**Benefits of Building Information Modeling in Road Projects for Cost Overrun Factors Mitigation**

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## ABSTRACT

Road projects around the world are widely affected by the cost overrun phenomenon. BIM can greatly contribute to the cost overrun mitigation; however, the BIM adoption in road projects is limited in comparison with building projects. Besides, studies focused on analyzing the impact of BIM on mitigating cost overruns in road projects are lacking. Therefore, this study presents a review of road projects with BIM implementation, in which the BIM benefits that can contribute to the cost overrun mitigation are analyzed. The research method is composed of the following stages: (1) a systematic review is performed; (2) relevant studies are chosen based on inclusion/exclusion criteria; (3) qualitative evidence is categorized; (4) qualitative evidence is analyzed with a set of experts; and (5) contributions are summarized. A total of 21 road projects were studied, in which a set of BIM implementation benefits were identified. Thus, the interactions between BIM benefits and the main cost overruns causative factors were analyzed through a professional workshop. The findings indicate that the BIM implementation in road projects contributes to the mitigation of cost overruns factors, such as: inadequate project planning, design changes, failures in design, project scope changes, late decision making by owner, and others.

## INTRODUCTION

Road infrastructure projects play a crucial role in the socio-economic development of the countries. Despite their importance, road projects in both developed and developing countries are widely affected by cost deviations, a phenomenon that emerges when the final cost differs from the planned cost (Herrera. Sánchez. Castañeda. & Porras. 2020). Due to their characteristics, road projects involve significant financial investments, therefore, developing projects within the planned cost is crucial to guarantee the continuity of the processes; however, the complexity and uncertainty associated with the life cycle stages of road infrastructure projects favor the occurrence of cost deviations, which are classified as cost overruns when the final cost exceeds the planned cost. For this, cost overruns can seriously affect the countries or region's economies, considering that the role of owner in most road projects is performed by government agencies, which depend on public resources. In the event of the cost overrun occurrence, the agencies must make significant efforts to manage the availability of unforeseen financial resources (Catalão, Cruz, & Sarmento, 2019).

The serious effects of cost overruns in road projects have led several researchers and industry professionals to make efforts to characterize and quantify cost deviations, in order to create technological and methodological solutions that promote the mitigation of the cost overruns factors. Despite the efforts made, the results of various studies show that the cost overrun continues to affect road projects. For instance, Love, Sing, Carey, & Kim (2014) studied the presence of cost overruns in 49 Australian road infrastructure projects, where they found an average cost overrun of 13.5%. Bordat, McCullouch, Labi, & Sinha (2004) analyzed 2,668 road infrastructure projects located in the United States, in which 55% presented cost overruns. Rwakarehe & Mfinanga (2014) studied 7 road infrastructure projects in Tanzania, in which they showed an average cost overrun of 44%. Cantarelli, Van Wee, Molin, & Flyvbjerg (2012) analyzed 37 Dutch road infrastructure projects, in which they evidenced cost overruns in 62.2% of the projects with an average value of 18.6%. The findings so far have shown that cost overruns in road projects are caused by various factors; some of the most important are: failures in design, price variation of materials, inadequate project planning, project scope changes, and design changes, among others (Herrera et al., 2020).

The recurrence of cost overruns in road projects generates the need to propose, develop, and implement new approaches that promote the cost overrun factors mitigation. In construction projects, one of the approaches with great potential to mitigate cost overruns is the Building Information Modeling (BIM) methodology, which has improved various issues in the life cycle of construction projects (Chan. Olawumi. & Ho. 2019). BIM can be assumed as a digital representation of the physical and functional characteristics of a project, in which the information is stored, managed, and shared in a digital database (Eastman, Liston, Sacks, & Liston, 2008). The adoption of BIM produces benefits such as: improvement of project quality, better understanding of design, use of life cycle data, reduction of construction costs, optimization of construction planning and monitoring, efficient communications, and scope clarification, among others (Chan. Olawumi. & Ho. 2019). Despite the broad BIM benefits and the potential to improve various issues in road projects, BIM adoption in road infrastructure projects is limited, compared to its adoption in building projects (Costin. Adibfar. Hu. & Chen. 2018).

The benefits generated by BIM implementation can contribute significantly to the cost overruns factors mitigation in road projects. Due to the emerging nature of BIM in road infrastructure, there is a knowledge gap on analyzing the interrelationship between BIM benefits and cost overrun factors. Therefore, this study aims to study the influence of BIM benefits in mitigating cost overrun factors that affect road projects.

## BENEFITS OF BIM IMPLEMENTATION

The identification of the benefits of implementing BIM in road infrastructure projects was carried out through a systematic review methodology composed of five main stages: 1) question formulation; 2) searching of relevant studies; 3) document selection; 4) evidence collection, analysis, and synthesis; and 5) results' report. This methodology is an adaptation of the one presented by Costin et al. (2018). The search for documents was carried out from Scopus and Web of Science databases; this was complemented with a validation process in other databases: American Society of Civil Engineers (ASCE), Taylor and Francis Group, ELSEVIER, Emerald Insight, and Springer. A total of 653 documents were collected, which were reviewed and classified based on four inclusion/exclusion criteria: 1) the document focused on BIM; 2) the type of project: road, highway or motorway; 3) the document reports a case study with BIM implementation; and 4) the case study reports benefits of BIM implementation. Through a review of the documents that met the four inclusion/exclusion criteria, 21 road projects with BIM implementation were identified (see Table 1).

**Table 1. Road projects with BIM implementation**

| Code | Reference | Project | Project stage | Location |
|---|---|---|---|---|
| $C_1$ | (O'Brien, Gau, Schmeits, Goyat, & Khwaja, 2012) | President George Bush Turnpike and I30 Interchange | Design | United States |
| $C_2$ | (Mawlana, Vahdatikhaki, Doriani, & Hammad, 2015) | Turco interchange reconstruction | Design | Canada |
| $C_3$ | (Chong, Lopez, Wang, Wang, & Zhao, 2016) | 500 m of road construction with four lanes in each direction | Design, Construction | China |
| $C_4$ | (Chong et al., 2016) | 4.2 km of road expansion from four to six lanes | Design, Construction | Australia |
| $C_5$ | (Borrmann, Hochmuth, König, Liebich, & Singer, 2016) | New four-lane roadway | Design | Germany |
| $C_6$ | (Borrmann et al., 2016) | 264 m of A19 highway | Design, Construction | Germany |
| $C_7$ | (Z. Aziz, Riaz, & Arslan, 2017) | The A56 project: 4.5 miles road dual carriageway | Design, Construction, Operation | England |
| $C_8$ | (Tezel & Aziz, 2017) | Motorway construction and seven overpass bridges | Design | England |
| $C_9$ | (Tezel & Aziz, 2017) | Three lane motorway construction | Design, Construction | England |
| $C_{10}$ | (Kumar, Cai, & Hastak, 2017) | 12 km dual three-lane motorway | Design | Scotland |
| $C_{11}$ | (Tolmer, Castaing, Diab, & Morand, 2017) | 10 km of L2 urban highway | Design | France |
| $C_{12}$ | (Vitásek & Matějka, 2017) | 5 km of D4 (Shalka) motorway | Construction | Czech Republic |
| $C_{13}$ | (Vitásek & Matějka, 2017) | 14 km of D1 (Přerov – Lipník nad Bečvou) motorway | Construction | Czech Republic |
| $C_{14}$ | (Džumhur, Ljevo, & Marić, 2018) | 1.5 km of the Kiseljak bypass road | Design | Bosnia and Herzegovina |
| $C_{15}$ | (Kohlböck, Griesser, Hillisch, Birgmann, & Fasching, 2018) | 21 km long section between Köstendorf and Salzburg | Design | Austria |
| $C_{16}$ | (Akob, Abang, & Abd, 2019) | 1060 km of Pan Borneo Highway Sarawak construction | Design, Construction | Malaysia |
| $C_{17}$ | (Zhao, Liu, & Mbachu, 2019) | 283 km of highway in Guizhou | Design | China |
| $C_{18}$ | (Biancardo, Capano, Guerra de Oliveira, & Tibaut, 2020) | Section design of an Italian road project | Design | Italy |
| $C_{19}$ | (Biancardo, Viscione, Cerbone, & Dessì, 2020) | 1.5 km of road connections in Naples Harbor | Design | Italy |
| $C_{20}$ | (Lee, Kim, Tanoli, & Seo, 2020) | 603 km of road corridor in the Republic of Korea | Design | Korea |
| $C_{21}$ | (Zhang, Zhao, Li, Huijser, & Skitmore, 2020) | 10,9 km of road design | Design | China |

Among the projects reported with BIM implementation, 61.9% are located in Europe (13 projects), 23.8% in Asia (15 projects), 9.5% in North America (2 projects), and a single project in Oceania. Regarding the projects stage with BIM implementation, 90.5% of the projects implement BIM in the design stage (18 projects), 38.1% in the construction stage (7 projects), and a single project in the operation stage. The identification of the benefits of implementing BIM in the analyzed road projects was carried out through an exhaustive review of the selected documents; some of the benefits reported by Chan et al. (2019) were adapted, as well as other benefits identified in the literature review. Thus, a total of 20 BIM benefits were identified, among which the five most frequently reported benefits are: 1) improvement in road design ($B_1$); 2) reduction of design errors ($B_2$); 3) obtaining accurate, integrated, and detailed information ($B_3$); 4) better visualization of project data and environment ($B_4$); and 5) better coordination and collaboration among stakeholders ($B_5$) (see Table 2). These benefits show the notable improvements that BIM can generate in the development of the design and planning activities of road projects, stages in which it is possible to identify, manage, and solve various issues that in later stages of the project can generate favorable situations for the cost overrun emergence.

**Table 2. Main benefits of BIM implementation in road projects**

| Id | Benefit of BIM implementation | Project code | % Frequency (n=21) |
|---|---|---|---|
| $B_1$ | Improvement in road design | $C_3$, $C_4$, $C_7$, $C_{10}$, $C_{11}$, $C_{14}$, $C_{15}$, $C_{16}$, $C_{17}$, $C_{18}$, $C_{19}$, $C_{20}$, $C_{21}$ | 61.9% |
| $B_2$ | Reduction of design errors | $C_1$, $C_2$, $C_3$, $C_4$, $C_6$, $C_7$, $C_{10}$, $C_{14}$, $C_{15}$, $C_{16}$, $C_{19}$, $C_{20}$, $C_{21}$ | 61.9% |
| $B_3$ | Obtaining accurate, integrated, and detailed information | $C_3$, $C_4$, $C_5$, $C_{10}$, $C_{14}$, $C_{15}$, $C_{16}$, $C_{17}$, $C_{18}$, $C_{19}$, $C_{20}$, $C_{21}$ | 57.1% |
| $B_4$ | Better visualization of project data and environment | $C_2$, $C_3$, $C_4$, $C_6$, $C_{10}$, $C_{14}$, $C_{15}$, $C_{16}$, $C_{18}$, $C_{19}$, $C_{21}$ | 52.4% |
| $B_5$ | Better coordination and collaboration among stakeholders | $C_1$, $C_3$, $C_4$, $C_5$, $C_{10}$, $C_{14}$, $C_{15}$, $C_{16}$, $C_{19}$, $C_{21}$ | 47.6% |
| $B_6$ | Better project planning | $C_1$, $C_2$, $C_3$, $C_4$, $C_5$, $C_7$, $C_{10}$, $C_{15,}$ $C_{19}$ | 42.9% |
| $B_7$ | Improvement in the analysis and selection of alternatives | $C_2$, C4, $C_{14}$, $C_{16}$, $C_{17}$, $C_{18}$, $C_{19}$, $C_{20}$ | 38.1% |
| $B_8$ | Better communication among stakeholders | C5, $C_{14}$, $C_{15}$, $C_{16}$, $C_{21}$ | 23.8% |
| $B_9$ | Improvements in decision-making processes | $C_{15}$, $C_{16}$, $C_{17}$, $C_{20}$, $C_{21}$ | 23.8% |
| $B_{10}$ | Project time reduction | $C_3$, $C_4$, $C_{12}$, $C_{10}$, $C_{16}$ | 23.8% |
| $B_{11}$ | Improvement in road safety | $C_7$, $C_{18}$, $C_{19}$ | 14.3% |
| $B_{12}$ | Improvement in construction control and monitoring | $C_3$, $C_7$, $C_{16}$ | 14.3% |
| $B_{13}$ | Project cost reduction | $C_2$, $C_3$, $C_4$ | 14.3% |
| $B_{14}$ | Increased productivity during the project life cycle | $C_{14}$, $C_{21}$ | 9.5% |
| $B_{15}$ | Support in waste reduction | $C_{10}$, $C_{14}$ | 9.5% |
| $B_{16}$ | Better project understanding | $C_4$, $C_{21}$ | 9.5% |
| $B_{17}$ | Improvement in risk management and prevention | $C_5$ | 4.8% |
| $B_{18}$ | Improvement in the land acquisition management | $C_1$ | 4.8% |
| $B_{19}$ | Reduction of claims and disputes among stakeholders | $C_{10}$ | 4.8% |
| $B_{20}$ | Improvement of traffic control plans | $C_4$ | 4.8% |

## INFLUENCE OF BIM BENEFITS IN MITIGATING COST OVERRUNS

The analysis of the BIM benefits influence in mitigating the main cost overruns causative factors in road projects was based on: 1) the top-ten of the BIM benefits reported more frequently in the analyzed road projects (see Tables 1 and 2); and 2) the top-ten of the main cost overruns causative factors reported by Herrera et al. (2020), who applied a systematic review methodology focused on identifying the cost overruns factors in road projects from a sample of 450 scientific documents. To quantify the BIM benefits influence in mitigating cost overruns, a focus group was carried out with a group of 10 professionals with more than 15 years of experience in the development of road infrastructure projects, and knowledge of the BIM methodology (Bhandari & Hallowell, 2021). Among the professionals, 2 with a B.Sc. Civil Engineering degree, five with a M.Sc. Civil Engineering degree, two in the process of doctoral training, and one with a Ph.D. degree (the three of them in the field of civil engineering too).

The focus group started with an oral presentation on the main characteristics of both the BIM benefits and the selected cost overrun factors. Then, the professionals were asked to evaluate the level of influence of each of the BIM benefits in the mitigation of each of the cost overrun factors; therefore, each professional carried out a total of 100 evaluations, this considering a matrix of 10 rows (cost overrun factors) and 10 columns (BIM benefits). The influence evaluation was carried out from a five-point Likert Scale, where: very low influence = 1, low influence = 2, medium influence = 3, high influence = 4, and very high influence = 5. For the level of influence quantification, an adaptation of the indices used by Amoatey et al. (2015) and Aziz and Abdel-Hakam (2016) was made. Therefore, the Relative Influence Index ($RII$) was used, which was calculated by Equation 1.

$$RII = \frac{\sum W_{influence}}{W_{max} \times N} \tag{1}$$

where: $W_{influence}$ is the assigned weight of the influence level of the BIM benefit in mitigating the cost overrun factors, according to the defined Likert Scale; $W_{max}$ is the maximum weight of the assigned influence level ($W_{max} = 5$); $N$ is the total number of professionals consulted ($N = 10$).

Table 3 shows the results obtained for each of the 100 relative influence indices evaluated. The findings of the influence analysis of the BIM benefits on the mitigation of cost overruns in road projects show that BIM can contribute significantly to the mitigation of some factors: 1) inadequate project planning ($F_3$), 2) design changes ($F_5$), 3) failures in design ($F_1$), 4) project scope changes ($F_4$), and 5) late decision making by owner ($F_9$), and others. These factors originate during the early stages of road projects. In accordance with what is proposed by Sacks, Koskela, Bhargav, & Owen (2010), BIM functionalities such as: visualization of form, rapid generation of design alternatives, automated generation of drawings and documents, collaboration in design and construction, and rapid generation and evaluation of multiple construction plan alternatives, it can lead to the early identification and adjustment of different project issues that can aggravate and generate cost deviations. For the mitigation of other factors, the integration of BIM with other methodological approaches can be very useful. There are several studies that mention that the use of BIM in conjunction with the Lean philosophy can generate greater benefits to projects (Herrera, Mourgues, Alarcón, & Pellicer, 2021; Sacks, Dave, Koskela, & Owen, 2009; Sacks et al., 2010).

**Table 3. Relationships between cost overruns factors and BIM benefits**

| Id | Cost overrun factors | Benefits of BIM in road projects | | | | | | | | | | Total score | Rank |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Improvement in road design | Reduction of design errors | Obtaining accurate, Integrated, and detailed information | Better visualization of project data and environment | Better coordination and collaboration among stakeholders | Better project planning | Improvement in the analysis and selection of alternatives | Better communication among stakeholders | Improvements in decision-making processes | Project time reduction | | |
| | | $B_1$ | $B_2$ | $B_3$ | $B_4$ | $B_5$ | $B_6$ | $B_7$ | $B_8$ | $B_9$ | $B_{10}$ | | |
| $F_1$ | Failures in design | 0.92 | 1.00 | 1.00 | 0.88 | 0.96 | 0.84 | 0.92 | 0.94 | 0.88 | 0.56 | **8.90** | **3** |
| $F_2$ | Price variation of materials | 0.30 | 0.24 | 0.26 | 0.20 | 0.38 | 0.36 | 0.34 | 0.20 | 0.36 | 0.50 | **3.14** | **8** |
| $F_3$ | Inadequate project planning | 0.88 | 0.90 | 1.00 | 0.94 | 0.98 | 1.00 | 1.00 | 0.98 | 1.00 | 0.70 | **9.38** | **1** |
| $F_4$ | Project scope changes | 0.84 | 0.82 | 0.94 | 0.88 | 0.96 | 0.94 | 0.96 | 0.96 | 0.94 | 0.64 | **8.88** | **4** |
| $F_5$ | Design changes | 0.96 | 0.96 | 1.00 | 0.88 | 0.98 | 0.88 | 0.96 | 0.98 | 0.96 | 0.52 | **9.08** | **2** |
| $F_6$ | Unrealistic contract duration | 0.36 | 0.40 | 0.62 | 0.58 | 0.72 | 0.72 | 0.36 | 0.66 | 0.62 | 0.66 | **5.70** | **6** |
| $F_7$ | Inadequate bidding method | 0.20 | 0.22 | 0.40 | 0.24 | 0.34 | 0.36 | 0.26 | 0.24 | 0.40 | 0.26 | **2.92** | **9** |
| $F_8$ | Legal issues | 0.50 | 0.22 | 0.50 | 0.26 | 0.56 | 0.26 | 0.22 | 0.54 | 0.52 | 0.42 | **4.00** | **7** |
| $F_9$ | Late decision making by owner | 0.66 | 0.62 | 0.90 | 0.92 | 1.00 | 0.76 | 0.92 | 1.00 | 0.94 | 0.70 | **8.42** | **5** |
| $F_{10}$ | Political situation | 0.20 | 0.20 | 0.20 | 0.20 | 0.24 | 0.22 | 0.20 | 0.28 | 0.30 | 0.20 | **2.24** | **10** |
| | **Total score** | **5.82** | **5.58** | **6.82** | **5.98** | **7.12** | **6.34** | **6.14** | **6.78** | **6.92** | **5.16** | **62.66** | |
| | **Rank** | **8** | **9** | **3** | **7** | **1** | **5** | **6** | **4** | **2** | **10** | | |

Particularly the cost overrun factors where BIM has a lower relative influence (see Table 3) can be solved in some way through the application of practices, tools and a culture aligned with Lean philosophy. The political situation ($F_{10}$) of the countries is affected by corruption in public administration, particularly corruption in construction projects has been studied in depth (A. Chan & Owusu, 2017; Shan, Chan, Le, Xia, & Hu, 2015). Lean has been applied in the public sector for several years, there is an annual conference called "Lean in the public sector"; additionally, there are studies where lean philosophy has been applied as a good practice to prevent corruption (Daramsis, Faour, Ahad, Salami, & Hamzeh, 2018; Rizk, Sobh, Yassin, & Hamzeh, 2018).

The factors inadequate bidding method ($F_7$), price variation of materials ($F_2$), and legal issues ($F_8$) can be addressed through procurement systems different from the traditional design-bid-build (Kulkarni, Rybkowski, & Smith, 2012). The use of relational contracts and the application of Integrated Project Delivery allows for a stronger relationship (Hickethier, Tommelein, & Lostuvali, 2013), with clear rules and protocols for conflict resolution, greater transparency of information, and a relationship where the risks and benefits of the project are shared between the client and the different contractors (Mesa, Molenaar, & Alarcón, 2019).

## CONCLUSION

The influence analysis of the BIM benefits in mitigating the cost overrun factors shows that BIM has a high potential to contribute to the cost deviation mitigation in road projects. The BIM implementation contributes to the improvement of different processes and project deliverables, which has a positive impact on the analysis and forecast of different variables that direct the cost development in the life cycle stages of a road project. This contributes to reducing the uncertainty associated with the occurrence of cost deviations, which can be achieved by anticipating, preventing, and managing unwanted events during the early stages of projects, a process in which BIM characteristics are ideal to support the decision-making processes. Therefore, it is crucial for organizations to undertake actions focused on BIM implementation processes that lead to obtaining various benefits. The findings of this study show that the five BIM benefits with the greatest influence on mitigating cost overruns are: 1) better coordination and collaboration among stakeholders ($B_5$); 2) improvements in decision-making processes ($B_9$); 3) obtaining accurate, integrated, and detailed information ($B_3$); 4) better communication among stakeholders ($B_8$); and 5) better project planning ($B_6$).

The results of this study show that the BIM implementation in road projects makes it possible to mitigate various cost overrun factors. According to the criteria of the professionals consulted, the five cost overrun factors, which are most influenced by the BIM implementation are: 1) inadequate project planning ($F_3$); 2) design changes ($F_5$); 3) failures in design ($F_1$); 4) project scope changes ($F_4$); and 5) late decision making by owner ($F_9$). Results that make it possible to infer the broad benefits that can be achieved through BIM implementation in the early stages of projects, which is related to the characteristics of BIM workflows that lead to significant improvements in design and planning activities, improvements related to the functionalities of management and visualization of the large volume of information that is captured, processed, stored, integrated, and produced during the development of the early stages of a road project, functionalities that contribute to the improvement of decision-making processes.

Although the BIM implementation in road projects has the potential to improve various existing problems, it is observed that the BIM implementation in road infrastructure is limited compared to the BIM implementation in building projects, therefore, the topic of BIM in road infrastructure projects can be considered an emerging topic in scientific research. The findings of the systematic review, of BIM benefits in road projects, show that the five most frequently reported benefits are: 1) improvement in road design ($B_1$); 2) reduction of design errors ($B_2$); 3) obtaining accurate, integrated, and detailed information ($B_3$); 4) better visualization of project data and environment ($B_4$); and 5) better coordination and collaboration among stakeholders ($B_5$).

Limitations of this study are: 1) the focus group approach that allow only a limited number of professionals, which is also related to the emerging nature of the research topic addressed and the limitations related to the Covid-19 pandemic; 2) the low number of BIM benefit and cost overrun factors selected for analysis; and 3) the moderate number of road projects reported in the literature with BIM implementation. Future studies may be focused on quantifying and characterizing in detail the impact of BIM benefits in mitigating cost deviations from road projects.

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