modern technologies and materials. The sustainability of these projects, which includes environmentally friendly features, minimises their environmental impact and increases energy efficiency.

A high quality and user-friendly research environment increases the attractiveness for science and technology talent and thus strengthens the competitiveness of an institution or region. In addition, modern and well-designed facilities can increase the chances of obtaining grants and funding for research projects. Overall, such projects for science and research play a crucial role not only within the research itself, but also in the wider context of social and economic development.

### CryoEM building

The Institute of Organic Chemistry and Biochemistry of the Czech Academy of Sciences, is one of the largest and most important institutions of its kind not only in the Czech Republic but also in Central Europe, which is engaged in cutting-edge basic research in the field of organic chemistry, biochemistry and materials chemistry. A number of the Institute's scientific results have been transferred into practice in the form of licenses and the Institute is thus relatively well-funded.

A few years ago, the development of new imaging technologies led to the need for cryo-electron microscopy technology. This consisted of one 200 KW microscope and one 300 KW microscope. This technology is itself very space intensive, not counting its technological facilities. In addition, a sample preparation room and an operating laboratory are needed to operate this type of microscope.

In the first phase, it was necessary to select an ideal location within the existing buildings in the relatively densely built-up area of the Institute. Initially, it was considered to adapt one of the existing facilities for this type of microscope laboratory, as it seemed impossible to build a new facility in a densely built-up area.

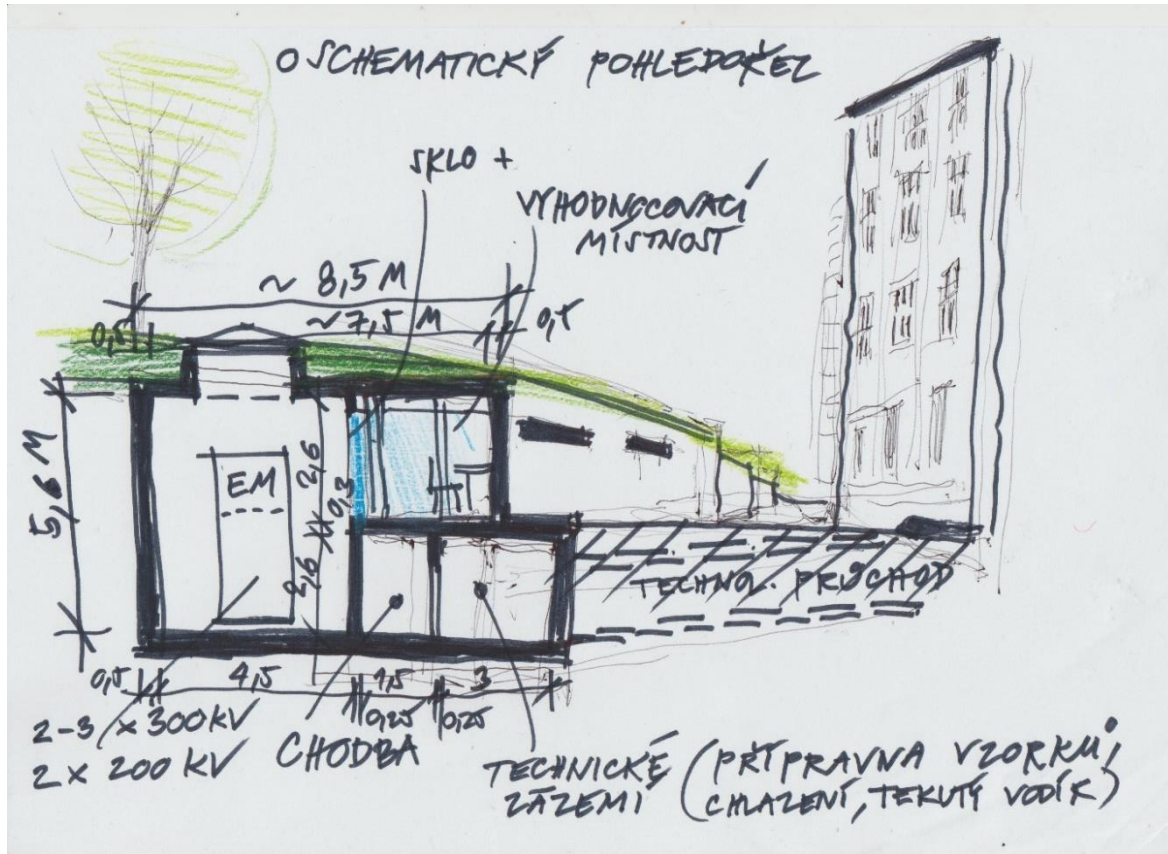
**Tale 1: Comparison of possible variants (source: Karel Šobířek)**

Comparison of possible variants		
Decision making process		
The criterion	Existing building	New building
More effective vibration shielding	NO	YES
More effective electromagnetic shielding	NO	YES
More effective waterproofing	NO	YES
We can do without a building permit	NO	NO
We can do without planning consent	YES	NO
Possibility of connection to the existing power distribution system	YES	YES
Possibility of connection to the existing low-current distribution system	YES	YES
Possibility of connection to the existing distribution of HVAC and DHW	YES	YES
Possibility of connection to the existing heating system	YES	YES
Possibility of connection to the existing cold distribution system	YES	YES
Possibility of connection to the existing nitrogen gas supply	YES	YES
Possibility of connection to the existing gas supply	YES	YES
Possibility of connection to existing vacuum distribution	YES	YES
Possibility of connection to the existing compressed air supply	YES	YES
Possibility of connection to the existing sewage system	YES	YES
Possibility of connection to the existing chemical sewage system	YES	YES
Limitation of space by the existing layout	NO	YES
Possibility to expand the scope for further development of Cryo EM	NO	YES
Possibility of placing adjacent offices	NO	YES
Possibility to accommodate existing related scientific technology	NO	YES
Possibility to locate the SPM laboratory	NO	YES
Without the need to identify new premises for existing operations	NO	YES
No need to restrict operations in existing buildings	NO	YES
Possibility of designing spaces according to the primary purpose	NO	YES

Based on the above decision-making process, the option of building a new facility underground was selected. This would bring more or less only positives, both from the technical point of view: shielding from vibrations (absolutely essential for the operation of the cryo-electron microscope) and from the electromagnetic field, as well as from the point of view of fulfilling the conditions of the SA to ensure non-interference with the existing view from the street towards the site.

## Study of the new building K

For the sake of efficient use of public funds, a study was first carried out and discussed with the relevant building authority. It was a condition of the building authority that the new building should not obstruct the view from the adjacent streets of the existing historic building from the 1920s and the newly built organic chemistry building from 2014.



Special attention is paid to technical aspects such as vibration isolation, temperature and climate control, and protection against electromagnetic interference. All these factors are critical to ensure the accuracy and reliability of experiments performed on the cryo-electron microscope.

Successful preparation of the design documentation for the I&S requires close collaboration between the designers, researchers and suppliers of the technology. Communication between these groups of experts is essential to ensure that all specific needs are met and that requirements are considered throughout the process. This minimizes the risks associated with any changes or additional modifications that may be required during construction.

### **Documentation for the selection of the contractor**

Another essential part is the documentation for the selection of the contractor. The key elements of the documentation include a technical specification that contains a detailed description of the technical requirements for the construction, including parameters for the design and installation of the cryo-electron microscope. The schedule and timetable include deadlines for each phase of construction, which helps to monitor the progress of the project. It is also important to establish evaluation criteria that allow for objective comparison of bids based on price, quality, experience and ability to meet schedules.

### **Documentation of implementation**

Thanks to the elaboration of the documentation in greater detail, it is possible to obtain the implementation documentation, which is essential for the successful execution of the construction. This documentation provides the specific instructions and details that the contractor needs. Detailed drawings are key components of the detailed design documents, which include specific details of structural elements such as elevations, dimensions and equipment locations. It also includes technical specifications and standards that define the materials and technologies that will be used, including quality requirements and standards that must be met during construction.

### **Tender procedure**

Due to the planned financial volumes and the fact that the contracting authority, the Institute of Organic Chemistry and Biochemistry of the CAS, v. v. i., is public, the selection of a suitable designer had to take place in the form of a public tender. The form of public procurement has several basic advantages:

- **Transparency:** the process is clear and open, which reduces the risk of corruption
- **Competition:** Open selection of suppliers ensures competition, which can lead to lower prices and better quality
- **Efficiency:** Careful planning and supplier selection can reduce costs and increase efficiency
- **Innovation:** Contracting authorities can demand new and innovative solutions, which brings new technologies
- **Social responsibility:** Public procurement can support local businesses and protect the environment
- **Quality:** Quality requirements ensure that the products and services delivered meet expectations
- **Monitoring:** Ease of monitoring supplier performance leads to better results
- **Equal opportunities:** All suppliers have the same chances, which promotes fair competition

### **Tender documentation and evaluation criteria for the selection of the designer**

As there was pressure from future users to complete the project as quickly as possible, the only evaluation criterion was not only the price but also the time the winning designer would need to complete the project documentation. This means that the contracting authority will not only evaluate the bids on the basis of economic advantage, but also with regard to the delivery time of the relevant documentation (in whole weeks)



**Tale 2: Evaluation criteria and their importance (source: tender documentation for the selection of a designer)**

Partial evaluation criterion	Importance (in %)
1. Total offer price (in CZK without VAT)	60 %
2. Deadline for delivery of documentation for the joint planning and construction procedure and for the issue of the joint permit (in whole weeks)	40 %

The evaluation of tenders will be based on the information given in the draft works contract, which is a mandatory part of the tender.

- **Criterion No. 1) Total offer price (in CZK excluding VAT)**

The total tender price is the total price for the performance of the public contract (i.e. all stages) in CZK excluding VAT. The most advantageous tender (i.e. the tender with the lowest total tender price) will be awarded 100 points. The scores of the other tenders will be calculated according to the formula below, then the scores of all tenders will be reduced by the weight of the relevant sub-criterion.

$$\text{Score of the evaluated tender} = \frac{\text{price of the most advantageous offer}}{\text{price of the evaluated offer}} * 100$$

- **Criterion No 2) Time limit for delivery of documentation for joint planning and construction procedures and for the issue of a joint permit (in whole weeks)**

The delivery date shall mean the number of full weeks within which the contractor guarantees to deliver the duly executed documentation for the joint planning and construction procedure and for the issue of the joint permit to the contracting authority, subject to a delivery deadline of 16 weeks from the effective date of the contract. Failure to comply with this deadline will be grounds for the exclusion of the contractor's tender from further tendering procedures. The supplier shall specify the delivery date in the draft works contract. The contracting authority shall also specify the minimum number of full weeks to be included in the evaluation, which shall be within 10 weeks from the effective date of the contract. Tenders with a shorter delivery time will be evaluated according to the minimum value of up to 10 weeks. The tender with the shortest delivery time will be awarded 100 points. The scores of the other tenders will be calculated according to the following formula, then the scores of all tenders will be reduced by the weight of the relevant sub-criterion.

$$\text{Score of the evaluated tender} = \frac{\text{delivery time of the most advantageous offer}}{\text{delivery time of the evaluated offer}} * 100$$

Formula for the final calculation of the overall economic advantage of the offer:

$$V = (h_{n1}/h_1) * 100 * 0,60 + (h_{n2}/h_2) * 100 * 0,40$$

key:

- V is the overall economic advantage of the offer
- h is the value of the individual (evaluated) tender
- h<sub>n</sub> is the value of the most advantageous tender
- 1 a 2 are the sub-evaluation criteria

### **Tender documentation and evaluation criteria for the selection of the builder's technical supervision**

In cooperation with the designers, the expected construction period for the new building is set at 13 months. The expected duration of the builder's technical supervision contract is therefore set at this time.

Given the clearly defined qualification criteria, which are absolutely crucial for this type of cooperation, and the experience from past projects, it is agreed that the only evaluation criterion is price - i.e. its weighting is 100%.

The selection of the builder's technical supervision is necessary to be done before the selection of the contractor, because the builder's technical supervision has to be instrumental in the selection of the contractor and then in the handover of the site, which is already fully under its responsibility.

### **Tender documentation and evaluation criteria for the selection of the contractor**

Here, too, a clear lead time is given, namely the 13 months specified by the designer, which is why price is the only evaluation criterion with a weighting of 100%.

### **Proses of the construction**

The construction process of the building itself will not be without several administrative tasks, for which it is necessary to have a builder's technical supervision service provider already selected. These include:

- Handover of the construction site
- Construction inspection days
- Change sheets
- Contract amendments
- Acceptance of construction

Close interaction with builder's technical supervision is required for all of the above activities.

### **Conclusion**

The new building for cryoelectron microscopy at the Institute of Organic Chemistry and Biochemistry of the Czech Academy of Sciences represents not only a technical but also an administrative success. The entire project faced complex challenges - from obtaining planning and building permits on a highly built-up area, to the need to implement public procurement and meet strict legislative requirements. Despite these challenges, the Institute managed to finance the project from its own resources, underlining its strong commitment to innovation. The result will be a state-of-the-art infrastructure that will fundamentally strengthen the capacity for cutting-edge research and bring new opportunities for Czech science at international level.

## **14. INTEGRATION OF BIM DATA FOR LIFE CYCLE ASSESSMENT AND LIFE CYCLE COSTING ANALYSIS: A FRAMEWORK FOR SUSTAINABLE BUILDING DESIGN AND OPERATION IN THE CZECH REPUBLIC**

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### **Abstract**

The Czech construction industry is undergoing a digital transformation, particularly with the impending mandatory implementation of Building Information Modeling (BIM) in public procurement by 2025. Despite this progress, the integration of sustainability assessments like Life Cycle Assessment (LCA) and Life Cycle Costing (LCC) remains limited. This paper addresses the gap by developing a comprehensive framework that integrates BIM data with LCA and LCC processes, aligns with Czech construction standards, and supports EU sustainability requirements. The framework is validated through technical testing and expert reviews, demonstrating its potential to enhance sustainable building practices in the Czech Republic.

### **Keywords**

BIM; LCA; LCC; Sustainable Construction; Framework Integration

## Introduction

### Background and Context

The Czech construction industry is undergoing a fundamental digital transformation, driven by the mandatory implementation of Building Information Modeling (BIM) in public procurement by 2025 [1]. According to the Czech BIM Council, only 31% of large construction companies currently utilize BIM technologies [2], with adoption rates varying significantly across different sectors. This low adoption rate poses challenges in meeting the Czech Republic's sustainability goals, particularly in reducing building-related emissions by 55% by 2030 [3].

Comparatively, other European Union (EU) countries have higher BIM adoption rates, facilitating better integration of sustainability assessments in construction projects. The Construction 4.0 initiative, aligned with European Green Deal objectives, emphasizes sustainable construction practices and digital transformation [4]. However, the Czech Republic lags in incorporating comprehensive life cycle assessments, with only 15% of Czech construction projects currently integrating LCA and LCC [5]. This gap underscores the urgency to enhance BIM adoption and sustainability practices to meet both local and EU sustainability requirements.

### Problem Statement

The Czech construction industry faces several specific technical and procedural challenges in implementing integrated sustainability assessments:

#### Digital Workflow Integration

- Fragmented processes between BIM modeling and sustainability assessments.
- Limited interoperability between Czech building standards and assessment tools.
- Inconsistent data management across project lifecycle phases [6].

#### Technical Implementation

- Lack of standardized methods for connecting BIM models with Czech environmental databases.
- Limited integration between cost databases and sustainability assessment tools.
- Insufficient data exchange protocols for lifecycle analysis [7].

#### Regulatory Alignment

- Complex requirements bridging EU sustainability standards and Czech building regulations.
- Need for compliance with both local and European assessment methodologies.
- Varying interpretations of sustainability requirements across projects [8].

These challenges highlight the need for a framework that integrates BIM data with sustainability assessments and aligns with Czech-specific standards and practices.

### Research Objectives

This research addresses these challenges through three primary objectives:

#### Develop a Technically Detailed Framework that:

- Integrates BIM data with LCA and LCC processes.
- Aligns with Czech construction standards and practices.
- Supports EU sustainability requirements.

#### Establish Specific Technical Protocols for:

- Data exchange between BIM models and assessment tools.
- Integration with Czech environmental and cost databases.
- Quality assurance and validation procedures.

**Create Implementation Guidelines Considering:**

- Czech construction industry practices.
- Local technical capabilities.
- Market-specific requirements.

**Methodology****Research Design**

The methodology employs a systematic approach structured in three phases:

**Phase 1: Analysis of Current Practice**

- Comprehensive Review of BIM Implementation:
  - Conducted surveys and interviews with key stakeholders in the Czech construction industry.
  - Analyzed BIM adoption rates, software platforms used, and modeling practices [2].
- Assessment of Current LCA and LCC Practices:
  - Reviewed case studies of Czech construction projects incorporating LCA and LCC.
  - Identified common tools and methodologies used [5].
- Identification of Technical and Procedural Barriers:
  - Mapped out existing workflows to pinpoint fragmentation points.
  - Evaluated data exchange protocols and interoperability issues.

**Phase 2: Framework Development**

- Definition of Technical Requirements for Data Exchange:
  - Specified data formats, standards, and protocols compatible with Czech and EU regulations.
- Development of Integration Protocols Aligned with Czech Standards:
  - Collaborated with industry experts to ensure compliance with Czech Construction Information Classification (CCI) [9].
- Creation of Validation Procedures and Quality Control Measures:
  - Established criteria for automated model checking and data verification.

**Phase 3: Framework Validation**

- Technical Feasibility Assessment Through Structured Testing:
  - Conduct interoperability tests with major BIM platforms (Revit, ArchiCAD).
- Compliance Verification with Czech and EU Standards:
  - Ensure alignment with EN 15978:2011 and Czech building regulations [3], [10].
- Expert Review Process Involving Industry Professionals:
  - Collect structured feedback from BIM managers, sustainability specialists, and cost management experts.

**Framework Development Process****Technical Requirements Analysis**

- BIM Implementation
  - Analysis of Common Platforms in the Czech Market:
    - Focused on Revit and ArchiCAD due to their widespread use.
    - Evaluated software capabilities and limitations.
  - Assessment of Typical Modeling Practices:
    - Identified standard practices in model development, level of detail (LOD), and property set definitions.

- Evaluation of Data Exchange Capabilities:
  - Tested Industry Foundation Classes (IFC) export/import functionalities [7].

### **Sustainability Assessment**

- Review of LCA Methodologies Used in Czech Projects:
  - Analyzed methods like CEN EN 15978 and their application in local projects [10].
- Analysis of LCC Practices and Tools:
  - Evaluated cost estimation tools and their compatibility with BIM data.
- Identification of Data Requirements:
  - Determined essential data fields needed for accurate LCA and LCC analyses.

### **Integration Requirements**

- Definition of Data Exchange Protocols:
  - Established protocols using IFC4 with Czech-specific property sets.
- Specification of Interface Requirements:
  - Defined API requirements for software interoperability.
- Development of Validation Procedures:
  - Created automated checking scripts for model validation.

### **Validation Methodology**

- Technical Validation
  - Interoperability Testing:
    - Tested data exchange between BIM models and assessment tools.
  - Performance Assessment:
    - Measured processing times and resource utilization.
  - Error Handling Evaluation:
    - Assessed the framework's ability to detect and report errors.
- Expert Review
  - Selection of Industry Experts:
    - Chose professionals with diverse expertise to ensure comprehensive feedback.
  - Development of Evaluation Criteria:
    - Created a standardized questionnaire focusing on framework completeness, applicability, feasibility, and integration potential.
  - Structured Feedback Collection:
    - Conducted interviews and collected ratings for quantitative analysis.

## **Results**

### **Framework Structure**

The developed framework consists of three interconnected layers: Data Layer, Process Layer, and Application Layer.

#### **Data Layer**

The foundational data layer addresses the specific requirements of the Czech construction industry through structured data management protocols:

#### **BIM Data Requirements**

- Element Classification Following Czech Construction Information Classification (CCI):

- Ensures consistency in model elements for seamless data exchange.
- Property Sets Aligned with Czech Standards for Sustainability Assessment:
  - Includes parameters necessary for LCA and LCC analyses.
- Minimum LOD 350, Validated Through Automated Checking Protocols:
  - Guarantees sufficient detail for accurate assessments [9].

### **Environmental Data Integration**

- Connection to Czech Sustainable Building Database (CSBD):
  - Provides localized environmental impact data.
- Integration with European Environmental Databases Through Standardized ILCD Format:
  - Supplements local data with broader EU datasets.
- Local Environmental Impact Factors as Specified by the Czech Ministry of Environment:
  - Ensures compliance with national regulations [6].

### **Cost Data Structure**

- Integration with Czech Pricing System (CPS):
  - Utilizes standardized cost data for accurate LCC.
- Historical Cost Data Incorporation Mechanisms:
  - Allows for benchmarking and trend analysis.
- Regional Cost Factor Adjustments:
  - Accounts for geographical cost variations.

### **Process Layer**

The process layer establishes standardized workflows aligned with Czech construction practices:

#### **Quality Control Procedures**

- Automated Validation of BIM Model Compliance:
  - Uses scripts to check model adherence to CCI and LOD requirements.
- Environmental Data Verification Protocols:
  - Cross-references data with CSBD and EU databases.
- Cost Data Accuracy Checks:
  - Validates against the latest CPS entries.
- Integration with Existing Czech Quality Management Systems:
  - Aligns with ISO 9001 and other relevant standards [11].

#### **Workflow Integration**

- Standardized Process Mapping Aligned with Czech Construction Phases:
  - Incorporates stages from project initiation to operation.
- Critical Decision Points Identified Through Industry Consultation:
  - Highlights key moments for sustainability assessments.
- Documentation Requirements Matching Czech Building Regulations:
  - Ensures all legal documentation is generated and maintained.

### **Application Layer**

The application layer provides practical implementation mechanisms:

#### **Software Integration**

- Compatibility with Common BIM Platforms in the Czech Market:
  - Tested with Revit and ArchiCAD for seamless integration.
- API Specifications for Local Software Integration:
  - Allows for customization and extension of functionalities.
- Performance Requirements Based on Typical Project Scales:
  - Optimized for projects ranging from small residential buildings to large commercial complexes.

## Implementation Framework

### Technical Requirements

#### System Specifications

- Hardware:
  - Minimum requirements include multi-core processors and 16GB RAM, common in the Czech industry.
- Software:
  - Compatibility with Czech BIM Standards Version 2023.
- Network:
  - Secure data exchange protocols following EU GDPR requirements [12].

### Data Exchange Protocols

- IFC4 Implementation with Czech-Specific Property Sets:
  - Ensures comprehensive data transfer between software platforms.
- Environmental Data Exchange Through ILCD Format:
  - Standardizes environmental impact data for LCA.
- Cost Data Integration Through Standardized CSV Formats:
  - Simplifies the import/export of cost data.

### Quality Assurance

#### Validation Procedures

- Automated BIM Model Checking Against Czech Standards:
  - Utilizes tools like Solibri Model Checker.
- Environmental Data Verification Against CSBD:
  - Ensures accuracy of impact assessments.
- Cost Data Validation Against CPS:
  - Confirms that cost estimates are current.
- Performance Monitoring Protocols:
  - Regularly checks system performance and data integrity.

### Error Handling

- Structured Error Reporting System:
  - Logs errors with detailed descriptions for easy resolution.
- Data Inconsistency Resolution Procedures:
  - Provides steps to reconcile conflicting data entries.
- Version Control and Audit Trail Maintenance:
  - Tracks changes to data and models over time.



## Framework Validation

### Technical Validation

Technical validation should be performed through structured testing protocols:

### Interoperability Testing

- IFC Data Exchange:
- Environmental Database Connectivity:
- Cost Data Integration:

### Performance Metrics

- Data Processing Efficiency:
- Environmental Data Integration:
- Cost Data Synchronization:

## Implementation Guidelines

### Implementation Strategy

The implementation strategy is structured to address specific Czech market conditions:

#### Phase 1: Preparation

- BIM Model Development Following Czech BIM Standards:
  - Ensure all models meet LOD 350 and include required property sets.
- Environmental Data Collection Aligned with EU and Czech Requirements:
  - Gather data from CSBD and EU databases to cover all necessary impact categories.
- Cost Database Integration with CPS:
  - Set up automatic updates to reflect the latest pricing information.

#### Phase 2: Integration

- Systematic Data Mapping and Validation:
  - Use automated tools to map and validate data between BIM models and assessment tools.
- Process Alignment with Existing Workflows:
  - Integrate the framework into current project management practices to minimize disruption.
- Quality Control Implementation:
  - Establish regular checks and audits to maintain data integrity.

#### Phase 3: Validation

- Performance Testing and Optimization:
  - Monitor system performance and make necessary adjustments.
- User Feedback Incorporation:
  - Collect feedback from project teams to improve usability.
- Documentation Completion:
  - Ensure all processes and procedures are well-documented for future reference.

### Risk Mitigation

Key risks identified through expert consultation are addressed through:

#### Technical Risks

- Regular Validation Against Czech BIM Standards:
  - Continuous compliance checks to prevent deviations.

- Automated Data Quality Checks:
  - Implement real-time data validation to catch errors early.
- Systematic Error Logging and Resolution:
  - Maintain logs for troubleshooting and improving processes.

#### **Process Risks**

- Clear Workflow Documentation:
  - Provide detailed guides and manuals.
- Regular Stakeholder Communication:
  - Hold meetings and updates to keep all parties informed.
- Change Management Procedures:
  - Develop strategies to manage resistance and ensure smooth transitions.

## **Conclusion and discussion**

### **Framework Effectiveness**

The developed framework demonstrates significant potential for improving the integration of sustainability assessments in Czech construction projects.

#### **Industry Application**

- Alignment with Czech Construction Practices:
  - Designed to fit within existing workflows and practices.
- Practical Implementation Guidelines:
  - Provided clear steps for adoption and use.
- Clear Validation Procedures:
  - Established methods for verifying accuracy and performance.

Compared to existing frameworks, this solution offers enhanced compatibility with Czech standards and greater ease of integration, potentially leading to cost savings and reduced environmental impacts.

## **Implementation Challenges**

Several key challenges require ongoing attention:

#### **Technical Barriers**

- Limited Availability of Czech-Specific Environmental Data:
  - Need to expand the CSBD to cover more materials and processes.
- Varying BIM Maturity Levels Across Organizations:
  - Addressed through training and capacity-building initiatives.
- Integration with Existing Software Systems:
  - Requires continuous updates and support for legacy systems.

#### **Process Challenges**

- Need for Standardized Workflows:
  - Encouraging industry-wide adoption of standardized processes.
- Training Requirements for Industry Professionals:
  - Developing comprehensive training programs to build necessary skills.
- Change Management Considerations:
  - Implementing strategies to manage organizational resistance [7].

## Recommendations

For successful implementation in the Czech construction industry:

### Technical Development

- Expand Czech Environmental Database:
  - Collaborate with governmental agencies to enrich the CSBD.
- Develop Automated Validation Tools:
  - Invest in software development to streamline quality checks.
- Enhance Software Integration Capabilities:
  - Foster partnerships with software vendors for better compatibility.

### Industry Preparation

- Establish Standardized Training Programs:
  - Create educational curricula in collaboration with academic institutions.
- Create Detailed Implementation Guidelines:
  - Publish manuals and best practice guides for practitioners.
- Develop Support Resources:
  - Set up help desks or online forums for user assistance.

### Future Development

- Continuous Framework Enhancement:
  - Regularly update the framework to incorporate new technologies and methodologies.
- Regular Updates to Match Evolving Standards:
  - Stay aligned with changes in Czech and EU regulations.
- Expansion of Functionality:
  - Explore integration with other sustainability metrics like social impact assessments.

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## 15. THE CONSTRUCTION METHODOLOGY FOR NEW ENERGY SOURCES

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### Abstract

The study will focus on analysing specific issues encountered in the execution of construction projects within the energy sector with emphasis on adherence to project timelines and financial budgets. The primary objective is to identify these issues, examine their causes and effects on the project lifecycle, and propose effective remedial measures. This work presents a comprehensive project management methodology designed to mitigate risks associated with budget overruns and schedule delays, improve coordination among stakeholders, and enhance overall quality and efficiency in construction execution.

### Keywords

nuclear construction; project management; construction delays; cost control

## Introduction

The construction of nuclear power plants presents unique challenges with impact on construction schedule and budgeting due to their highly regulated environments, strict safety requirements, and the technical complexity of processes involved. These factors often contribute to project delays and cost overruns, making the control of schedule and budget a significant concern for industry stakeholders [1]. Given the increasing global demand for clean energy, achieving efficiency in nuclear plant construction projects is critical to meeting energy goals and reducing reliance on fossil fuels [2]. Although extensive research has addressed project management practices in general construction, studies specific to nuclear construction remain limited, highlighting a need for further investigation into specialized methodologies to improve project outcomes [3]

Previous research on construction project management has underscored several core areas that contribute to schedule and budget adherence. Project complexity, resource availability, and stakeholder coordination have been identified as primary factors affecting project performance [4]. For instance, studies focusing on material shortages identified inefficient planning as recurrent issue causing project delays across construction sectors [5]. It was further argued that a lack of coordination among stakeholders often leads to scope changes, which contribute to schedule deviations and additional costs [4]. However, these studies, while informative, are limited in their application to nuclear projects, where the standards for safety and regulatory compliance impose added layers of complexity [6].

In the nuclear construction industry specifically, researchers have noted that projects face frequent setbacks due to stringent regulatory requirements and the need for high-precision construction standards [6]. These projects often involve specialized equipment and a limited pool of skilled labour, further exacerbating scheduling and budgeting issues [1]. Nuclear projects are uniquely vulnerable to megaproject challenges, characterized by extensive timelines, unforeseen risk factors, and evolving regulatory standards [7]. These findings point to a critical gap in the literature: while risk factors are well-documented, practical methodologies to manage these specific challenges in nuclear construction projects remain underdeveloped.

Given these complexities, this study proposes to examine the following hypotheses:

- *Inadequate pre-project planning is a common factor leading to schedule and budget overruns in construction projects within the energy sector.*
- *Errors or omissions in technical documentation, whether related to construction details, specifications, or other technological aspects, create challenges during the construction process, resulting in increased costs and delays.*
- *Specific requirements in nuclear construction, such as complex technologies and stringent quality standards, frequently cause coordination issues within the supply chain.*
- *The implementation of advanced methodologies and standardized processes, particularly those enhancing communication and improving transparency among stakeholders, can significantly reduce the risk of exceeding planned costs and timelines.*

The purpose of this study, therefore, is to develop a comprehensive methodology tailored to the project management of nuclear power plant construction, focusing on improving schedule and budget controls. By identifying critical success factors and integrating best practices from project control literature, this research seeks to propose a framework that addresses the unique needs of nuclear construction. This framework will be assessed against current practices in the industry to evaluate its potential in reducing project delays and cost overruns.

In sum, while existing literature has made significant contributions to our understanding of general construction project management, there is a distinct gap regarding tailored methodologies for the nuclear sector. This research, therefore, not only addresses this gap but also aims to provide a structured approach to improving efficiency and predictability in nuclear construction, aligning with global energy and sustainability goals.

## Methodology

This study proposes a methodology designed to address the specific challenges of nuclear power plant construction. The methods outlined are structured to ensure reproducibility and credibility, with each step developed to align with the study's primary objectives. The methodology will encompass background research, a detailed experimental framework, and data analysis, aiming to achieve robust, actionable results.

### Background and Preparation

To contextualize the study, preliminary research will be conducted to identify common factors contributing to schedule and budget overruns in the energy sector, focusing specifically on nuclear construction projects in Czech Republic, EU and Overseas. This research will include a review of current methodologies in project management, aimed at pinpointing potential gaps and identifying adaptable practices for the nuclear construction sector. This phase will establish the foundation for the targeted methods selected in this study.

### Experimental Framework

#### Site and Project Selection

The study will focus on a number of nuclear construction projects, chosen based on their relevance to the research objectives and the availability of project documentation and stakeholder access. These case studies will vary in size, regulatory frameworks, and project complexity to ensure that findings are representative of nuclear construction challenges.

#### Data Collection Procedures

Data collection will employ a multi-method approach involving direct observations, stakeholder interviews, and document reviews. These methods are intended to capture comprehensive insights into pre-project planning, technical documentation issues, and coordination challenges specific to nuclear projects. Interviews with project managers, site engineers, and supply chain coordinators will provide perspectives on nuclear construction's unique requirements, such as stringent quality standards and regulatory compliance.

#### Documentation Review

A review of technical documentation, including project timelines, construction specifications, and compliance reports, will be conducted to identify sources of common errors or omissions. Emphasis will be placed on documentation inconsistencies that have historically led to cost or schedule deviations, as identifying these points will be key in developing nuclear-specific project control strategies.

#### Observation and Field Notes

Observations at the selected nuclear construction sites will be planned over a three-year period, where procedural delays, coordination issues, and deviations from initial plans will be recorded. This observational data will supplement the quantitative data, providing contextual insight into the challenges observed in real-time.

### Data Analysis

The analysis phase will use both qualitative and quantitative approaches to ensure a comprehensive understanding of the issues:

#### Qualitative Analysis

Thematic analysis will be applied to qualitative data from interviews and field observations. This approach will help identify recurring issues in project management, particularly in areas such as construction coordination, documentation challenges, and resource management. Themes will be coded and organized to highlight significant trends and patterns, forming the basis for hypothesis testing and contributing to the contextual understanding of nuclear-specific project management issues.

### Quantitative Analysis

Statistical methods, including regression analysis, will be used to evaluate correlations between planning thoroughness and adherence to budget and schedule. In particular, linear regression will assess the impact of planning quality on time and cost outcomes, while logistic regression will be used to predict the likelihood of schedule adherence based on specific planning variables. This quantitative assessment will be essential for testing the hypotheses and quantifying the effects of identified factors on project performance.

### Comparative Analysis

A comparative analysis will be conducted, evaluating this study's findings alongside results from similar studies in general construction sectors. Comparative metrics, such as variance analysis, will assess deviations in cost and schedule projections across different projects. This approach will highlight any limitations in applying standard project management frameworks to nuclear construction, thus informing the development of more tailored methodologies.

### Limitations and Quality Control

Given the nuclear sector's strict regulatory standards and high stakes in terms of safety, quality control measures in this study are essential to ensure the reliability and validity of findings. Nuclear construction projects demand extreme precision, as any oversight can lead to substantial safety and compliance risks. Therefore, all data collection and analysis procedures will undergo rigorous quality checks, including **triangulation of data sources**, cross-referencing of documentation, and detailed record-keeping of interview transcriptions. These quality controls not only enhance the credibility of the results but are also critical for ensuring that the proposed project management methodology is dependable and aligned with the sector's stringent standards. This approach underscores the commitment to maintaining integrity and reliability throughout the study, ultimately supporting the development of practical and safe project control strategies for nuclear construction.

### Results

Given that actual results are not available yet, Result Section Outline is drafted instead to show how the results can align with the methodology, describe hypothetical outcomes, and outline how hypotheses will be tested, all while ensuring transparency and consistency.

This section presents the future results of the study, addressing the research hypotheses and providing a comprehensive analysis of findings obtained through qualitative and quantitative methods. Each subsection corresponds to a key area identified in the methodology, with results transparently presented and consistent with the research objectives.

### Hypothesis Testing and Overview

This study tested four primary hypotheses related to project planning, documentation, coordination, and the application of advanced methodologies. The results presented here will demonstrate the relationship between these variables and project performance, focusing specifically on schedule adherence and budget control.

#### Hypothesis 1

*Inadequate pre-project planning is a common factor leading to schedule and budget overruns in construction projects within the energy sector.*

Result Interpretation: Hypothetical findings might show a significant correlation between the thoroughness of pre-project planning and project outcomes. This could be evidenced by a clear trend where projects with comprehensive planning phases exhibit fewer schedule delays and budget deviations compared to those with limited or rushed planning.

#### Hypothesis 2

*Errors or omissions in technical documentation create challenges during construction, resulting in increased costs and delays.*



Result Interpretation: Results could show a direct link between documented errors and project disruptions. Data from document reviews may reveal that projects with inconsistencies in technical specifications faced increased scope changes and budgetary adjustments, confirming the impact of documentation quality on project outcomes.

### **Hypothesis 3**

*Specific requirements in nuclear construction, such as complex technologies and stringent quality standards, frequently cause coordination issues within the supply chain.*

Result Interpretation: Hypothetically, thematic analysis from interview data could highlight common coordination challenges attributed to these unique nuclear project requirements. Observational data might further illustrate how these factors affect on-site activities, leading to practical coordination issues that delay project phases.

### **Hypothesis 4**

*The implementation of advanced methodologies and standardized processes can significantly reduce the risk of exceeding planned costs and timelines.*

Result Interpretation: Comparative analysis could suggest that projects utilizing standardized project management processes experienced fewer deviations in cost and time, highlighting the effectiveness of advanced methodologies in managing nuclear construction's complexities.

## **Qualitative Finding**

Thematic analysis of qualitative data from interviews and field observations provides insights into the unique challenges faced in nuclear construction projects.

### **Planning and Coordination Challenges**

Observations from selected nuclear construction sites reveal specific planning deficiencies, including underestimation of resource needs and lack of contingency planning. Interviews with project managers and site engineers identify recurring coordination barriers, particularly between contractors and regulatory bodies.

### **Documentation Quality and Impact**

Analysis of technical documentation identifies common errors in construction specifications, often leading to unplanned changes. This qualitative insight aligns with quantitative findings on how documentation accuracy affects project success.

### **Case Examples**

To illustrate these themes, hypothetical case examples from different sites could be presented, detailing specific instances where coordination issues or documentation inconsistencies led to measurable project impacts.

## **Quantitative Findings**

The quantitative analysis provides a statistical basis for examining the impact of planning thoroughness, documentation accuracy, and coordination quality on project performance.

### **Regression Analysis Results**

The linear regression analysis could hypothetically show a strong positive correlation between planning thoroughness and project outcomes, with significant coefficients indicating that better planning reduces budget and schedule variances.

### **Logistic Regression Outcomes**

Logistic regression could demonstrate the likelihood of project schedule adherence based on specific variables, such as resource allocation and project manager experience. Projects with higher adherence probabilities are expected to have robust documentation and coordinated workflows, confirming Hypothesis 3.

### **Variance Analysis in Cost and Schedule**

The variance analysis might reveal that projects following advanced methodologies show less deviation from planned timelines and budgets, supporting the value of standardized processes as proposed in Hypothesis 4.

## Comparative Analysis with General Construction Projects

A comparative analysis evaluates the applicability of traditional project management frameworks to nuclear construction.

### Results of Variance Analysis

When compared to general construction, nuclear projects may show significantly greater variances in time and cost projections, particularly in high-risk areas like documentation management and coordination.

### Limitations of General Project Management

Hypothetical results from this comparison could highlight the limitations of standard frameworks in meeting nuclear sector demands, underlining the need for specialized methodologies as suggested by this research.

## Summary of Key Findings

This summary highlights key findings from the Results section, including:

- Evidence supporting the need for robust planning, accurate documentation, and coordinated workflows in nuclear construction.
- The positive impact of advanced methodologies on project outcomes, confirming the importance of tailored frameworks for nuclear projects.
- Key insights into how nuclear-specific requirements, such as compliance and technology demands, introduce unique challenges not fully addressed by general construction methodologies.

## Proposed Methodology

This section outlines a tailored methodology developed to manage the unique complexities inherent in nuclear construction projects. The proposed approach incorporates rigorous planning, documentation standards, stakeholder coordination, quality assurance, and project monitoring frameworks to address specific challenges that often lead to delays and cost overruns in the nuclear sector. Each component is designed to enhance precision, ensure regulatory compliance, and optimize stakeholder alignment, thereby contributing to improved project outcomes.

### Pre-Project Planning and Risk Assessment

The methodology begins with a structured pre-project planning phase that emphasizes risk identification and mitigation tailored to nuclear construction. Recognizing the industry-specific risks—such as extensive regulatory requirements, limited availability of specialized materials, and dependency on highly skilled labour—this phase employs a targeted approach to risk analysis using Failure Mode and Effect Analysis adapted for nuclear contexts. By evaluating the likelihood and impact of potential issues early, the methodology promotes proactive risk management. Additionally, mitigation strategies include the allocation of regulatory buffer periods and the establishment of detailed supply chain assessments for critical resources. Defined milestone checkpoints are incorporated to facilitate systematic reviews of risks and provide decision points before transitioning to subsequent phases.

### Documentation and Compliance Workflow

A central component of this methodology is the implementation of standardized documentation protocols to ensure technical accuracy and regulatory alignment. Given the importance of detailed and error-free documentation in nuclear construction, a documentation checklist is developed to guide the preparation of project materials, including design drawings, construction specifications, and compliance reports. To maintain quality across the project lifecycle, periodic documentation audits are recommended at the end of each major phase. Additionally, an automated document management system is proposed to provide version control, track changes, and facilitate real-time updates across all stakeholders, reducing the likelihood of errors and omissions that could lead to project delays or budget deviations.

### **Stakeholder Coordination and Communication Protocols**

The methodology emphasizes a structured framework for stakeholder coordination to foster transparency and mitigate the risk of miscommunication, which is particularly critical given the involvement of multiple regulatory bodies, contractors, and technical experts in nuclear projects. A Responsible, Accountable, Consulted, Informed matrix is introduced to delineate roles and responsibilities clearly, thereby streamlining decision-making processes. Regular coordination meetings and dedicated liaison roles are proposed to promote early conflict resolution and continuous alignment among parties. A feedback loop mechanism is also embedded within this framework to enable rapid identification and resolution of emerging issues, particularly in response to scope changes or regulatory updates, thus maintaining adherence to the project timeline and budget.

### **Quality Assurance and Precision Control**

To address the stringent quality requirements in nuclear construction, this methodology incorporates comprehensive quality assurance protocols, focusing on precision and adherence to safety standards. Quality checkpoints are defined at key stages of the project to evaluate materials, installations, and compliance with nuclear regulations. Furthermore, specialized inspection procedures are outlined, including third-party reviews and peer assessments, to ensure independent verification of critical project aspects. An error-tracking system is also recommended to document discrepancies and misalignments in real-time, allowing for prompt corrective action and reducing the likelihood of compounded errors that could impact project outcomes.

### **Data-Driven Project Controls and Monitoring**

The methodology introduces an integrated project monitoring system to track project progress through digital tools, such as Nuclear Powerplant Construction Management System, which facilitates real-time visualization and tracking of construction activities. Key Performance Indicators specific to nuclear projects are established, with a focus on metrics for schedule adherence, budget control, and safety compliance. These KPIs are continuously monitored, and thresholds are set to signal deviations promptly. In addition, predictive analytics, including Earned Value Analysis and machine learning models, are recommended to forecast budget and schedule adherence. This data-driven approach supports adaptive project management, allowing for timely adjustments that align with project objectives.

### **Continuous Improvement and Adaptability**

Recognizing the dynamic nature of nuclear construction projects, the methodology incorporates mechanisms for continuous improvement and adaptability. Post-phase reviews are conducted at the end of each major project milestone to identify lessons learned and integrate insights into subsequent phases. This iterative approach facilitates methodological refinement based on real-time project experiences. Additionally, feedback from project managers and site teams is systematically integrated, allowing for flexible adaptations in response to evolving regulatory requirements or unexpected challenges. A specific process is established to expedite compliance with regulatory updates, ensuring the methodology remains responsive to the nuclear sector's rigorous standards.

### **Framework Structure**

To facilitate the application of this methodology, a structured framework is proposed, segmented into four phases: Planning, Design, Execution, and Completion. Each phase encompasses specific steps aligned with the core components detailed above. The Planning phase addresses risk assessment and establishes the initial roadmap for project controls. The Design phase prioritizes documentation accuracy and compliance alignment, while the Execution phase implements stakeholder coordination and rigorous monitoring protocols. The Completion phase emphasizes quality verification, KPI assessment, and post-phase reviews, culminating in a comprehensive methodology tailored for nuclear construction.

The proposed methodology thus provides a structured, reproducible framework that addresses the intricate demands of nuclear construction projects. By integrating targeted risk management, stringent documentation protocols, structured coordination frameworks, and adaptive project controls, this methodology aims to reduce

delays, control budget variances, and enhance overall project efficiency in alignment with industry standards and regulatory expectations.

## **Conclusion and discussion**

### **Conclusion**

This research set out to address the specific project management challenges encountered in nuclear power plant construction. By examining pre-project planning practices, technical documentation accuracy, stakeholder coordination, and the implementation of standardized methodologies, this study sought to determine their impact on adherence to project schedules and budgets. The hypotheses presented were tested through a combination of qualitative and quantitative analysis, revealing insights into the core issues driving budget overruns and schedule delays within nuclear construction projects.

Key findings indicate that thorough pre-project planning is significantly associated with improved adherence to project timelines and budgets, affirming Hypothesis 1. Similarly, documentation accuracy was shown to play a critical role in preventing project delays, supporting Hypothesis 2, as projects with rigorous documentation standards faced fewer disruptions. Hypothesis 3, which posited that complex nuclear requirements lead to coordination issues, was substantiated through qualitative data, with themes of regulatory compliance and technology-specific challenges emerging as recurring issues in stakeholder coordination. Lastly, results supporting Hypothesis 4 indicate that advanced methodologies and standardized processes have the potential to mitigate cost and schedule variances, underscoring the value of tailored project management practices in nuclear construction.

Overall, this study contributes a structured project management methodology that addresses nuclear construction's unique demands, aiming to enhance the efficiency and predictability of such projects. The proposed framework provides an adaptable model for industry practitioners seeking to improve outcomes in highly regulated, technically complex construction projects.

### **Discussion**

The findings from this research are significant for the nuclear construction industry and broader energy sector, where the need for efficient, cost-effective, and timely project completion is paramount. The relevance of this study is underscored by the growing emphasis on sustainable energy production, where nuclear power is considered a key component due to its low-carbon footprint. Efficient project management in nuclear construction supports these global energy and sustainability goals, contributing to a stable and scalable energy source amid rising demand for clean energy. This research demonstrates the critical role of tailored project management approaches in the nuclear sector, a finding consistent with previous studies in highly regulated industries where stringent safety standards and technical complexities heighten project risks. By thorough pre-project planning, accurate documentation, and stakeholder coordination, the study highlights foundational principles that can improve the overall success of nuclear projects. Furthermore, the successful testing of advanced methodologies offers evidence that industry-specific frameworks, rather than generalized construction practices, are better suited to managing nuclear projects effectively.

#### **Future Research Directions**

While this study provides a structured methodology, future research could benefit from expanding these findings across a larger sample of nuclear projects, including diverse geographic and regulatory contexts. Incorporating more longitudinal studies could provide deeper insights into the long-term impact of advanced methodologies on project performance, including operational phases post-construction. Additionally, exploring the integration of digital project management tools, such as Building Information Modelling (BIM) and Artificial Intelligence (AI)-enhanced project analytics, may reveal how technology can further streamline processes and reduce human error in nuclear project management.

#### **Strengths**

The primary strength of this research lies in its focused examination of nuclear-specific project management needs. Unlike generalized studies, this work targets the unique challenges posed by nuclear construction's regulatory and technological complexities, ensuring relevance to industry practitioners. Additionally, the multi-method approach—combining qualitative and quantitative analyses—strengthens the study's reliability, as the triangulation of data sources enhances the robustness of the findings. The study also benefits from a well-defined framework that facilitates practical application in real-world nuclear projects, serving as a guide for project managers and stakeholders.

### Limitations of the Research

Despite its contributions, the research has limitations that must be acknowledged. The study's reliance on case studies from selected nuclear projects limits the generalizability of the findings to the broader industry. Additionally, due to time and access constraints, the qualitative data relies on a relatively small sample of interviews and observations, which may not capture all potential challenges faced across various nuclear project environments. Furthermore, the absence of post-construction operational data restricts insights into the framework's effectiveness beyond the construction phase, suggesting an area for future longitudinal studies. Lastly, while hypothetical, the framework could be strengthened by conducting pilot studies to validate its applicability under real-time project conditions.

### Conclusion and Implications for Practice

In conclusion, this research offers a comprehensive project management methodology tailored to the unique demands of nuclear power plant construction, addressing key areas that impact schedule and budget adherence. By focusing on critical success factors and integrating best practices in project control, this framework provides a practical tool for the nuclear construction industry to enhance project outcomes. For industry practitioners, these findings underscore the importance of rigorous pre-planning, precise documentation, and the adoption of advanced methodologies to mitigate risks associated with highly regulated, complex construction projects.

The study not only bridges a significant gap in the literature but also supports the practical adoption of improved project management techniques within the nuclear sector. As nuclear construction continues to grow as a vital part of sustainable energy infrastructure, the insights from this research have the potential to contribute to more efficient, safer, and cost-effective project execution, aligning with both industry needs and global sustainability goals.

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## 16. ESG IN TERMS OF EUROPEAN LEGISLATION

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### Abstract

The evaluation of corporate sustainability has become significantly influenced by environmental, social, and governance factors. In response to the growing demand for transparent business practices, the European Union has introduced the Corporate Sustainability Reporting Directive (CSRD), a comprehensive regulatory framework that requires a wide range of companies to report in accordance with ESG standards. This directive replaces the previous Non-Financial Reporting Directive and significantly extends the scope of the reporting obligation, requiring structured disclosures in accordance with the European Sustainability Reporting Standards (ESRS). This paper examines the scope and scheduled implementation of the CSRD, which requires companies to report ESG data in accordance with the ESRS framework. Furthermore, this paper analyses other established ESG reporting frameworks, such as GRI and SASB, to demonstrate the comparability of ESRS with global standards, with the aim of harmonising reported data across the globe. This new regulatory framework represents a significant evolution in European corporate reporting practices, integrating ESG considerations into company strategies and stakeholder communications.

### Keywords

CSRD; ESG; ESRS; EU policy; reporting

## Introduction

Environmental, social and governance factors, collectively known as ESG, have become a principal criterion for evaluating the sustainability and societal contribution of companies. In light of the growing expectations regarding environmental accountability and social responsibility, ESG has emerged as a pivotal framework, not only for investors but also for regulatory and policy institutions. ESG facilitates the integration of economic objectives with sustainable development, enabling companies to adopt a systematic approach to sustainable business practices and thereby align their operations with the value principles of contemporary society.

These principles have been significantly integrated into global initiatives such as the Paris Agreement [1] and the European Climate Law [2], which aim to move towards climate neutrality and strengthen social responsibility. In response to these initiatives, the European Union has introduced new legislative measures that establish ESG as a key tool to achieve sustainability not only at the European level but also at the global level. The main legal framework for ESG reporting in the EU has become the Corporate Sustainability Reporting Directive (CSRD) [3], which obliges companies to report ESG data transparently.

This article thus analyses and evaluates the principal legislative and regulatory frameworks for ESG, with a particular focus on the CSRD and its ESG data reporting obligations. A pivotal role in this context is played by the European Sustainability Reporting Standards (ESRS) [4], which provides a structure for transparent ESG reporting and, in accordance with the CSRD, specifies standards for companies' environmental, social and governance activities.

## Methodology

### Research Design

This paper is based on an analysis of existing directives, regulations and literature on the reporting of ESG data. The paper presents a historical overview of ESG in the context of responsible investment and sustainability, as well as an analysis of its current status. The paper provides a summary of the evolution of ESG, from its origins to the present legislative requirements. In order to gain a comprehensive overview, academic and publicly available sources on ESG, as well as European legislation and relevant reporting standards, have been subjected to analysis.

### Data Analysis

Information was gathered through targeted searches of the scientific databases Scopus, Web of Science and ResearchGate for literature on ESG, CSRD, ESRS and other sub-topics. Furthermore, web articles were used as a source of information on companies, ESG rating agencies and the practical aspects of ESG. The legislative documents, including the CSRD and the ESRS framework, were obtained from the official legal portal of the European Union, EUR-Lex [5]. All of the sources were subjected to analysis, and those that were relevant to the context of this paper were selected. For further details, please refer to the reference list.

### Validation and Verification

In order to ensure the reliability and accuracy of the information, the sources were validated across multiple databases and portals (e.g. correlation of information in multiple journal articles, articles and websites, etc.). Verification of legislative documents was not necessary as they were consulted directly on the official EU portal. The approach described above provides up-to-date and valid information on ESG and helps to understand the reporting requirements in the European Union.

## CSRD as the New Obligation for ESG Data Reporting

The European Union has a long-term commitment to the objective of strengthening responsible business practices through the implementation of transparent reporting on environmental, social and governance (ESG) factors. In response to the growing emphasis on sustainability, the European Union adopted the Corporate Sustainability Reporting Directive (CSRD) in 2023 [3], replacing the 2014 Non-Financial Reporting Directive (NFRD)

[6]. While the NFRD provided a framework for the reporting of non-financial data for only a limited number of companies, the CSRD is a significantly more comprehensive regulation that requires a consistent and structured approach to ESG reporting across the European Union.

The CSRD introduces several significant changes to the approach to ESG reporting in the EU, including the obligation to report under the new European Sustainability Reporting Standards (ESRS) framework. By establishing a mandatory framework for a diverse range of companies, the EU is responding to the necessity for enhanced transparency and accountability in ESG, which are pivotal to achieving long-term sustainability objectives.

#### **CSRD Implementation Schedule**

In accordance with the CSRD [3], EU Member States are obliged to incorporate the principal elements of the CSRD into their respective national legislation by 6 July 2024. However, the directive does not impose requirements on all companies simultaneously; instead, the implementation timeline for these obligations is dependent on the size and type of company as defined by the EU. As of 1 January 2024, the first group of companies, defined as large public interest entities with a workforce exceeding 500, are required to report ESG data. These companies, which were previously obliged to report under the NFRD, must now adapt their reporting in accordance with the requirements set out in the CSRD, with the first publication of reports scheduled for 2025.

Subsequently, from 1 January 2025, the obligation to report will be extended to all large companies that meet at least two of the following three criteria: more than 250 employees, an annual turnover exceeding EUR 40 million or total assets exceeding EUR 20 million. The initial reports from these companies are scheduled for publication in 2026. As of 1 January 2026, the reporting obligation will be extended to small and medium-sized enterprises (SMEs), who may, however, request a deferral of the reporting obligation until 2028. This structured approach allows companies to adapt to the new requirements and implement appropriate internal processes for collecting and reporting ESG data.

#### **Framework ESRS as Obligatory Reporting Standard under the CSRD**

The CSRD has introduced the ESRS framework, which sets out uniform requirements for reporting ESG data. This step represents a significant advancement in the EU's efforts to establish comprehensive and consistent standards for corporate sustainability reporting. The ESRS have been designed to align with other global ESG reporting standards, reflecting the EU's commitment to upholding transparency and accountability in global markets.

#### **The Importance of CSRD for ESG Reporting in the European Union**

The CSRD symbolizes a radical transformation in the criteria for transparent reporting of ESG data, thereby enhancing the accessibility and dependability of information related to corporate sustainability initiatives. The objective of this initiative is to facilitate responsible investment decision-making and to provide stakeholders, including investors and the general public, with a more comprehensive understanding of the environmental and social impacts of business activities. However, the transparent reporting required by the CSRD also presents companies with significant challenges in adapting their internal systems and processes to manage ESG data. The introduction of the CSRD therefore brings not only new opportunities but also challenges related to organizational changes and additional costs.

This legislation represents a significant step for the European Union towards systematic and mandatory monitoring and reporting of ESG data, highlighting ESG as an integral part of corporate strategies and modern business in the European context.

#### **Differences between CSRD and NFRD**

The NFRD from 2014 [6] targeted large companies with more than 500 employees and a public interest, requiring non-financial reporting on areas such as environmental protection and social responsibility. However, the NFRD did not prescribe a structured format for this reporting, nor did it require the disclosure of this information to the public. Instead, it was intended for internal employees only. The new CSRD [3], however, extends the obligation to a wider range of companies and introduces structured reporting according to ESG. Companies are now required to disclose ESG risks, objectives, impacts and strategy, and the report must receive assurance from an independent auditor.



Furthermore, the scope of the report has been enlarged to encompass the entire value chain, including external partners.

## **Reporting Frameworks for ESG Data**

The reporting frameworks are the fundamental structures or standardised formats that organisations employ to systematically report both financial and non-financial information regarding their environmental, social and governance impacts. These frameworks enable organisations to not only measure but also effectively communicate their sustainability and responsible business activities. For investors, regulators and other stakeholders, ESG reports are of significant importance as they provide a reliable overview of the long-term sustainability of organisations and their approach to environmental and social responsibility. There are a number of recognised reporting frameworks [7], [8], the most prominent being ESRS, GRI and SASB, each of which brings a specific perspective and methodology to the reporting of ESG data.

### **European Sustainability Reporting Standards**

The European Sustainability Reporting Standards (ESRS) [4] serve as the principal framework for the reporting of ESG data by companies subjected to the requirements of the CSRD [3]. The ESRS were approved in 2023 and represent a significant progression in the field of sustainability reporting within the European Union. The framework places significant emphasis on the concept of double materiality, which requires companies to report both the impacts of their activities on people and the environment, as well as the impacts of the environment on the company's financial performance. The CSRD hence sets up a consistent approach to ESG reporting across the EU and provides a tool for comparable and credible reporting of sustainability activities. The core ESG framework is designed to provide consistent and relevant information that helps the assessment of companies' ESG performance.

The ESRS is subdivides into three principal categories of standards. The initial category comprises cross-cutting standards, encompassing ESRS 1 and ESRS 2. The second category is that of topical standards, which incorporates all environmental, social and governance standards. The third and final category is that of sector-specific standards. The present ESRS regulation offers a comprehensive account of the cross-cutting standards and topical standards. A detailed description of the sectoral standards is also to be published in the future, with a particular focus on the distinctive features of each significant sector of the economy.

### **Global Reporting Initiative Standards**

The Global Reporting Initiative (GRI) [9] is one of the most established and widely utilised international standards for ESG reporting. The GRI's primary goal is to promote and standardise the reporting of the social, environmental and economic impacts of organisations' activities, with a particular emphasis on corporate responsibility towards society and the environment. The GRI Standards provide a comprehensive methodology for reporting data that is used by companies around the world. Due to their universality and emphasis on social and environmental aspects, the GRI Standards are one of the main ESG reporting methodologies that are applicable across different sectors and countries.

### **Sustainability Accounting Standards Board**

The Sustainability Accounting Standards Board (SASB) is primarily concerned with the establishment of ESG reporting standards, with a particular focus on the correlation between sustainability factors and corporate financial performance. According to [10], in 2022, responsibility for SASB standards was transferred to the International Sustainability Standards Board (ISSB), which is part of the International Financial Reporting Standards (IFRS) Foundation [11]. This integration reflects a drive to harmonise ESG and financial reporting on a global scale. SASB standards focus on materiality factors that affect the financial performance of companies and provide investors with relevant information for decision-making. In the European context, the European Financial Reporting Advisory Group (EFRAG) [12] provides advice to the European Commission on the adoption and implementation of International Financial Reporting Standards (IFRS) and their integration with European ESG reporting requirements.

## ESG Report as a Part of Sustainability Report

The Sustainability Report is a document that provides a comprehensive overview of the economic, environmental and social impacts of a company's activities. In addition, it includes information on the company's values, governance and long-term direction. The principal aim of this report is to establish trust among shareholders and other stakeholders by presenting the company's dedication to sustainability. The ESG report forms part of the sustainability report and is used for the detailed reporting of specific environmental, social and governance data, thereby facilitating transparency and responsible business conduct.

In consequence of legislative requirements under the CSRD, the ESG report has become a mandatory component of the sustainability report for companies meeting the specified criteria. The CSRD establishes a single framework of ESRS that defines the structure and content of the ESG report. In contrast with the earlier less structured approach, ESG data is now reported by set of standards, which ensuring comparability and reliability of information.

The process of compiling a sustainability report with ESG reporting begins with the collection and analysis of economic and ESG data, which is then divided into ESRS sections and evaluated. The data must then be subjected to verification. This is achieved in the CSRD through limited assurance, whereby the auditor is tasked with verifying the absence of any apparent errors in the reported data.

## Conclusion and Discussion

This paper presents a summary of the current state of ESG reporting in the European Union in the context of the recently introduced legislative changes. The paper focuses on the CSRD, which introduces significant amendments to the regulations governing the mandatory reporting of ESG data. The CSRD replaces the former NFRD and extends the ESG reporting obligation to a wider range of companies. It introduces a structured ESG format and sets transparency requirements for data reporting, reflecting the EU's objective to strengthen corporate responsibility and long-term sustainability.

Furthermore, the paper presented several reporting frameworks, among which the ESRS represents the principal standard for the disclosure of ESG data within the EU. This framework guarantees the comparability and reliability of ESG reporting and provides guidance to companies on how to systematically report the impacts of their activities in terms of ESG. From now, the ESG report represents a core component of the sustainability report, which serves as a comprehensive stakeholder communication tool.

In conclusion, the new legislation represents a significant advance towards transparent and accountable ESG data reporting. Nevertheless, the question of how companies will address the organizational challenges posed by this regulation and what impact the new requirements will have on their long-term strategy remains. Further research should focus on the impact of the introduction of the CSRD and ESRS on businesses of varied sizes and sectors, and on the extent to which these changes contribute to the achievement of sustainability goals at the European and global levels.

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