DIGITALIZATION IN ENGINEERING FIRMS: THE ROLE AND IMPACT OF BUILDING INFORMATION MODELING ON PRODUCTIVITY

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ABSTRACT

In recent decades, digitalization has become increasingly important in the construction industry. Building Information Modeling (BIM), a digital planning method, is becoming increasingly important in the infrastructure sector. Infrastructure planning implementation is complex, so engineering firms still use conventional planning. This study sheds light on the influence of Building Information Modelling (BIM) on increasing productivity in the construction industry. Through a combination of qualitative interviews and quantitative data analysis, an in-depth understanding of the implementation processes, challenges and benefits of BIM was developed. Particular focus was placed on identifying components of success for the effective implementation of BIM in infrastructure engineering firms. The results show that BIM contributes significantly to increasing efficiency by improving the accuracy of project planning, facilitating communication between project participants and reducing the error rate in the execution phase. The study emphasises the need for a clear strategy and training to fully exploit the potential of BIM and provides valuable insights for companies planning to implement BIM.

KEY WORDS

digitalization, Building Information Modeling, productivity, infrastructure planning

JEL CODES

A100, R420, R410, O320

1 INTRODUCTION

In recent decades, increasing digitalization has significantly changed several industries, including the construction industry. This evolution has particularly accelerated the adoption and application of Building Information Modeling (BIM), a pivotal tool in modern construction practices. This shift towards digitalization has spurred numerous new infrastructural network

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planning projects across different areas, with some already implemented and others in various stages of development or planning (Banister and Berechman, 2003). Such networks affect road construction and network structures for energy, civil engineering, and other utilities, which are becoming increasingly interconnected (Giannopoulos, 2014; Bertolini and Bevilacqua, 2006).

BIM is an advanced digital planning method that involves creating and managing digital models of structures. BIM is becoming increasingly important in the modern construction industry as it optimizes the planning and execution of construction projects. The construction industry increasingly relies on digitalized support to accompany such construction projects in planning, execution, and property management (Succar, 2009). In this context, engineering offices, utilizing modern digital tools like BIM for planning and executing construction projects, play an increasingly important role. Computer models or computer-aided planning structures are intended to help make planning more efficient in terms of costs, time, resources, and personnel deployment in all these projects (Eastman et al., 2011). In the infrastructure planning industry, digital technologies such as BIM could contribute to better project outcomes and greater sustainability (Borrmann et al., 2015). Especially in large projects with many trades, it is necessary to simplify the collaboration with various digital tools (Whyte and Lobo, 2010). To make this even more accessible and to make planning and execution even more efficient, a method is being used in some European countries and also worldwide in which "Building Information Modeling" forms the core of the entire planning process and is the basis for monitoring the construction project in all phases (Azhar et al., 2015; European Union, 2019).

Especially in building construction, BIM is applied throughout the whole construction process. BIM is a method or process in construction and design that involves the creation and management of a digital model of a structure (Porwal and Hewage, 2013; Sacks et al., 2018). Thus, BIM is an as-built model of a structure that contains various information, such as what materials were used or what part number the component has. In addition, a BIM model ideally also contains a schedule or information about the cost of the structures (Barbosa et al., 2017; Bryde et al., 2013). However, BIM still needs to be used to the same extent as in building construction in infrastructure construction, such as road, tunnel, or sewer construction. This is because the available BIM software is mainly suitable for building construction and less for infrastructure (Volk et al., 2014). Insights from Varvařovská and Staňková (2021) on the electricity sector's production possibilities may shed light on the intersections of digitalization and sector-specific challenges, potentially guiding varied BIM adoption across the industry.

In the infrastructure sector, 3D BIM models cannot be represented with the required accuracy, especially for linear structures such as roads. In addition, it still needs to be sufficiently clarified whether the BIM method is worthwhile for engineering firms in the infrastructure sector (Jun and Lee, 2010; Oti et al., 2016). Infrastructure construction has various service phases, some of which can be commissioned individually. Through BIM, there is a shift of effort into the early service phases, which can lead to more effort being invested in digital 3D planning than is subsequently remunerated (Succar et al., 2012; Smith, 2014). It is still to be clarified to what extent an optimized way of working can amortize the costs incurred by the new software. Amjad and Rehman (2018) point out, that the cost-effectiveness and productivity enhancements attributed to BIM could be deeply influenced by the caliber of e-information and the adeptness in adopting information communication technology. This accentuates the pressing need for a holistic scrutiny of the digitalization trajectory in civil engineering.

The primary aim of this manuscript is to explore the productivity of the BIM method in infrastructure planning via expert interviews and quantitative analysis and to work out initial recommendations for action or needs for action that can be useful for engineering offices to optimize productivity with the BIM method. Given the relative lack of comprehensive studies examining the use of BIM in infrastructure design, there is an urgent need for this research. It aims to educate engineering firms about the potential benefits and challenges, and impacts of BIM adoption in infrastructure development (Cao et al., 2015; Howard et al., 1998). Building on this will shed light on the under-researched aspects of BIM's effectiveness, time management and financial impact on infrastructure design. This will help determine whether BIM, although proven effective in building construction, can achieve the same level of productivity in infrastructure (Sackey et al., 2014). It will also clarify whether long-term operational efficiencies and cost savings can offset the potential increase in initial costs and resources allocated to BIM implementation.

The article is organized as follows: Section 1 introduces the research topic and also the importance and background of BIM in infrastructure planning. Section 2 presents the current state of research and its implications in detail. Section 3 describes the methodology chosen for our study. In Section 4, we present our research findings, highlighting in particular the implications and challenges of BIM. In Section 5, we engage in a discussion that draws on the insights from our findings. Finally, the conclusions drawn from this work are laid out in the last section.

2 THEORETICAL FRAMEWORK

The construction industry has very complex planning, execution, and control phases; moreover, individual projects usually involve many different players. Errors in value creation, processes, and the quality of construction services frequently occur. In a US study, additional costs of around 4.3% were calculated for public construction projects that arose when processes were incompatible. In the USA, these annual costs amount to around 15.8 billion dollars (von Both et al., 2013). Efficiency requirements are increasing due to the constantly evolving competitive pressure. Improved coordination of planning and more efficient analysis processes can bring about a significant increase in efficiency (Strohe, 2013; Pereira et al., 2021).

In the European context, there are significant differences in the adoption and requirements of BIM. In Finland, BIM has been in operation since 2007, in the UK the use of BIM has been mandatory for government funded projects since 2016, which has led to a significant increase in BIM awareness and usage. In contrast, there is a high percentage of BIM users in Germany, but its use is not mandatory on all projects, with BIM being used on major projects. In France, although BIM is not required by law, it is still widely used, particularly in public projects and building construction. Spain and the Czech Republic have had active BIM programs since 2017 to achieve the introduction of BIM. Countries such as Poland and Austria are moving towards greater BIM implementation, with Poland planning to make BIM mandatory for state-funded construction projects by 2030. In Austria, it is already being used for budget control. Countries such as Croatia, on the other hand, are still lagging in the introduction of BIM and mainly use it in individual cases (PlanRadar, 2021; MagiCAD Group, 2020).

In a North American study by McGraw-Hill, which focuses primarily on the economic efficiency of BIM, experts confirm that an increase in efficiency can be achieved with the help of innovations in planning methods, technologies, and construction processes. In pilot projects of the McGraw-Hill study, time savings of around 50% were achieved in the USA, and some Scandinavian countries when the BIM method was applied in the planning and execution phase, and planning errors were significantly reduced (von Both et al., 2013). Furthermore, considerations regarding data governance and automated individual decision-making have also been shown to play a significant role in the efficiency and effectiveness of construction processes (Lăzăroiu et al., 2018). In this context, it is worth considering the public administration's role in facilitating or impeding the implementation of new planning and construction technologies. Marišová et al. (2021) found that building offices in the Slovak Republic and the Czech Republic reported dissatisfaction with providing material, technical, and financial support from the state. This indicates the need for a supportive administrative environment to utilize innovative methods such as BIM effectively.

Existing studies often refer to building construction, e.g., large buildings, and not civil engineering measures, such as roads, pipelines, or other infrastructure measures. There is also a scientific gap in the economic viability of BIM for engineering companies in infrastructure and civil engineering. The BIM method should accompany the entire life cycle of a construction project – from the planning phase to the execution phase (König et al., 2016).

The application of BIM in infrastructure planning represents another relatively underrepresented dimension in current research. The specifics of infrastructure projects, particularly the linear nature of many, present unique requirements for the BIM methodology and its implementation. Moreover, the impact of BIM on the workflow within an engineering office still needs to be thoroughly understood. The transition to a BIM-centric approach signifies a significant shift in how engineers work and demands substantial training and adaptation (Cao et al., 2015; Howard et al., 1998).

Despite the paucity of extensive research in the field, certain studies have shown promising results. For instance, time savings and improved project delivery have been reported in cases where BIM was utilized effectively (Zhang et al., 2009). Several investigations also suggest BIM can contribute to cost savings in infrastructure projects. Arayici et al. (2012), for example, found that BIM's implementation in infrastructure planning led to cost savings due to fewer errors and reworks. Moreover, a growing body of research explores BIM's potential to improve sustainability in infrastructure projects. A study by Zhang et al. (2009) highlighted that BIM could aid in integrating sustainable design elements in infrastructure projects, potentially leading to environmentally friendlier results.

3 METHODOLOGY AND DATA

The main aim of this research is to answer the following research questions:

RQ 1: *How does the use of BIM methodology in infrastructure planning affect the productivity and efficiency of engineering firms?*

RQ 2: *What is the connection between BIM methodology and time management in infrastructure planning? Does BIM result in overall time savings, or does it increase the amount of time spent?*

RQ 3: *How does BIM use in infrastructure planning impact engineering firm costs? Are the initial costs and resources spent on BIM implementation offset by long-term operational efficiencies and cost savings?*

3.1 Qualitative Survey of BIM Experts

To address these questions, guided interviews with experts were used and evaluated with the help of content-structuring qualitative content analysis. The primary aim of conducting expert interviews is to obtain information by interviewing people identified as experts concerning an existing research interest. Expert interviews thus represent a method for generating qualitative data, which in text form forms the basis for subsequent analysis (Bogner et al. 2014). Moreover, these interviews provide rich, detailed insights that can lead to understanding the nuances and intricacies of BIM use in the industry, providing a depth of understanding that surveys and other methods might not achieve (Meho, 2006).

Respondents were carefully selected and included a broad range of 19 experts in the field, including ten engineers or drafters who use the BIM method, three trainers who help engineering firms implement and use BIM, four engineering firm executives, and two software developers who develop BIM software for infrastructure. It was ensured that all respondents had used the BIM methodology in infrastructure planning in their companies for several years.

In selecting the experts, engineers from the field of infrastructure planning were chosen who use the BIM methodology in their companies. In addition, software manufacturers from these areas and consultants from the areas of infrastructure and BIM were interviewed. In addition, managers and designers were interviewed. A total of 19 interviews were conducted. The guide comprises open-ended questions that allow for the most concrete and concise answers possible but to which the interviewees are free to respond. This comprehensive and diversified selection of experts ensures an array of perspectives on the BIM adoption, implementation, and challenges, providing a richer understanding of the subject matter (Fusch and Ness, 2015).

The interviews were transcribed and evaluated with the content structuring qualitative content analysis according to Kuckartz and Rädiker (2022). MAXQDA was used to analyze the expert interviews. The expert interviews were structured using multilevel categorization and coding, enabling a transparent, category-based evaluation of the individual aspects, resulting in a descriptive presentation of the results and a critical appraisal (Kuckartz and Rädiker, 2022). This method of analysis allows the discovery of patterns, themes, and categories within the data, which can lead to comprehensive and insightful conclusions about the productivity impacts of BIM (Saldaña, 2015).

3.2 Quantitative Data Collection and Analysis

In order to validate and expand the results obtained in the guideline-based expert interviews as part of this study, a quantitative research approach was chosen in accordance with the recommendation of Saunders et al. (2019), which enables the hypotheses derived from the expert interviews to be placed on a broader empirical basis and their generalisability to be tested.

In the quantitative phase of this study, an online survey was conducted. The sample size was limited to 66 participants due to the small number of BIM users in the field of infrastructure planning. This limitation resulted from the lack of a comprehensive database listing engineering firms that use both conventional and BIM-based methods in infrastructure planning. Participants were recruited primarily through the authors' network and by sharing the survey in specialised groups and professional social networks focused on BIM in infrastructure design. The not yet widespread establishment of BIM in this sector, compared to building construction, meant that some potential participants were reluctant to share their data and information. In order to focus the research on the planning of infrastructure measures, construction companies were excluded from the survey, which further limited the range of potential participants.

The questionnaire used in this study covered seven topics based on the findings from the qualitative expert interviews. In the first part of the questionnaire, demographic information was requested, including the number of years in the profession, the duration of involvement with BIM technologies, the proportion of BIM projects in the company and the size of the company in terms of the number of employees. In addition, the participants' position in the company was recorded, differentiating between roles such as project engineer, project manager, manager, BIM consultant, software manufacturer and others. These roles can be categorised into two main occupational groups: Consultancy and Planning. While the consulting group primarily supports engineering firms with the introduction of BIM, the planning group focusses on the application of this methodology after its implementation. The integration of BIM consultants and software manufacturers into the study was deliberate, as these groups are actively involved in the BIM planning process.

The other topics from two to seven covered aspects such as obstacles (O), added value (AV), competition (C), investment (IC) and operating costs (OC), productivity (P) and time management (T) in relation to BIM in infrastructure planning. A five-point Likert scale was used for most questions, allowing respondents to express their agreement on a scale of 1 ("strongly disagree") to 5 ("strongly agree"). In the seventh topic area, specific questions were asked about the time saved by BIM, both in general and in various service phases. Participants were also asked to estimate the number of hours required for two hypothetical projects, one with and one without the use of BIM. These estimates were to be based on similar projects that had already been completed.

The data collection for this study was conducted using Unipark's online survey tool Tivian. When designing the questionnaire, care was taken to ensure that answering all questions was mandatory. This was to ensure that participants did not intentionally or inadvertently skip any questions. Despite this measure, in some cases incorrect answers were found in the final questions on the hours spent on various projects. These inconsistent or erroneous data were excluded from the analysis to ensure the integrity and reliability of the survey results.

The statistical software IBM SPSS was used to analyse the collected data. The first step involved a descriptive analysis of the data in order to identify basic trends and distributions. A factor analysis was carried out for question group 5 (costs) and divided into investment costs (IC) and operating costs (OC). Scales were formed from the mean values of the individual variables within the seven different question blocks, and *t*-tests and correlation analysis were applied on these scales. To check the reliability of the scales, Cronbach's α, a standard measure for the internal consistency of questionnaire items, was calculated. In addition, *t*-tests, correlation analysis and paired *t*-tests were included in the statistical analysis to investigate differences and relationships between different variables and to test hypotheses. This quantitative approach complements the qualitative findings and enables a more comprehensive understanding of BIM use in infrastructure planning.

In the expert interviews, different perceptions regarding obstacles, time management and investment costs in the use of BIM in infrastructure planning were identified between consultants and planners. The *t*-test was used as a method for analysing differences in order to examine these differences in more detail statistically. Before applying the *t*-test, the data was checked for normal distribution using Kolmogorov-Smirnov and Shapiro-Wilk tests to ensure the suitability of the *t*-test for data analysis. The *t*-test is a robust statistical method that makes it possible to determine significant differences between the mean values of two independent samples. This test is therefore used to analyse the following hypothesis 1: There is a significant difference between the professional groups consulting and planning in the perception of investment costs (H1.1), time management (H1.2) and obstacles (H1.3) incurred by BIM.

Following the findings from the qualitative expert interviews, which revealed different perceptions and opinions on the impact of BIM in infrastructure design, a correlation analysis was conducted to quantify the relationships between different aspects of BIM utilisation. This analysis was conducted using a non-parametric method and aimed to explore the relationship between key elements such as barriers to implementation, capital and operational costs, productivity gains and improvements in time management. The hypotheses for the correlation analysis were carefully formulated to test the qualitative insights derived from the interviews for statistical significance and strength of relationships. By combining this quantitative analysis with the qualitative data from the expert interviews, a more comprehensive picture of the impact of BIM in infrastructure planning could be drawn. This integrated approach made it possible to place the hypotheses derived from the expert interviews on an empirical basis and to test their generalisability. This resulted in the following hypothesis 2: There is a significant correlation between the obstacles to the implementing BIM in infrastructure planning and investment costs (H2.1), between added value and operating costs (H2.2), between added value and time management (H2.3), between time management and operating costs in engineering firms (H2.4), between productivity and perceived improvement in competition (H2.5), between time management and productivity (H2.6), between added value and productivity (H2.7).

The qualitative expert interviews revealed different views on how effective BIM is in terms of time management in different project phases. In order to quantitatively substantiate these perceptions and to test whether BIM actually has a measurable effect on time management and in which phases this effect is particularly pronounced, a normal distribution was first tested and then a paired *t*-test was carried out. This test compares the time required for two specific infrastructure projects – the planning of bus stations and a 3100 m long road – both with and without the use of BIM. The corresponding questions in the questionnaire were aimed at determining the estimated hours required for these projects in different work phases, both for the year 2013 (without BIM) and for the year 2023 (with BIM). By comparing this data, it was possible to analyze whether and to what extent the introduction of BIM has led to time savings in the various phases of project planning. The paired *t*-test provides a robust methodology to test for significant differences in time spent between the two points in time. This analysis is crucial to understand in which phases BIM offers the greatest efficiency gains and whether these gains are consistent with the experts' perceptions from the interviews. For this reason, hypothesis 3 follows: The use of BIM in infrastructure planning leads to time savings if all service phases are commissioned.

4 RESULTS

4.1 Costs Arising from Digitalization and BIM

For a large number of experts, the costs incurred represent a challenge. With BIM, a new concept for quality management would have to be developed as the working methods and focal points change; the areas of responsibility for drafters and specialist engineers change. The exchange of information and cooperation is increasing, and the required IT landscape is also changing. New software systems are required, and higher costs arise when integrating the new way of working because the IT has to be adapted to the corresponding projects. Not every software solution can be applied to every project. Specific clients still require conventional 2D plans. With BIM, however, planning is usually done in 3D models, and these models often do not meet the requirements that cities and municipalities, in particular, have for their plans.

For this reason, flexibility in the working method is still required, which increases the cost of training new employees. The additional effort would often not be compensated by the customers, especially if the client does not require a BIM method. However, the request for BIM is increasing, especially for large clients or more significant measures, such as the construction of highways or large bridges. The rising costs and the complex integration would lead to substantial engineering offices using the BIM method, and thus small offices have only little chance to exist in the long term. In particular, the software manufacturers interviewed explain that large engineering firms benefit from a market advantage due to their capacities and use this to commission large BIM projects.

Nevertheless, the study results by Staniulienė and Lavickaitė (2022) underline the importance of providing adequate training and education opportunities for the successful implementation of BIM in infrastructure planning. By investing in skills development for employees and improving their BIM knowledge, companies can maximize productivity, reduce resistance to change, and achieve better project outcomes.

4.2 Effects of BIM on Time Management

The interviewees had very different opinions on the amount of time spent with BIM. Particularly in the first service phases, the time required increases significantly due to digitalisation with the BIM method, and it is precisely there that it is essential to have well-trained employees who work efficiently in these first service phases. One project manager describes that, for example, a draftswoman planning conventionally for over 20 years could produce a 2D plan within a very short time but would first have to be trained for a 3D design over a more extended period. For this reason, it is essential to be flexible in these first service phases when there is time pressure from the client, as one can then plan conventionally and achieve a result more quickly. The time required is also due to the lack of interfaces and data exchange; clients often cannot evaluate the results because they do not have the software. In addition, applying the BIM method primarily involves working with 3D models. The modeling of such models takes significantly more time, although 3D modeling is not always necessary in the early service phases, depending on the project. The software manufacturers interviewed report that it is a technical challenge for them to develop the software systems so that the workload for the specialist engineers does not increase. In addition, respondents report that experience shows that educating clients about the effort and options is significant in the early phases of performance. The respondents who state that BIM leads to time savings think that time savings only occur when the entire project is considered in all service phases and under the condition that the employees are trained. The software systems have been integrated into the way of working. Especially during the construction phase, there are many advantages because there are fewer errors in the planning due to the modeling in 3D, and in this way, there can be no construction stop. In addition, it is not so often necessary to adapt the planning quickly during the construction project because it has already been adopted by the BIM method.

Furthermore, a direct exchange on the construction site is possible, and necessary corrections can be discussed and adjusted promptly. Some clients only work with the BIM method, and some have their service and product catalogs, which the engineering offices can use for planning. Such product catalogs reduce the effort since they are components that no longer have to be modeled by specialist engineers. In addition, automated error checking means that the plans are not checked individually for errors, but this is done much more quickly via the software. Another point mentioned by the interviewees is that invoicing is faster and more accessible when the BIM method is integrated. In this way, invoices from construction companies can be checked more quickly. However, the engineering companies' invoices can also be made faster, which leads to further time savings.

4.3 Effects on Productivity in Engineering Offices

During the expert interviews, productivity was mentioned, particularly when a general question was asked. The interviewees were asked what generally comes to mind when they think of BIM or what they associate with the BIM methodology. Some mention that through digitalization with BIM, the understanding between the specialist planners improves so that the planning of other engineers can be understood more quickly. Some describe that the previous work is simplified by BIM (Fig. 1).

One software manufacturer describes that the expectations for digitalization with BIM are sometimes too high. Clients expect a complete solution with the BIM method that works

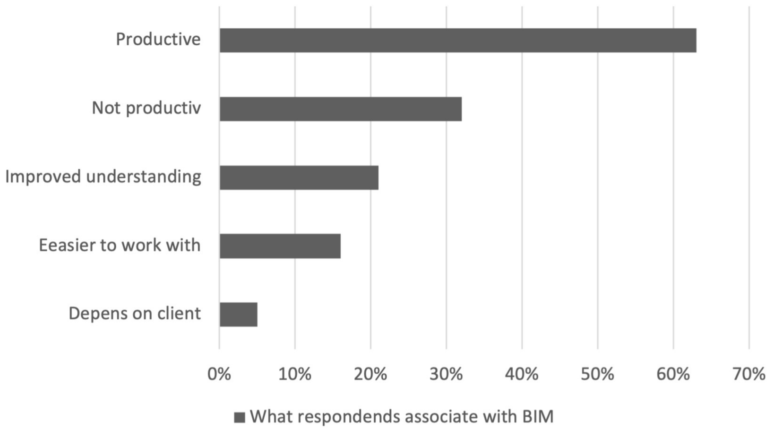

Fig. 1: What engineers associate with the BIM method in infrastructure planning

flawlessly and is directly applicable. In addition, there is a problem with the complete data exchange between different software solutions, for which there is currently no applicable interface. The data could only be displayed in another software to a limited extent; applicable solutions would still have to be developed here. Working with BIM is easier for some respondents because the software "thinks for itself." Thus it facilitates monitoring on the construction site because the 3D models can generate details at any point along the structures, which can be used to supervise and check the measurements on-site. Thus delays can be avoided. Some interviewees think that productivity is not improved by the BIM method; the effort would be about the same or even higher. More time would be invested in the modeling of the individual components. If a structure change is required, this is associated with an increased effort so that productivity decreases compared to the conventional method. For most respondents, the BIM method increases productivity, but this is highly dependent on the working method. Especially at the beginning, it is essential to plan with a low level of detail in order not to have too much effort. Since changes are often made at the beginning of planning, the client can also enter change requests directly on the model, which are analyzed by the specialist planners and processed quickly. If the comments on changes or errors are linked directly to the model, they can be corrected efficiently. Specialist engineers can, for example, digitally monitor tunnels or bridges via live transmissions and generate data from them. This leads to additional time savings, as engineers do not have to be continuously on-site at the structure and have more time to deal with problems. Digitalized simulations check whether the planned measure can be realized before construction begins. The number of employees and the construction machines required for the construction of the measure can be estimated more precisely, leading to efficient personnel management. Whereas with conventional planning, there were often situations in which different plans could not be merged without making changes. This occurs less frequently with 3D planning because the models are displayed in three dimensions from the start, and specialist planners ideally work in the same model. One project manager describes that operating costs are kept to a minimum, especially in collaborative projects.

4.4 Wider Benefits of BIM in Infrastructure Planning

The impact of BIM on time management and costs was considered from different angles, with many respondents seeing significant benefits of BIM in the context of infrastructure planning. Using BIM leads to a better understanding of the structure, better coordination, and better collaboration between project stakeholders.

This has led to a more harmonious, efficient, and effective project delivery process among the respondents. For example, engineers can better visualize complex measures with the BIM method. This understanding can help reduce errors in the design phase. By minimizing errors early on, engineering firms can avoid costly rework and changes later in the project. This advantage can be particularly beneficial in large infrastructure projects with numerous stakeholders and complex systems.

Similarly, BIM offers the potential for improved communication and collaboration. With BIM, engineers can coordinate their work more effectively with other stakeholders, resulting in a more streamlined and efficient planning process. In addition, BIM enables more transparent and effective communication with clients, as improved visualization allows them to understand the project better.

Another significant benefit of BIM is the existing potential to improve project management. With BIM, project managers can better track and manage project progress to ensure the project stays on time and within budget. They also have an overall view of the construction progress they can share with all project stakeholders. In this way, all project participants are on the same level of knowledge throughout the entire process. The 3D visualization BIM provides allows project managers to more accurately assess project status and identify potential problems before they become significant.

Although the benefits of BIM go beyond time and cost savings, its implementation requires significant investment, especially at the beginning of the roll-out and particularly in terms of staff training and IT infrastructure. Companies need to be prepared to incur these upfront costs and be aware that the full benefits of BIM may not be immediately apparent. According to experts, the true value of BIM only becomes apparent in the longer term as companies become more experienced with its use, and it becomes an integral part of their standard operating procedures.

4.5 Transition to BIM: Obstacles and Possible Solutions

The transition from conventional methods to BIM is challenging. Most respondents agreed that introducing BIM is a complex and lengthy process that requires financial investment and a high level of effort, time, and effort. The main barriers identified by respondents included a lack of staff knowledge and skills, resistance to change, and difficulties integrating BIM into existing systems and workflows.

Despite these barriers, respondents pointed to several possible solutions. These included continuous training and support for staff, developing clear implementation strategies, and fostering a culture of innovation and change within the organization. The need for broader industry and government support was also pointed out. This could include the development of industry-wide standards and guidelines, incentives for BIM adoption, and efforts to increase awareness and understanding of BIM across the industry.

In addition, respondents agreed that the successful implementation of BIM requires a holistic approach. It is not enough to simply buy BIM software; companies also need to invest in training their staff, upgrade their IT infrastructure and adapt their workflows and processes to take full advantage of the potential benefits of BIM. This requires a shift from viewing BIM as merely a tool to fundamentally changing how construction projects are managed and executed.

Although the transition to BIM can be challenging, with the right strategies and support, companies can overcome these obstacles and reap the full benefits of BIM. Respondents' experiences suggest that successfully adopting BIM requires strategic planning, ongoing training and support, and a willingness to innovate and adopt new working methods.

4.6 Quantitative Results: Detailed Analysis of BIM Effects in Infrastructure Planning

In order to determine the internal consistency of the various topics – obstacles, added value, competition, investment costs, operating costs, productivity and time management – the consistency coefficient Cronbach's α was used. Cronbach's α, a widely used coefficient for determining the reliability of data sets, varies between 0 and 1. A value close to 1 indicates high reliability, whereby it is generally assumed that values above 0.70 are considered acceptable (George and Mallery, 2003).

Scales were computed via arithmetic mean of variable manifestations. Reliability analysis yielded the following results: In the Obstacles section, one question was excluded from computation of the scale because we deemed corrected item-total corr. (0.088) too low. For the same reason one question each in the subject areas of competition and productivity was excluded from the computation of the corresponding scales (corrected item-total corr.: 0.225 and 0.184 respectively). Cronbachs α was deemed satisfactory for all scales. (H: 0.771; M: 0.895; W: 0.791; K_{1-4}: 0.852; K_{5-9}: 0.837; P: 0.710; Z: 0.838).

The Kaiser-Meyer-Olkin (KMO) test and the Bartlett test for sphericity were used to check the suitability of the data for the factor analysis. The KMO test, an indicator of sample size adequacy, yielded a value of 0.688, indicating moderate suitability of the data for factor analysis. According to Hutcheson and Sofroniou (1999), a KMO value above 0.5 is considered acceptable. With a χ^2 value of 303.830 and a significance level of $p < 0.001$, the Bartlett's test for sphericity showed that the correlation matrix of the items does not have the identity and is therefore suitable for factor analysis.

The subsequent exploratory factor analysis with a principal component method and a Varimax rotation with Kaiser normalisation led to the identification of two factors, which corresponds to the theoretical division into investment and operating costs. According to the scree plot, there was a clear kink after the second factor, which supports the selection of two factors. The principal component analysis with varimax rotation confirm this dichotomy: The first four questions load primarily on the first factor (IC), while the last five questions load primarily on the second factor (OC). This clear allocation of the items to the two factors confirms the underlying assumption that the cost structure in the context of BIM in infrastructure is two-dimensional.

In order to verify the assumption made in the expert interviews that the consulting and planning professional groups have different perceptions with regard to obstacles, time management and investment costs of BIM in infrastructure planning, a t-test for independent samples was carried out. Of the 66 study participants, 18 belonged to the consulting professional group and 48 to the planning professional group. For the application of the t-test, the normal distribution of the data was checked using the Kolmogorov-Smirnov and Shapiro-Wilk tests. The data of both groups showed only slight deviations from the normal distribution, as determined by visual inspection of the histograms.

The null hypothesis of the Levene test, that there are no differences in variance, could not be rejected in the area of investment costs ($p = 0.268$), which justifies the use of the t-test (Tab. 1). A significant difference (H1.1) was found between consultants (M = 2.667, SD = 0.809, $N = 18$) and planners (M = 2.062, SD = 0.768, $N = 48$) in the perception of investment costs through BIM, $t(64) = 2.807$, $p = 0.007$. Accordingly, there is a significant difference in the perception of investment costs through BIM between the professional groups of consulting and planning. It was found that planners are more critical of the investment costs of BIM in infrastructure planning than consultants. In the area of time management and obstacles, equal variances were not assumed after the Levene test. The results of the Welch's t-test are therefore reported. In the area of time management, there are significant differences (H1.2) in perception between consultants (M = 2.147, SD = 0.648, $N = 18$) and planners (M = 1.583, SD = 0.512, $N = 48$),

Tab. 1: Independent Samples Test

	Levene's Test for Equality of Variances					*t*-test for Equality of Means		95% Confidence Interval of the Difference	
	F	Sig.	t	df	Sig. (2-tailed)	Mean Difference	Std. Error Difference	Lower	Upper
IC*	1.250	0.268	2.807	64	0.007	0.60417	0.21523	0.17419	1.03415
T			3.324	25.363	0.003	0.56424	0.16974	0.21491	0.91357
O			2.723	23.805	0.012	0.45448	0.16692	0.10982	0.79913

Note: * Equal variances assumed.

Tab. 2: Spearman's Rank Correlation Coefficient (N = 66)

		O	C	P	AV	IC	OC	T
O	Correlation Coefficient	1.000	0.214	0.157	0.128	0.437**	−0.048	0.118
	Sig. (2-tailed)	.	0.085	0.207	0.306	0.000	0.700	0.345
C	Correlation Coefficient	0.214	1.000	0.488**	0.303*	0.276*	0.316**	0.362**
	Sig. (2-tailed)	0.085	.	0.000	0.013	0.025	0.010	0.003
P	Correlation Coefficient	0.157	0.488**	1.000	0.290*	0.270*	0.184	0.538**
	Sig. (2-tailed)	0.207	0.000	.	0.018	0.028	0.140	0.000
AV	Correlation Coefficient	0.128	0.303*	0.290*	1.000	0.136	0.629**	0.502**
	Sig. (2-tailed)	0.306	0.013	0.018	.	0.275	0.000	0.000
IC	Correlation Coefficient	0.437**	0.276*	0.270*	0.136	1.000	−0.034	0.259*
	Sig. (2-tailed)	0.000	0.025	0.028	0.275	.	0.788	0.036
OC	Correlation Coefficient	−0.048	0.316**	0.184	0.629**	−0.034	1.000	0.413**
	Sig. (2-tailed)	0.700	0.010	0.140	0.000	0.788	.	0.001
T	Correlation Coefficient	0.118	0.362**	0.538**	0.502**	0.259*	0.413**	1.000
	Sig. (2-tailed)	0.345	0.003	0.000	0.000	0.036	0.001	.

Note: Correlation is significant at the 0.01 (**) or 0.05 (*) level (2-tailed).

$t(25.363) = 3.324$, $p = 0.003$. This confirms the significant difference in the perception of time management of BIM between the professional groups consulting and planning. It is clear that planners perceive a more positive effect with regard to time management than consultants. In the area of obstacles, there are significant differences (H1.3) in perception between counsellors (M = 2.235, SD = 0.649, N = 18) and planners (M = 1.780, SD = 0.463, N = 48), $t(23.805) = 2.723$, $p = 0.012$. It becomes clear that the planners perceive more obstacles than the consultants.

In order to statistically verify the views identified in the expert interviews regarding the relationships between the analysed topics, a correlation analysis was carried out. The Pearson correlation analysis also assumes a normal distribution, which is assessed here using the Shapiro-Wilk test, the Kolmogoroff-Smirnov test and visual inspection of the histograms. The assessment shows that the assumption of bivariate normal distributions in the corresponding pairs of scales must be regarded as at least problematic. For this reason, the results of the non-parametric correlation analysis are presented using Spearman's ρ. The results for the correlations mentioned in the expert interviews are shown in Tab. 2.

The results of our study confirm significant correlations between various aspects of BIM in infrastructure planning. It is clear that there is a strong correlation (H2.1) between the obstacles to implementing BIM and the investment costs (Spearman $\rho = 0.437$, $p < 0.001$, $N = 66$). Furthermore, the results (H2.2) indicate that the added value resulting from BIM is related to the reduction of operating costs (Spearman $\rho = 0.629$, $p < 0.001$, $N = 66$). In addition, the results indicate a significant correlation (H2.3) between the added value resulting from BIM and the improvements in time management (Spearman $\rho = 0.502$, $p < 0.001$, $N = 66$). The link (H2.4) between improvements in time management through BIM and the reduced operating costs is also confirmed (Spearman $\rho = 0.413$, $p < 0.001$, $N = 66$). In addition, the study leads to the assumption (H2.5) that the increased productivity through BIM is also linked to a perceived improvement in competition (Spearman $\rho = 0.488$, $p < 0.001$, $N = 66$). Although no clear correlation became apparent in the expert interviews, the quantitative analysis indicates that the improvements in time management through BIM correlate (H2.6) with increases in productivity (Spearman $\rho = 0.538$, $p < 0.001$, $N = 66$). It also leads to the conclusion (H2.7) that the perceived added value is related to the improvement in productivity (Spearman $\rho = 0.290$, $p < 0.001$, $N = 66$). These findings are particularly relevant in practice, they are an indicator that BIM not only poses challenges in terms of cost and implementation, but also offers clear advantages in terms of operating costs, productivity, competitiveness and time management.

During the expert interviews, it was reported that BIM leads to time savings if all service phases are commissioned, which is why this study collected data on the hours spent on two different infrastructure projects at two different points in time (2013 without BIM and 2023 with BIM). To examine the differences between planning with and without BIM, paired samples t-tests were carried out for the various service phases. For all pairs near normality in the mean differences was assumed. (Assessed via visual inspection of respective histograms). For the project of eight bus stations, the results indicate significant differences in the time required between the various work phases with and without BIM. For the early service phases (1–4) without BIM (M = 243.63, SD = 137.342) and with BIM (M = 268.27, SD = 137.919), a mean difference of 24.643 (SD = 48.701) was found, $t(55) = -3.787$, $p < 0.001$, $N = 56$. This indicates a significant difference. For the same project of eight bus stations and the entire service phases (1–9) without BIM (M = 387.38, SD = 235.406) and with BIM (M = 359.86, SD = 224.700), there was a mean difference of 27.518 (SD = 101.044), $t(55) = 2.038$, $p = 0.046$, $N = 56$. This also leads to a significant difference. In a further comparison, data is collected for a larger project, which is comparable to the construction of a 3100 m long road. The early service phases (1–4) without BIM (M = 749.62, SD = 226.400) and with BIM (M = 840.91, SD = 287.066) resulted in a mean difference of 91.291 (SD = 107.797), $t(54) = -6.281$, $p < 0.001$, $N = 55$. This also indicates a significant difference. For the same project and the entire service phases (1–9) without BIM (M = 1174.55, SD = 332.522) and with BIM (M = 1061.02, SD = 404.610), a mean difference of 113.527 (SD = 185.087) was found, $t(54) = 4.549$, $p < 0.001$, $N = 55$. This also indicates a significant difference.

These results indicate (H3) that the use of BIM leads to time savings for both small and large infrastructure projects when the planning service is commissioned throughout

Tab. 3: Paired Samples Test

		Mean	Std. Dev.	Std. Error Mean	95% Confidence Interval of the Difference		t	df	Sig. (2-tailed)
					Lower	Upper			
Project 1	Early Phases (1–4)	−24.643	48.701	6.508	−37.685	−11.601	−3.787	55	0.000
	Entire Phases (1–9)	27.518	101.044	13.503	0.458	54.578	2.038	55	0.046
Project 2	Early Phases (1–4)	−91.291	107.797	14.535	−120.432	−62.149	−6.281	54	0.000
	Entire Phases (1–9)	113.527	185.087	24.957	63.491	163.563	4.549	54	0.000

Notes: Project 1 – eight bus stations. Project 2 – 3100-metre road the construction process (Tab. 3). However, the time savings identified vary depending on the project phase, which indicates the specific advantages of BIM in certain phases of project planning. These findings are consistent with the perceptions of the experts from the qualitative interviews, who emphasised the effectiveness of BIM in terms of time management in different project phases. The quantitative results emphasise the importance of using BIM for more efficient project planning and execution in the infrastructure sector.

5 DISCUSSION

The results of this paper contribute to the current literature on the productivity of engineering firms through the implementation of BIM. That the implementation of BIM leads to an increase in productivity in engineering firms is only partially consistent with the findings of previous publications. Similar to the present study, Succar et al. (2012) describes that BIM improves communication and collaboration, primarily through 3D models and other data that provide information about the entire life cycle of a building. This study found, through both expert interviews and quantitative data collection, that there are still challenges in integrating BIM into existing workflows and that investment in technology and training is required, a point also highlighted by Succar et al. (2012). He describes that staff training plays an essential role in effectively using BIM. In this study, however, it is clear that a change in working methods and corporate culture is required, especially for infrastructure measures. Thus, companies need to adapt their processes and structures to the new requirements to exploit BIM's benefits fully.

In line with the findings of Gerber et al. (2010) and Smith (2009), this paper can confirm that BIM contributes to improving productivity across the construction industry and can be used as a lean process to reduce waste and improve project quality, which is perceived as an added value by BIM users in the expert interviews as well as in the quantitative analysis. In the present study on current research, it becomes clear that engineering offices in infrastructure planning initially have high investment costs, which can be perceived as an obstacle and can act as a deterrent, especially for medium-sized and smaller engineering offices. Since Gerber have focused on the entire construction industry, the differences and details in the individual areas, such as the executing construction company, the engineering and architecture firms, and the other parties involved in the project, are not analyzed. Smith (2009), on the other hand, emphasizes the role of cost managers in implementing BIM, which can provide more certainty in implementing BIM.

This study also indicates that the improved productivity will change the competition for engineering firms. Experts report that companies that use BIM could be favoured by the methodology used, as the implementation of the BIM method also results in added value in terms of productivity for clients in the long term. Pan and Zhang (2020) describe a similar observation for construction companies. The use of BIM and the associated increases in productivity give them a competitive advantage. significant added value in terms of operating cost optimisation in the planning phase of infrastructure projects.

Barlish (2011) also concluded in case studies that applying BIM methodology leads to productivity improvements in engineering firms. The present study supports Barlish's conclusion that BIM can significantly reduce planning time. Some of the experts confirm the connection between the increase in productivity and the time saved with BIM in infrastructure planning, and this assumption is strengthened via quantitative analysis.

There is also a clear correlation between perceived added value and the resulting time savings. However, the study points out that this is only the case when BIM is used throughout the design process. Engineering firms only experience time savings if they are involved in all service phases, as the effort required to design with BIM in infrastructure planning increases, especially in the early service phases. This is illustrated by the number of hours spent on the different service phases in this study. The remodelling of eight bus stations saves around 27 hours for the entire project if the project is commissioned in its entirety. The remodelling of a 3.1 km long road results in a time saving of around 114 hours. However, if only the first service phases are commissioned, the time required for both projects is higher. Shin et al. (2022), who compared real projects in a study on the use of BIM in railway construction and examined railway lines between approximately 1.7 km and 5 km in length, came to a similar conclusion. The results of Shin et al. (2022) show a time saving of around 103.5 hours compared to the conventional planning method. However, the study only considers rail transport and distinguishes between the data from three companies in each case. In his study, Shin et al. (2022) also describes a correlation between the time saved and the reduced operating costs. The study presented here also indicates a significant correlation between operating costs and time savings.

The expert interviews conducted revealed some different views between consultants and planners regarding the use of BIM in infrastructure planning. This observation led to further statistical analysis. The results of the present study indicate that the perceptions of consultants and planners differ in terms of challenges, investment costs and time management when applying the BIM method in infrastructure planning. A similar finding regarding different perceptions depending on professional groups was also made in the study by Rahmawati et al. (2019). This study implies that there are different views between consultants and managers in the architecture sector regarding the success factors of BIM. However, it should be noted that the study by Rahmawati et al. focuses on the architecture sector and primarily examines the factors that contribute to the success of BIM.

In the study by Olawumi and Chan (2019), a model is developed for improving project information management through BIM, so Olawumi and Chan do not consider BIM as a tool for a planning measure of a building, but primarily the management of BIM information and data, which has a positive effect on project control and project management in particular. The study by Rahman et al. (2016) also looks at the implementation of BIM and the associated change in the skills of project and BIM managers. On the other hand, this paper primarily considers the user-related view of BIM, i.e., particularly those planners and consultants who directly apply the software and methodology and already plan the measure as a 3D BIM model.

While the adoption of BIM has revolutionized insights and decision-making capabilities throughout the lifecycle, it is primarily focused on providing concrete data and lacks the ability to update information in real time without external data sources (Deng et al., 2021; Tang et al., 2019). The emergence of Internet-of-Things (IoT) applications and their integration with BIM models have enabled the emergence of the concept of the digital twin (Deng et al., 2021; Tang et al., 2019). Digital twins strive to synchronize the real world with a virtual platform, enabling seamless management and control of construction processes, building management and environmental monitoring. This represents a significant advance over BIM, as digital twins incorporate real-time data that enables dynamic visualization, analysis and automatic updating of models based on the real-time status of structures. However, the state of research in the field of digital twins is still at an early stage. It requires a deeper understanding for ongoing and future research, especially in the advancement of BIM to Digital Twins (Deng et al., 2021).

Regarding the limitations of our research, there might be some restrictions in the sample size and geographical coverage. Our sample focused on engineering companies in German-speaking countries, and therefore, the results might not be transferable to other geographical areas or other sectors of the construction industry; this limits the generalisability of the results. In addition, our results were based on self-reports by engineering firms, software vendors, and training companies, which may lead to bias. Future researchers could encompass these issues by using a broader sample in German-speaking countries or beyond in several countries.

Conducting both a qualitative and a quantitative analysis offers a comprehensive approach. However, the sample size for the quantitative analysis is relatively small at 66 participants. This limitation was not only a reflection of the fact that the BIM method is not yet widely established and implemented in infrastructure planning and engineering firms but also due to practical constraints. Given the specific challenges in the adoption of BIM in infrastructure planning, it was neither feasible nor economically and timewise practical to reach a larger number of participants. Furthermore, some engineering firms that already use BIM in infrastructure planning are reluctant to share their knowledge in order to avoid increasing competition from other firms. Future research could therefore benefit from a broader sample in a European or international context.

In addition, future studies could investigate other aspects of BIM, such as its impact on collaboration and communication in construction projects or its influence on the environmental performance of buildings or infrastructure structures. As the use of BIM in infrastructure is still relatively new, there is significant potential for further research in this area. Further studies could also examine the long-term impact of BIM on productivity and efficiency in engineering firms and broaden the comparison with other industries. In particular, it could explore how BIM and other digital tools can contribute to improving sustainability and resilience in the construction industry. Finally, future research could also explore the development of best practices and guidelines for implementing and using BIM in different contexts to help companies realize the full potential of this technology. It would also be of interest to repeat this study at a later date when the BIM method has found wider application in infrastructure planning.

Further studies could also examine the long-term impact of BIM on productivity and efficiency in engineering firms and broaden the comparison with other industries. In particular, how BIM and other digital tools can contribute to improving sustainability and resilience in the construction industry could be investigated. Finally, future research could also explore the development of best practices and guidelines for the implementation and use of BIM in different contexts to help organisations realise the full potential of this technology.

6 CONCLUSIONS

The demand for digitalization, especially for BIM, is increasing in the infrastructure sector. However, small engineering firms, in particular, are shying away from the costs, training, and restructuring within the company, which can lead to small engineering firms being displaced by giant engineering firms. In addition, integrating the BIM method in the companies leads to a change in the fields of activity within the engineering offices. The demand for the profession of drafters, who in particular created 2D plans and supported engineers, may decline. To prevent this, it is essential that the training of drafters is adapted to the ongoing digitalization in the construction industry. In principle, the engineers' experience reports, in particular, agree that productivity increases across the entire BIM project but that the time invested in modeling the individual structures is higher than in conventional planning. To optimize productivity, according to the experts' statements, it makes sense to define requirements regarding planning with the client before starting the measure and to clarify the possibilities of the software systems and the methodology. To avoid the 3D models are not accepted by the client, it is necessary to define the level of detail of the digitized models before the start of planning. In this way, repeated re-planning into conventional 2D plans can be avoided, which requires renewed effort. In addition, flexibility in methodology can have a positive impact on productivity. Certain representations can be shown more quickly via a sketch in 2D without the need for detailed clarification in 3D. This can result in further time savings by eliminating the need for additional modeling. Modeling can then take place after the client has approved the sketch. In this way, the BIM method can be used in a targeted manner and according to the situation. In principle, it can be said that BIM can optimize productivity under certain conditions. Since the 19 expert interviews are individual opinions, it is necessary to analyze productivity and cost-effectiveness via qualitative surveys and profitability calculations and to compare them with conventional planning methods. By combining individual perspectives from the 19 expert interviews with the findings from the quantitative analysis, it becomes clear that BIM in infrastructure planning has both productivity-enhancing and cost-intensive aspects, and further research is needed to enable a balanced assessment of the overall cost-effectiveness compared to conventional planning methods.

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