# Sustainable Productivity Improvement in CPM Through Building Information Modeling in the Context of Circular Construction

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**Abstract.** Increasing productivity is one of the primary goals in the context of economic sustainability. This will bring several challenges, which, however, can be managed through the digital technologies that the 21st century brings. The growth rate of digitization is seen in every industry. As an essential sector of the economy, the construction industry has the same plans. Objectives in circular economy and sustainability in the construction industry are also prioritized for the management of the industries. Innovative modelling of buildings, like the implementation of new digital technologies, also brings many challenges, but on the other hand, also opportunities. This process in construction project management can also be key to improving sustainable productivity. This research aims to map the current state of the use of information modelling of buildings and their impact on yield. The research was carried out on 199 construction projects in three countries (Slovakia, Croatia, and Slovenia). Data collection was ensured by questionnaire inquiry. Subsequently, the data were processed, and essential tools of statistical processing were used. In addition to descriptive statistics, data redistribution tests and subsequent retesting of statistical significance, namely ANOVA and the Kruskal-Wallis's test, were used. Correlation analysis was used to examine the dependencies between variables. The survey results highlight the impact of building information modelling in construction project management for sustainable productivity improvements. Research has shown that information modeling of constructions brings an increase in productivity, including through a circular economy approach, when machines and equipment, technologies, and materials are used more efficiently, which leads to the optimization of costs.

**Keywords:** Building Information Modelling · Productivity · Sustainability · Construction Project management · Circular Construction

## 1 Introduction

Productivity in the construction industry is perceived based on outputs and inputs that are necessary to achieve the goal. Some authors state that the idea concerns the production ratio with the lowest possible waste rate. This means that we are talking about the efficient use of available resources [1]. Even a survey in North Africa pointed to the


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need to increase productivity in the construction industry in second place in the ranking of the need for improvement, to which 52 managers responded [2].

Other studies were also devoted to performance management in the construction industry. They pointed out the need to solve this problem, including a view on productivity [3]. A close parallel between the measurement of success and the measurement of performance was also based on studies that addressed the connection and perception of the so-called critical success factors of construction projects and performance [4, 5]. The study mentioned in 1999 [4] addressed the close connection between key performance indicators and project success. These claims are supported by even older studies that were oriented to the construction industry and the interconnectedness of measuring the success of construction projects and the industry precisely through similar perceptions and indicators. This was also confirmed by the Construction Productivity Network (CPN) and the Construction industry board (CIB) [6, 7].

Several studies are devoted to cost parameters in the context of a critical success factor. One of the key factors of the success of the construction project, as well as its performance indicators, is also described by Zawawi et al. [8]. Likewise, the impact on the cost side (part of the productivity indicator if it is perceived as an input) was addressed in other studies [9 − 14]. In the context of key performance indicators, these impacts were addressed in studies, where the need for their measurement and the effort to improve them will be demonstrated through several methods [15 − 17].

Spangenberg also defined the concept of economic sustainability as part of comprehensive sustainability, where it is impossible to perceive sustainability separately. However, within the monitoring of indicators and the focus of construction project management, it is possible to focus on selected, for example, economic parameters that are part of economic sustainability. It is also about evaluating the impact on results in the long term [18, 19]. In the context of economic sustainability and the principles of the circular economy, it is an effort to minimize inputs and maximize outputs, defining productivity [20]. This means the so-called green design of public space in the context of green infrastructure [21].

An economic analysis and its economic indicators are used to assess a construction project comprehensively. This also applies to building information modelling of traffic structures [22]. Digitization in construction brings, at the same time, support for contextual design in the construction industry [23], which brings a new dimension to the use of data and building information modelling [24, 25].

Several authors and studies in the construction industry addressed the importance of solving performance. Also, around implementation and the current state, there are several studies of the complexity of the perception of building information modelling. However, the space for camping impacts the process of Sustainable Productivity Improvement in CPM through Building Information Modeling has yet to be fully explored by any study.

Despite several studies carried out for the construction industry (Table 1) and the monitoring of KPIs, it can be concluded that these studies highlighted the need to monitor productivity but were not directly aimed at monitoring the impact of building information modelling on productivity.

Poor performance results are often based on low efficiency and productivity, leading to a rapid cost increase. These studies also clearly indicate the need to focus on tracking

**Table 1.** Research of key performance indicators of construction projects and focus on productivity.

| | Year of study | Cost | Profit | Productivity | Quality | Time and scheduling | Safety |
|---|---|---|---|---|---|---|---|
| Radujković, et al. [26] | 2010 | ✓ | | ✓ | ✓ | ✓ | |
| Weber, et al. [27] | 2011 | ✓ | ✓ | ✓ | | | |
| Nasir, et al. [28] | 2013 | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Gosling, et al. [29] | 2014 | ✓ | ✓ | ✓ | ✓ | | ✓ |
| Nasrollahzadeh a Basiri [30] | 2014 | ✓ | ✓ | ✓ | | ✓ | ✓ |
| Hana, et al. [31] | 2014 | ✓ | | ✓ | | ✓ | |
| Nyangwara a Datche [32] | 2015 | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Sibiya, et al. [33] | 2015 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Ofori-Kuragum et al. [34] | 2015 | ✓ | ✓ | ✓ | ✓ | ✓ | |
| Nobanee, H. [35] | 2016 | ✓ | ✓ | ✓ | | | |
| Ofori-Kuragu, et al. [36] | 2016 | ✓ | | ✓ | ✓ | ✓ | ✓ |
| Forcada, et al. [37] | 2017 | ✓ | ✓ | ✓ | ✓ | | |
| Liebetruth [38] | 2017 | ✓ | | ✓ | | | |
| Davis, et al. [39] | 2018 | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Bilal, et al. [40] | 2019 | | ✓ | ✓ | | | |
| Mbugua, et al. [41] | 2021 | ✓ | | ✓ | ✓ | ✓ | ✓ |

changes in productivity based on multiple factors. The fact that productivity impacts other key indicators is indisputable, as mentioned in the studies above.

As another study states, the close connection of smart technologies and technologies based on working with information and people increases the efficiency of production machines and equipment, reduces costs, and saves resources [42 – 44]. This is possible if I apply it to building information modeling. The implementation of digital and information technologies in the production process can ensure the flexibility of production and the adaptation of product units to the requirements of the Market [45]. This can lead to a sustainable increase in productivity.

The 70s and 80s of the 20th centuries can be considered important milestones in the field of building information modeling. BIM began to develop, with the first computer programs that enabled the modeling of buildings. The first use of the term "Building Information Modeling" dates to the 1990s [46]. In the 1990s and early 2000s, BIM became the standard in the construction industry as technological advances enabled the creation of complex digital models of buildings. However, the perception of the standard did not automatically mean progress in use, but rather on a theoretical scale. Many countries and regions have started to promote the use of BIM in their construction projects, leading to further development of the technology [47].

However, the BIM issue opens challenges and opportunities for the implementation of the use and for better decision-making, which can lead to better results in productivity.

# 2 Methodology

## 2.1 The Research Gap and Problem

Please Based on the literature mentioned, this research aims to map the situation in building information modelling and the impact on productivity in construction project management. Overall, the perception of productivity is not one-sided. Studies confirmed the importance of investigating and monitoring the impacts on productivity in construction project management. The perception of productivity is possible from the point of view of the results of human work and machines. Many other indicators can fall under productivity. However, the fundamental division based on sources and inputs is one of the most used in comparative studies.

However, check productivity comprises many partial areas where productivity can be monitored. However, based on many professional discussions and pre-research, productivity for human resources is used for this research, i.e., productivity of work and productivity of machines and equipment. The perception of overall productivity may be different. Partial areas of productivity monitoring were selected for the research needs, assuming that these are the primary and essential areas of productivity.

From the point of view of the cost rate, these are the most critical areas where it is highly desirable to examine productivity. This led to the main research question.

- What is the impact of BIM on productivity in construction project management?

  This main question was partially divided into two sub-questions based on the definition of the expected importance of partial views on productivity:
- What is the impact of using BIM on the productivity of machines and equipment?
- What is the impact of BIM on the productivity of construction works?

Based on this, the research hypothesis was established:

$H_0$: The use of BIM technology does not affect the productivity of the construction project.

In contrast, the hypothesis was established:

$H_1$: The use of BIM technology has an impact on the productivity of the construction project.

## 2.2 Data Collection and Research Sample

Data for the survey were collected through a pre-town survey. Considering the examination of three construction markets and the need to obtain the exact data for quantitative research, it was the best choice. The questionnaire was divided into three parts, which contained thematically oriented questions. The first part contained questions focused on the characteristics of the research sample, which was necessary for comparative analysis, based on the countries (markets) where the survey was conducted, the size of the construction projects and, finally, the participants in the construction project.

The second part of the questionnaire contained questions focused on using BIM in construction project management. These questions were later used to map the use of BIM technology for specific purposes and activities. The third part was focused on the already mentioned productivity indicators, primarily around productivity research for this research. Here it is necessary to clarify that the respondents quantified these results based on a Likert scale, for which a clear description and interpretation was made. Despite this, it was a quantification based on internal data of construction projects, which are part of the economic agenda within managerial accounting. However, the evaluation and quantification were done according to these tools and with the help of the mentioned management data directly by the project managers.

The research was carried out in three countries. The reason for researching an international scale was to apply the results in practice in several markets. For research purposes, it can also be stated that it was an expansion of the scope of the research and a higher number of potential participants. The research was carried out in similarly large markets (relatively small countries within the EU were involved), which is also the advantage of the international nature of the research.

Figure 1 shows the research sample according to the countries where construction projects were implemented. As can be seen in the picture, almost half of the projects were implemented in Croatia. Construction projects in Slovakia had the second largest representation. Construction projects in Slovenia have the smallest share.

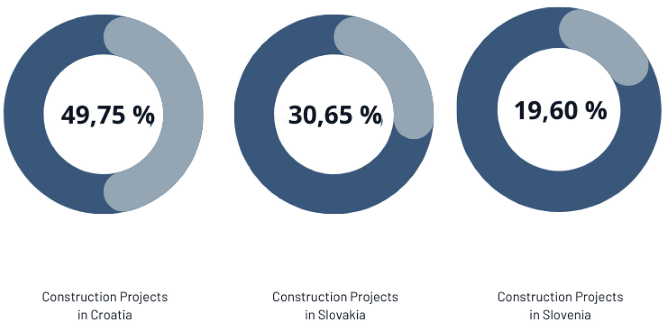


**Fig. 1.** Research sample by country of construction projects

Figure 2 shows the breakdown of the research sample based on the size of the projects involved. Almost a quarter of the projects were classified as large construction projects.

This division was based on legislation and limits on public care. More than 57% of respondents represented medium-sized projects, and more than 18% of construction projects were classified as minor.

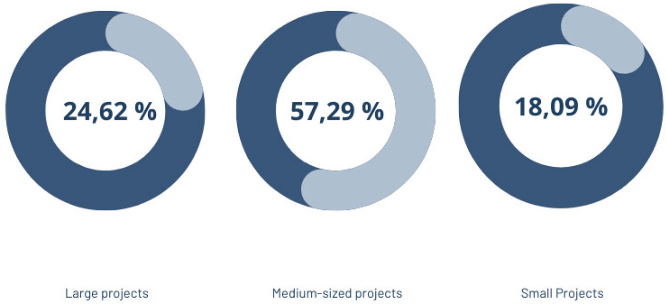


**Fig. 2.** Research sample by construction projects size

Figure 3 shows the breakdown of the research sample based on types of construction projects. Almost 40% of the projects represented the construction of residential buildings. 40% of the projects fell into the non-residential category. Almost 20% of the projects represented engineering constructions and half a percent of the projects represented the processing of project documentation.

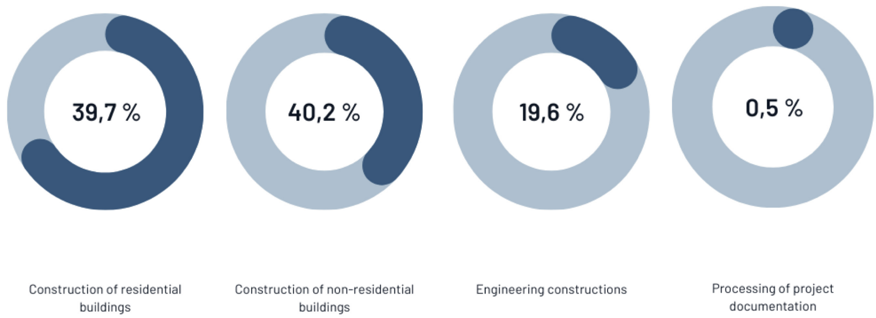


**Fig. 3.** Research sample by kind of construction project

### 2.3 Data Processing

The data of construction projects implemented in Slovakia and Slovenia were evaluated as part of the research. Data processing was carried out in MS Excel, and the advanced statistical program SPSS was also used. The questionnaire survey included data that was quantified on a Likert scale from 1 to 5. A value of 1 meant a low BIM use or impact on the productivity indicator. Conversely, a value of 5 meant a high level of BIM use or an impact on the productivity indicator.

Contingency tables and initial data processing for descriptive statistics were processed in the MS Office program. Advanced data processing, such as the measure of normality and distribution of data, statistical tests, and correlations, was carried out in the SPSS program.

The Kolmogorov and Smirnov tests were used to determine the normality of the data. Due to the sample size of 199, only one of the values was used. Statistical tests were carried out based on the result of data distribution; the most common are the ANOVA test and the Kruskal-Wallis's test. Spearmon's correlation coefficient was used to determine and quantify correlations. The statistical significance of the achieved correlations was verified through regression analysis.

### 2.4 The Research Limitations

This research works with data from three markets. On the one hand, the diversity of markets is an advantage. On the other hand, it must be considered that these markets have their specifics and conclusions valid on one of them, which may not automatically be applicable to another market. In practice, however, the fact that there are three markets significantly reduces the risk of inaccuracy and increases the likelihood of general applicability.

Another limitation may be the size of the research sample. Despite the sample of 199 construction projects, this represents a fraction of the implemented construction projects. However, the substitutability of the research sample is representative, as the projects were approached based on the available statistics in proportion to how they are implemented. Large construction projects, as well as small projects, are also part of the research sample.

Despite the detailed description of clearly defined values, where the data were taken from official documents (such as accounting, reports, statements, etc.), a small degree of subjective assessment by project managers must be included.

Mostly based on predetermined statistical significance, research results point to general intentions and recommendations. However, they are always research data that, in practice, may only apply to some construction projects.

## 3 Results and Discussion

When planning and managing construction projects, productivity is an important indicator that provides information on the effectiveness of the use of available resources for the project, not only capital and financial, but also human and material resources. As part of the research issue, productivity indicators for machines and equipment that could be clearly quantified and labor productivity were investigated. Figure 30 brings values for the degree of influence of BIM on productivity for machines and equipment through the so-called total productivity index and labor productivity indicator from the perspective of employees.

The average values of the BIM impact rate on selected performance indicators reached the level of 3.19 for the productivity index for machinery and equipment and 2.91 for labor productivity. Construction projects in Croatia and Slovakia achieved a level of BIM influence on selected key indicators lower than the average values. The situation in Slovakia was different, construction projects recorded a higher level of BIM influence on productivity indicators, namely the Productivity Index for machinery and equipment at the level of 2.92 and the labor productivity indicator at the level of 3.94.

The analysis of the results showed that the situation in construction projects in Croatia and Slovakia is very similar. The degree of BIM influence in both indicators was almost the same, there were significant disparities between Slovenia and the other research countries.

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Subsequent paragraphs, however, are indented Fig. 4.

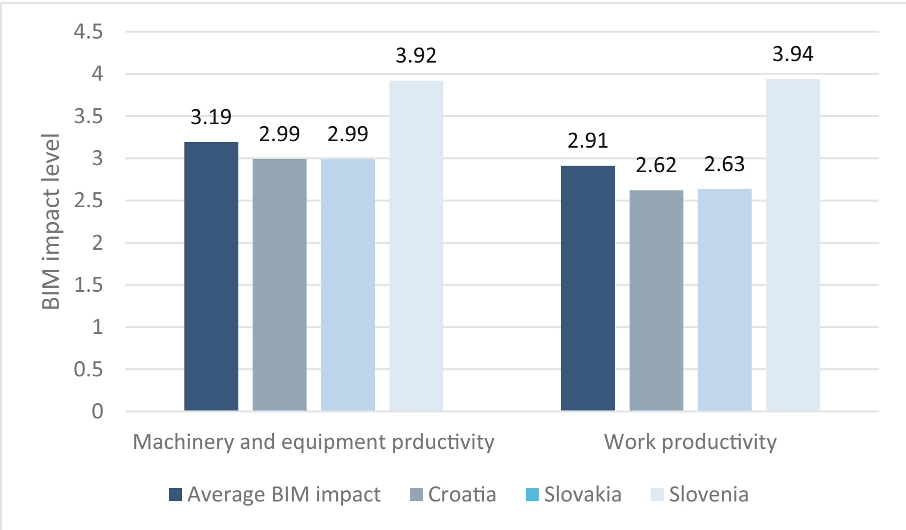


**Fig. 4.** The impact level of BIM on productivity in construction project management.

Tests for the normality of the data distribution indicated a non-normal data distribution; Kruskal-Wallis tests were chosen for statistical testing, the results of which can be seen in the Table 2.

Based on Kruskal-Wallis tests, it is possible to consider the research results for productivity indicators as statistically significant. The testing results are shown in Table 3.

Based on this, the research hypothesis was established:

$H_0$: The use of BIM technology does not affect the productivity of the construction project.

In contrast, the hypothesis was established:

$H_1$: The use of BIM technology has an impact on the productivity of the construction project.

**Table 2.** Normality test of research sample.

| | Kolmogorov-Smirnov test | | | Shapiro-Wilk test | | |
|---|---|---|---|---|---|---|
| | Statistic | df | Sig | Statistic | df | Sig |
| Machinery productivity | .270 | 199 | $< .001$ | .861 | 199 | $< .001$ |
| Labor productivity | .334 | 199 | .354 | .800 | 199 | .350 |

**Table 3.** Results of statistical significance testing of key productivity indicators of construction projects.

| | ANOVA | | Kruskal-Wallis test | | Levanse test | Equal-ity of vari-ance |
|---|---|---|---|---|---|---|
| | F | Sig. | F | Sig. | Sig. | |
| Machinery productivity | | | 195.034 | | | |
| Labor productivity | | | 179.714 | | | |

Regarding productivity, data was monitored and analyzed for two sub-indicators, namely, the productivity index for machines and equipment and the employee productivity indicator. The summary of results for this group of indicators can be seen in the Table 3.

At the significance level $\alpha = 0.05$, it is possible to reject hypothesis $H_0$: The use of BIM technology does not affect the profitability of the construction project, and to leave $H_1$ valid, the use of BIM technology affects the profitability of the construction project. Statistical significance in testing reached the value of $p = 0.022$ Table 4.

**Table 4.** Results of statistical significance testing of key productivity indicators of construction projects.

| Code | Impact of BIM | Value (p) | Rejection $H_0$ | $H_1$ |
|---|---|---|---|---|
| A | PRODUCTIVITY | .022 | yes | ✓ |
| A1 | Machinery productivity index | .001 | yes | ✓ |
| A2 | Labor productivity | .001 | yes | ✓ |

Regarding productivity, data was monitored and analyzed for two sub-indicators: the productivity index for machines and equipment and the employee productivity indicator. The summary of results for this group of indicators can be seen in the Table 3.

At the significance level $\alpha = 0.05$, it is possible to reject hypothesis H04: The use of BIM technology does not affect the profitability of the construction project, and to leave H1 valid, the use of BIM technology affects the profitability of the construction project. Statistical significance in testing reached the value of $p = 0.022$.

Several research studies have pointed out the need to monitor productivity. For a sustainable increase in productivity, it is necessary to monitor this indicator and adopt and implement solutions that will contribute to this increase. Shortly, BIM technologies represent a challenge and opportunities to improve several processes and activities in construction project management. In the long term, however, this may mean using BIM.

Therefore, this research issue oriented towards sustainable productivity increase in circular construction is a current and very desirable topic. From the point of view of circular construction, it is, therefore, appropriate to monitor the productivity index for machines and equipment in accordance with the principles of the circular economy.

Determining partial areas of productivity in the context of sustainable productivity growth and the context of circular construction.

## 4 Conclusion

The research focused on sustainable productivity growth has produced results that confirm the assumptions that the use of building information modelling positively impacts sustainable productivity growth.

The selection of partial areas of productivity assessment in construction project management was based on thorough studies and assessment of hypothetical impacts. Considering the issue of the use of digital technologies in the form of building information modelling in the context of circular construction, hypotheses were established to monitor the impact on the Machinery productivity index and Labor productivity.

In the context of economic sustainability and circular economy principles, these partial monitoring areas represent this representation and the likely impact on overall productivity. The assumed hypotheses were established in such a way as to lead to finding out what impact the use of building information modelling has on the sustainable increase in productivity. In the digital age, information management is important, and decision-making support tools can lead to improvements in indicators in productivity and efficiency. The research was carried out on a sample from three countries with approximately the same market size. Interesting findings brought knowledge for practice as well. Research-based on selected tools of the statistical apparatus confirmed the positive impact of using building information modelling on the sustained increase in productivity in construction project management. This finding was confirmed based on tests for statistical significance. However, the above-mentioned limitations of the research show that these research results can be helpful in practice. However, despite the statistical confirmation of the significance of the results, it is necessary to consider the mentioned limitations. Therefore, the results for practice should only be an orientation guide but, not an exact fact.

Implementation in practice is necessary with a sensitive assessment of other factors that this research does not consider, and due to the specifics of the construction industry, each construction project must be assessed individually.

Future research should deal with the possibility of extending the research to other countries and creating an even more extensive comparative study. Likewise, from the point of view of the achieved results, it is necessary to focus on other partial areas of productivity and thus exclude areas where the use of building information modelling does not impact the sustainable improvement of productivity.

Increasing productivity is also among the goals of sustainability. Circular construction and its principles lead to an effort to achieve efficiency and increased productivity. The increase in productivity also has an impact on other aspects of sustainability. Above all, there are savings in using materials, an increased recycling rate, etc. These are also other goals and directions of research.

Research direction and focus in the future should lead to consideration of the quantification of the impacts of building information modeling on a specific performance indicator in the context of the circular economy. Likewise, the issue of the use of artificial intelligence and the pressing increase in the rate of digitization in the construction industry opens space to connect this issue. Effective work with information is a significant support for decision-making. The need for solutions to the implications of this topic and decision-making processes based on the use and digital use of information in the form of the use of building information modeling and artificial intelligence tools, which can have an immense impact on productivity in the construction industry and thus increasing the principles of the circular economy, is the subject of future research.

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