An Interactive Decision-Support Tool to Improve Construction Cost Management with Building Information Modeling

Nicolas Strange, Daniel Forgues, and Conrad Boton

Abstract Cost overruns in construction projects are currently one of the biggest problems in the industry. Factors causing these cost overruns have been identified in order to improve current management practices. Building Information Modeling (BIM), and in particular the fifth dimension relating to cost management (5D BIM), offers techniques and processes to improve the quality, performance, and efficiency of projects. Current BIM 5D practices are evolving and many software programs are being developed in this direction. However, due to the multiplicity of the proposed solutions and the wide range of the possibilities and associated functionalities, it is challenging for the practitioners to select the right tool adapted to their particular requirements. Previous research works have attempt to solve the issue by proposing some comparison of the existing 5D BIM tools. While very interesting, such comparisons are not sufficient since they do not provide the user with the level of interactivity necessary to adapt the choice to their particular business context. The research project presented in this paper proposes an interactive decision-support tool for the effective choice of 5D BIM solutions. The proposed tool is based on the characteristics and functions of the existing software and uses a personalized weighting by the user for each of the identified cost management requirements. Thus, the proposed tool makes it possible to inform users about 5D BIM software according to their specific requirements and to provide them with informed software selections. The results were evaluated and validated by experts in construction cost management.

Keywords Building information modeling · Cost management · 5D BIM · Interactive decision support

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1 Introduction

Cost overruns are among the main challenges observed in construction projects and the construction industry is constantly evolving in technology in an attempt to improve cost management, reduce cost overruns, save time in running estimates, and better control costs. Many studies have been dedicated to identifying the problems facing the overall cost management of projects [9, 12] and the Project Management Institute has established a breakdown of cost management into different activities with the aim of facilitating the resolution of cost overruns, as follows: cost management planning, cost estimation, budget determination, cost control, life cycle cost analysis, and claim management [19, 30].

In recent years, advances in Building Information Modeling (BIM) have made it possible to considerably improve these different aspects based on digital models [31]. The BIM-based cost management practices are generally referred to as 5D BIM. The advantages of the 5D BIM are numerous and well documented in the scientific literature [26, 29], and many technological solutions are commercially available in the industry. However, due to the fragmentation of the practices in the industry and the specificities of the existing software, it is very challenging for the practitioners to select the right software adapted to their particular needs and context. While some recent research works have proposed a comparison of existing solutions [37], these tools are constantly evolving and such a comparison needs to be constantly updated. Moreover, the most recent comparisons lack the interactive aspect, necessary to allow each user to adapt the comparison criterion to his particular needs.

The research work presented in this article aims at proposing an interactive decision-support tool in the selection of 5D BIM software for variable business contexts. This tool aims to help estimators in selecting the BIM 5D software that best suit their practices and needs, in order to improve their cost management. The article is organized into four main sections. Section 2 proposes a literature review, including research works related to the use of 5D BIM for construction cost management, the challenges related to its application, and the need for a decision-support tool. Section 3 presents the methodology, encompassing the steps of the development and the validation of the proposed tool. Section 4 presents the structure of the tool, its operation, and the results of the validation process. Section 5 concludes the work, including its limitations and identifies the future work.

2 Related Works

2.1 Cost Management in the Construction Industry

Cost management is defined as “the cost estimation of all activities and effort necessary to deliver the project” [16]. However, cost management encompasses much more, including the “application of management accounting concepts, methods of

data collection, analysis and presentation in order to provide the information needed to plan, monitor and control costs" [36]. Thanks to the work in three studies [4, 30, 32], it is possible to categorize the activities of cost management in construction into cost estimation, cost budgeting, cost control, life cycle cost analysis, and claims.

Cost estimation can be described as "a process that allows stakeholders to determine monetary resources required for a project's completion" [37]. The budget determination process basically consists of a summation of the activities and work packages' cost estimates executed earlier [37]. It can be done either "once, early in a project's life-cycle, or multiple times at predetermined milestones and serve as the baseline against which the project's performance can be controlled" [30]. The critical aspect of cost control is the analysis of the consumption of project funds in relation to the actual work being accomplished with the aim of maintaining the baseline previously established throughout the whole duration of a project [30]. Life cycle costs' analysis evaluates the costs involved in a project, from the early stages till the end of the life of the project [7, 38]. It is usually performed early in a project's life cycle [13] in order to help in evaluating the investment options and easing the choice of design criterion [38]. Construction claims refer to the claims resulting from changes in the scope of the works, delays and productivity factors, or deficient contract documents [23].

2.2 Uses of 5D BIM for Cost Management

5D BIM offers the possibility of linking cost information with digital models to enable better cost management [22, 33, 37]. 5D BIM models have great potential since they have the ability to contain elements, or assemblies of objects, with associated costs directly through the BIM software, or through an internal or external database [34]. Mitchell [28] argues that the objectives of 5D BIM for design and construction are to provide a transparent framework in order to make the best decisions, in terms of quality, especially in terms of quantity extraction, tendering, variation evaluation, change orders, and progress payments [26, 28, 32]. Thus, 5D BIM is a project visualization and monitoring tool, allowing stakeholders to control, in a collaborative environment, the flow of information, to effectively manage planning and estimation aspects by improving and facilitating control of costs and planning [1, 34].

Cost planning is the basis of overall cost management in a construction project [28]. The quantity extractions, retrieved from 3D models, assembled with the corresponding cost information make it possible to target the available budget on the most important characteristics of the building design [28]. In addition, Stanley and Thurnell show through a study that cost planning, with the quantities extracted using 3D BIM modeling software, is easier and faster than when carried out by estimators from 2D plans [34].

Quantification based on digital models becomes more and more automated as the models develop [32]. Thus, the extraction of quantities makes it possible to improve the good management of projects, in particular on the production of estimates, cost planning, measurements, preparation of bills of materials and tender documents, and finally cost control and proper preparation of evaluations and payments [2, 26, 34]. The study presented by Stanley and Thurnell shows the importance of precise quantities' takeoff based on 5D BIM in making budget estimates [34].

Estimating costs is a very important part of project decision-making. By extracting quantities from digital models, 5D BIM software can produce project cost estimates with varying degrees of precision [22, 37]. 5D BIM enables to quickly create more accurate cost estimates and to explore different project options before and during construction based on variations that are likely to occur. It also helps to identify factors that have different advantages or options in order to select the most interesting proposals [34].

Performing cost monitoring and control allows project cash flow to be forecast more quickly and accurately than at the start of the project life cycle [20, 37]. Thanks to 5D BIM technologies, it is possible to establish a cost at a given point in the project, by isolating the elements completed on the model and using the associated cost information. Thus, it is possible to compare the current calculated budget with that initially planned.

Life cycle costs can be defined as the sum of the present value of all expected costs from the construction phase to the end of the life of the facility [7]. A more recent research presented the development of a solution of life cycle cost analysis (LCCA) using 5D BIM by adding a life cycle cost calculation model structure to an innovative 5D BIM model associated with a spreadsheet file [18]. The main benefit of this process is that it links cost planning, quantity extraction, and life cycle cost calculations in an integrated environment [18]. However, while some 5D BIM software, specific to quantity extraction, provides appropriate costs for performing an LCCA [17], some authors claim that the BIM-based tools and technologies do not yet have the necessary capacities to adapt to the conditions of an effective LCCA [10, 35].

The capabilities of BIM allow the management and the pricing of construction claims, while reducing the number of claims issued during a project [37]. In addition, 5D BIM offers new technological opportunities for document management and visualization [14]. A study by El Hawary and Nassar shows that the use of new BIM technologies has a very positive effect on the reduction of claims in construction projects [15]. New working methods have been devised to find all flaws in logic and planning activities that will not be respected, based on the combination of a claims matrix and a 5D BIM model [25].

2.3 The Need for a Decision-Support Tool for the 5D BIM Software Selection

The scientific literature shows that there are many challenges to implementing 5D BIM in the construction industry, primarily regarding the details of the design, standardization, and skills required [26]. BIM induces significant changes in the management and the delivery of construction project [5], and its implementation of BIM within companies is also a challenge due to the associated training load from the start, the investment, and the time required to assimilate new processes [35]. In addition, the high costs of this investment are a hindrance, especially if the company plans to use it only for extracting quantities [35].

It is important to note that all trades do not use BIM the same way. Architecture firms are among the most active stakeholders when it comes to BIM adoption [27]. A study presented by Ding et al. [8] shows that motivation plays an important role in BIM adoption by architects and the implications of BIM in the architecture design process have been thoroughly discussed by Marcos [24]. Beyond the design itself, however, architects "may add as much data as any element within the entire architectural fabric could need to be thoroughly defined, properly speaking, the model is a three-dimensional data model (3DD model" [24]. The model created can then be used for further uses, including estimating and managing costs (5D). Unlike architects who merely use BIM authoring tools, contractors tend to "utilize a broader range of BIM solutions" [3]. A challenging issue regarding contractors' BIM needs is related to implementing both "preconstruction BIM" and "site BIM". In their study on the strategies for managing 5D BIM adoption, Chan et al. [6] explored, through a case study, contractors' perspectives regarding the adoption of 5D BIM. The results suggest that contractors have a passive and conservative attitude, with a relatively low openness to change, as it appears to be difficult for them to perceive the possible benefits [6]. Based on various studies, it can be reasonably argued that contractors have a passive and conservative attitude [6] and they prefer to outsource the 3D modeling task, but prefer to keep BIM-based cost management activities in-house [3], Fountain and [11, 21].

Anyway, whether architect or contractors, due to the multiplicity of the proposed solutions and the wide range of the possibilities and associated functionalities, it is challenging for the practitioners to select the right tool adapted to their particular requirements. Previous research works have attempted to solve the issue by proposing some comparison of the existing 5D BIM tools. The most advanced work on the subject is proposed by [37] who proposed a neutral framework to help practitioners in choosing the appropriate 5D BIM solutions. The proposed framework is particularly and is an important milestone toward the resolution of the issue. Unfortunately, the proposed framework did not come in the form of an interactive tool and did not provide the practitioners with the capability of weighting the criterion according to their specific context and needs. In addition, the proposal does not include a

more visual graph, which is very useful for synthesizing the results and making them more accessible to practitioners. Thus, there is still the need for an interactive decision-support tool in the selection of 5D BIM software for variable business contexts.

3 Research Methodology

The work proposed in this project is a continuation of the projects already carried out on the development of a tool to support 5D BIM software selection decision. Vigneault et al. [37] carried out part of his research work on the representation of a table summarizing the main criteria useful for managing the costs of a construction project, as well as a list of 5D BIM software currently available on the market. This information has served as the starting point for our methodological approach. First, the software list and the criteria have been updated. Then, the decision-support tool has been developed and evaluated with practitioners from the industry.

3.1 Updating the Software List and the Criteria

The software selected deals with cost management for all phases of a construction project, such as design, construction, layout, and management. The objective is to identify all the specifics and characteristics of these new technologies, in order to derive full descriptions.

The list of criteria is based on scientific literature, including the Project Management Book of Knowledge (PMBoK), the Royal Institute of Chartered Surveyors, and the Australian Cost Management Manual, to classify the criteria according to five cost management categories: cost management planning (criteria for sharing information and management tools), cost estimation (criteria for assessing the quality of models, information extraction capacities, and interoperability), budget analysis (criteria for budget comparisons, budget visualization, and Business Intelligence), cost control (cash flow, monitoring of cost trends, and Business Intelligence), as well as complaints and pricing management (criteria related to modifications, changes, payment requests). These categories are then structured into several sub-categories, then into criteria.

3.2 Development of the Decision-Support Tool

The research was conducted in such a way that the board evolves and becomes interactive for users. This tool was produced on an Excel file, so that it is possible to include intelligent calculation formulations. The tool is built iteratively, so that all

users can use it freely, while getting the desired information about these 5D software. The interactivity of the tool is measured thanks to the weighting system put in place, allowing the user to judge the criteria and thus have results that are specific to him. Its development within an Excel-type document offers an iterative and re-executable aspect of all parts of the tool.

3.3 Evaluation of the Developed Tool

Some experts in the field of cost management in the construction industry were contacted, such as a chief estimator, director of estimation, and BIM coordinator and manager. The goal is to have a broad horizon of trades and specialties in order to have as much feedback and comments as possible and to improve the tool and make it as usable as possible. The questions put to the experts focused on compliance with the requirements relating to cost management, the completeness of the list of BIM 5D software, their assessment of the general appearance of the tool, and finally the relevance of the comparison and presentation of results.

4 Main Result: An Interactive Decision-Support Tool to Support 5D Software Selection

In this section, we present the results obtained, through the structure and operation of the tool developed.

4.1 Structure of the Proposed Tool

The tool is made up of four parts corresponding to four Excel spreadsheet tabs, to guide the user in handling it (Fig. 1).

The first tab concerns the presentation and gives the first steps to follow to use the tool correctly. The second tab corresponds to the presentation of the structural table of criteria according to the categorization carried out and proposes a definition for each of them in order to have a homogeneous understanding. The user is required to fill in the weighting column for each of the criteria in this tab in order to subsequently observe the results. The third tab represents the main complete table of the tool

Fig. 1 Four tabs of the interface (*in French*)

comprising the list of criteria, 5D software, and the transcription of the weighting performed in the previous step. This table displays all the detailed results for each software based on the user's choices. The fourth tab details all the results in the form of graphs, allowing you to better visualize the results obtained from the software, by displaying only totals and sub-totals. The user therefore has access to a summary of the results in a precise and visual manner.

4.2 Operation of the Tool

The purpose of this tool is to interact with the user and give them results that are unique to them. To do this, a weighting system has been put in place. When filling out the tool, a score is assigned to each software for each criterion. The interactivity of the tool developed in this project comes from the weighting and therefore on the user's participation to obtain results. Thus, the tool offers a weighting system, chosen by the user according to his preferences and the importance he places on each of the criteria. The weighting is free, and each user can fill in what he wants.

The criteria weighting interface is in the form of a table showing all the criteria identified, grouped by category and sub-category. A definition is proposed for each criterion to ensure a common understanding and to avoid any ambiguity or confusion on the part of the user (Fig. 2).

When the weighting is completed by the user, the table is automatically filled to give the results of the information. The table is constructed in such a way that the weighting will multiply with the software score for each of the criteria and a synthesis for the different categories corresponding to the 5D BIM uses is provided (Fig. 3). The results of the tool appear when the user has finished filling in the criteria weighting. They come in the form of detailed notes, sub-totals, totals, rankings, and finally graphs to give a visual aspect to the user. The detailed notes allow the user

Catégorie	Sous-catégorie	Critères	Définition	Pondération
Analyse budgétaire		Comparaison des coûts de plusieurs éléments de même type	Capacité du logiciel à comparer lui-même les coûts de plusieurs éléments de même nature, afin de proposer à l'utilisateur de "meilleures" solutions.	
		Comparaison des quantités relevées manuellement et automatiquement	Capacité du logiciel à permettre une comparaison manuelle des quantités relevées grâce aux logiciels de conception et à souligner les différences.	
	Visualisation budgétaire	Rapports sur les coûts modifiables	Capacité du logiciel à sortir des rapports sur les coûts du projet en fonction de ce que l'utilisateur a choisi d'estimer, avec la possibilité pour l'utilisateur de modifier ces rapports par la suite.	
	Business intelligence	Solutions budgétaires proposées par le logiciel avec la base de données	Capacité du logiciel à comparer les solutions budgétaires obtenues après avoir comparé les bases de données et les choix de l'utilisateur, et à proposer ainsi une solution "meilleure" que l'utilisateur peut, ou non, accepter.	
Contrôle des coûts	Flux de trésorerie	Analyse des flux de trésorerie	Capacité du logiciel à analyser en temps réel les flux de trésorerie, permettant à l'utilisateur de contrôler ses coûts.	
		Prévision des flux de trésorerie	Capacité du logiciel à générer un flux de trésorerie à partir de modèles 4D	
	Évolution des coûts et suivi	Évolution des coûts tout au long du cycle de vie du projet	Capacité du logiciel à suivre l'évolution des coûts durant toute la durée du cycle de vie du projet.	
		Valeur des activités complétées	Capacité du logiciel à calculer et mettre à jour les coûts de toutes les activités complétées lors de la construction.	
		Évaluation de la performance des coûts	Capacité du logiciel à évaluer la performance des coûts, c'est-à-dire la différence (ou le ratio) entre le budget planifié et les coûts réels du projet.	
		Rapports personnalisables de suivi des coûts	Capacité du logiciel à réaliser le suivi des coûts tout au long du projet, sur les quelques aspects évoqués dans cette catégorie. Ces rapports sont personnalisables et peuvent être modifiés par l'utilisateur.	
		Système d'alerte de dépassement des coûts	Capacité du logiciel à prévenir l'utilisateur lorsque l'estimation des coûts du projet a dépassé les objectifs de ce dernier.	

Présentation | Pondération des critères | Tableau pondéré | Résultats graphiques | +

Fig. 2 User criteria weighting interface (*in French*)

	Assemble	Bexel Manager	BIM4YOU	CATO Suite	CostX	Cubicost Suite	Cubit	Destini Estimator	Ideate BI
	Assemble Systems	Bexel Manager	BRZ France	Causeway	Exactal	Glodon	Buildsoft	Beck Technology	Ideate So
Sous-total "Plan de gestion des coûts"	11	4	12	11	11,5	8,5	4	9	6,5
Sous-total "Estimation des coûts"	34	44	55	44	38	28	32,5	26	5
Sous-total "Budgétisation des coûts"	4	10	7	7	10	10	10	11	4
Sous-total "Contrôle des coûts"	3,5	17	22	20	8	15	2	20	2
Sous-total "Gestion des réclamations et des tarifications"	7	7	8	7	8	0	0	7	0
TOTAL GÉNÉRAL	59,5	82	104	89	75,5	61,5	48,5	73	17,5
Sous-total "Plan de gestion des coûts"	44,00%	16,00%	48,00%	44,00%	46,00%	34,00%	16,00%	36,00%	26,00
Sous-total "Estimation des coûts"	34,00%	44,00%	55,00%	44,00%	38,00%	28,00%	32,50%	26,00%	5,00
Sous-total "Budgétisation des coûts"	13,33%	33,33%	23,33%	23,33%	33,33%	33,33%	33,33%	36,67%	13,33
Sous-total "Contrôle des coûts"	6,36%	30,91%	40,00%	36,36%	14,55%	27,27%	3,64%	36,36%	3,64
Sous-total "Gestion des réclamations et des tarifications"	23,33%	23,33%	26,67%	23,33%	26,67%	0,00%	0,00%	23,33%	0,00
TOTAL GÉNÉRAL PONDÉRÉ	24,79%	34,17%	43,33%	37,08%	31,46%	25,63%	20,21%	30,42%	7,29

Fig. 3 Example of results by sub-category for a specific weighting (in table format) (*in French*)

to observe with precision the data of each software. These scores are then added together and give a sub-total. Each of these sub-totals corresponds to a category of criteria. The averages of the sub-totals of all software are then calculated, and the implementation of a visual indicator allows the user to have a global overview of the software sub-totals.

The tool also offers a graphical presentation of the results, so that users can better visualize the results. It takes the form of a bar graph and radar, generated after the criteria have been weighted. The bar chart automatically ranks software according to the total score obtained for all criteria. While this helps to get a general view of software capacity, it is generally necessary to have results for different sub-categories. Radar corrects this lack and allows the user to visualize the strengths and weaknesses of top software according to the different cost management uses (Fig. 4).

5 Conclusion and Future Work

The article presented an interactive decision-support tool in the selection of 5D BIM software for variable business contexts. The aim is to help the practitioners from the construction industry to select the right tools adapted to their particular requirements. The validation carried out with practitioners in the field shows an interest in the tool and the relevance of the criteria and the weighting principle. It also shows that the tool can be improved and made accessible to the entire industry.

To achieve this, it is essential to switch from its current form of Excel workbook to an online tool allowing wider use, but also a permanent update of the list of tools and criteria, directly by the community. Future work will focus on the development of an online version capable of reaching a large audience and a larger scale evaluation of the proposed tool.

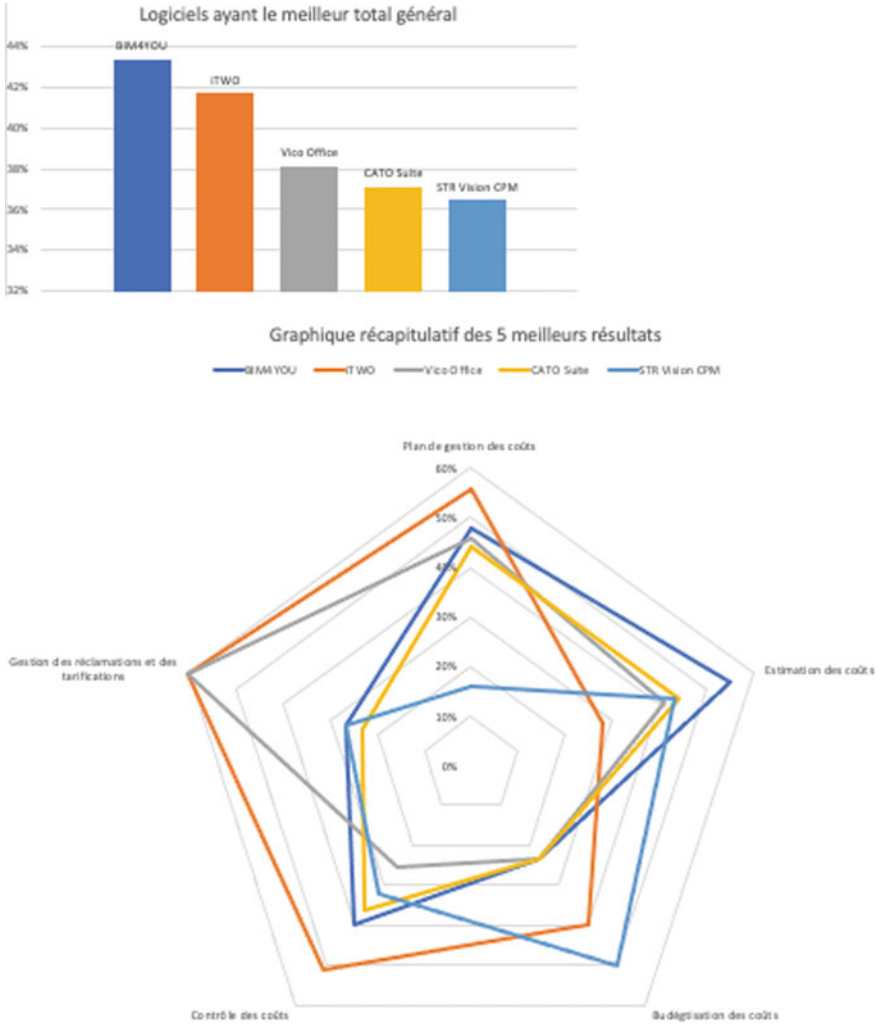

Fig. 4 Example of results by sub-category for a specific weighting (in graphical format) (*in French*)

References

1. Agostinelli S, Cinquepalmi F, Ruperto F (2019) 5D BIM: tools and methods for digital project construction management. Build Inf Modell (BIM) Des Construct Oper III 1:205–215
2. Aibinu A, Venkatesh S (2014) "Status of BIM adoption and the BIM experience of cost consultants in Australia. J Prof Issues Eng Edu Pract 140(3)
3. Becerik-Gerber B, Rice S (2010) The perceived value of building information modeling in the U.S. building industry. J Inf Technol Construct 15(February):185–201
4. Boton C (2013) Conception de vues métiers dans les collecticiels orientés service: Vers des multi-vues adaptées pour la simulation collaborative 4D/nD de la construction. Université de Lorraine

5. Boton C, Forgues D (2018) Practices and processes in BIM projects: an exploratory case study. Adv Civil Eng 2018:1–12
6. Chan IYS, Liu AMM, Chen B (2018) Management strategies for 5D-BIM adoption in Hong Kong. In: Proceedings of the 21st international symposium on advancement of construction management and real estate, 2016, (209889), pp 1023–1039
7. Chang SE, Shinozuka M (1996) Life-cycle cost analysis with natural hazard risk. J Infrastruct Syst 2(3):118–126
8. Ding Z, Zuo J, Wu J, Wang JY (2015) Key factors for the BIM adoption by architects: a China study. Eng Constr Archit Manag 22(6):732–748
9. Doloi H (2012) Cost overruns and failure in project management: understanding the roles of key stakeholders in construction projects. J Constr Eng Manag 139(3):267–279
10. Eastman C, Teicholz P, Sacks R, Liston K (2011) BIM handbook: a guide to building information modeling for owners, managers, designers, engineers and contractors
11. Fountain J, Langar S (2018) Building information modeling (BIM) outsourcing among general contractors. Autom Construct 95(February 2017):107–117
12. Frimpong Y, Oluwoye J, Crawford L (2003) Causes of delay and cost overruns in construction of groundwater projects in a developing countries; Ghana as a case study. Int J Project Manage 21(5):321–326
13. Fuller S (2006) Life-cycle cost analysis (LCCA)
14. Gibbs D-J, Emmitt S, Ruikar K, Lord W (2013) An investigation into whether building information modelling (BIM) can assist with construction delay claims. Int J 3-D Inf Model 2(1):45–52
15. El Hawary AN, Nassar AH (2015) The effect of building information modeling BIM on construction claims. Int J Sci Technol Res 4(8):25–33
16. Herszon L (2017) The complexity of projects : an adaptive model to incorporate complexity dimensions into the cost estimation process. University of Huddersfield
17. Kehily D, McAuley B, Hore A (2013) Leveraging whole life cycle costs when utilising building information modelling technologies. Int J 3-D Inf Model 1(4):40–49
18. Kehily D, Underwood J (2017) Embedding life cycle costing in 5D BIM. J Inf Technol Construct (ITcon) 22(22):145–167
19. Kerzner HR (2013) Project management: a systems approach to planning, scheduling, and controlling. Wiley
20. Kim H, Grobler F (2013) Preparing a construction cash flow analysis using building information modeling (BIM) technology. KICEM J Construct Eng Project Manage 704:1–9
21. Ku K, Taiebat M (2011) BIM experiences and expectations: the constructors' perspective. Int J Constr Educ Res 7(3):175–197
22. Lee XS, Tsong W, Khamidi MF (2016) 5D building information modelling—a practicability review. In: The 4th international building control conference 2016 (IBCC 2016), pp 2–7
23. Levin P (1998) Construction contract claims changes & dispute resolution. ASCE Press
24. Marcos CL (2017) BIM implications in the design process and project-based learning: comprehensive integration of BIM in architecture. WIT Trans Built Environ 169:101–110
25. Marzouk M, Azab S, Metawie M (2018) BIM-based approach for optimizing life cycle costs of sustainable buildings. J Clean Prod 188:217–226
26. Mayouf M, Boyd D (2019) Activity-based vs. object-based scheduling in construction: a phenomenological study of the potential shift of construction scheduling process. In: CIB world building congress 2019, Hong Kong SAR, China, pp 1121–1131
27. McGraw Hill Construction (2014) The business value of BIM in Australia and New Zealand : SmartMarket report managing editor. SmartMarket report
28. Mitchell D (2012) 5D BIM: creating cost certainty and better buildings. In: RICS Cobra conference, pp 1–10
29. Olusola BS, Srinath P, Damilola E, Esther AT (2019) An investigation into BIM-based detailed cost estimating and drivers to the adoption of BIM in quantity surveying practices. J Financ Manage Property Construct 25(1):61–81

30. Project Management Institute (2017) A guide to the project management body of knowledge. Project Management Institute Inc
31. Sacks R, Eastman C, Lee G, Teicholz P (2018) BIM handbook: a guide to building information modeling for owners, designers, engineers, contractors, and facility managers. Wiley, Hoboken
32. Smith D, Lovegrove S, Muse A, Pan DDZ, Sawhney A, Watkins P, Whisson G, Seah Kwee Yong T (2015) BIM for cost managers: requirements from the BIM model. RICS guidance note
33. Smith P (2014) BIM & the 5D project cost manager. Proc Soc Behav Sci 119:475–484
34. Stanley R, Thurnell D (2014) The benefits of, and barriers to, implementation of 5D BIM for quantity surveying in New Zealand. Australas J Construct Econ Build 14(1):105–117
35. Thurairajah N, Goucher D (2013) Advantages and challenges of using BIM: a cost consultant's perspective. In: 49th ASC annual international conference proceedings
36. Verbeeten FHM (2011) Public sector cost management practices in The Netherlands. Int J Public Sect Manag 24(6):492–506
37. Vigneault M-A, Boton C, Chong H-Y, Cooper-Cooke B (2020) An innovative framework of 5D BIM solutions for construction cost management: a systematic review. Arch Comput Methods Eng 27(4):1013–1030
38. Woodward DG (1997) Life cycle costing–theory, information acquisition and application. Int J Project Manage 15(6):335–344