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Quantitative and Qualitative Analysis of Applying Building Information Modeling (BIM) for Infrastructure Design Process

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Abstract: Building information modeling (BIM) has opened up many possibilities for the construction industry. However, most studies focus mainly on its overall uses and management areas. By investigating real projects that could utilize BIM in the design phases for railway construction, the authors examine the possible advantages and disadvantages in BIM implementation. To do so, the authors have selected three projects that utilized BIM implementation during the design process and three other projects with a non-BIM, traditionally designed working environment. Similar-scale projects were carefully chosen, and their differences in costs, man-hours, and labor forces were analyzed quantitatively. In addition, an in-depth interview was conducted with four BIM-designing firms to provide a more comprehensive perspective on the advantages and issues in BIM implementation. The average results showed that BIM-implemented projects spent USD 65,800 less than their counterparts and could increase productivity by about 2.9%. More importantly, the primary difference between BIM and non-BIM projects are in their man-hours. BIM-adopting projects spent 103.5 days less than non-BIM projects on average, and required three fewer professional labor forces during the entire design process.

Keywords: building information modeling (BIM); cost analysis; BIM environments; rail BIM; infrastructure design

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Citation: Shin, M.-H.; Jung, J.-H.; Kim, H.-Y. Quantitative and Qualitative Analysis of Applying Building Information Modeling (BIM) for Infrastructure Design Process. *Buildings* **2022**, *12*, 1476. https://doi.org/10.3390/buildings12091476

Academic Editors: Jun Wang and Heap-Yih Chong

Received: 18 August 2022
Accepted: 14 September 2022
Published: 17 September 2022

1. Introduction

BIM provides nD computer-aided drawing (CAD) services that are not traditionally available in many cases [1–3]. BIM is an effective tool for managing construction processes in a number of different circumstances, and its information-oriented interface is a powerful tool that can be implemented during every step in construction [4–8]. With its capability to represent the physical and functional characteristics of a facility in a digital representation, BIM is regarded as a key factor for the future construction industry.

One of the significant features of BIM is in its transparent information-sharing and facility abilities. In addition, interactive operations for clients or users through the entire project life-cycle is considered another important dimension [9,10]. For example, BIM-enabled facility management includes visualization, interoperability, and real-time data accessibility as the top-most cited benefits realized [11]. BIM capabilities save the costs associated with inadequate interoperability and the time often wasted in searching for information, manually inputting data, and analyzing data [9]. Using new information systems and models such as 5D BIM, all the design options, including the associated costs of each design scenario, can be evaluated concurrently [12].

However, although this technology demonstrates numerous possibilities for construction innovation, its utility and effectiveness have not been tested properly. Some studies have articulated the use of BIM and its advantages in construction, but most of them are theoretical, not practical [13–15]. Many of these studies emphasize the theoretical perspectives of using BIM and thus do not suggest a more specific economic argument [7,16,17].

This is especially true for civil engineering projects. Unlike the architecture industry, civil engineering involves a larger number of stakeholders, workers, and other resources, and oftentimes, BIM is regarded as a minimum change in industry culture. As a result, most of the literature analyzing the effectiveness of BIM focuses on architecture projects. In this regard, some have raised questions regarding the use of BIM in actual infrastructure projects [7,18–21]. It is true that BIM can be applied to architecture, infrastructure, restoration, and conservation, as well as in other types of projects, but ongoing work to establish the expanded use of BIM should be tested from a broader perspective.

Many countries around the world are rapidly adopting BIM standards and associated regulations at the national and municipal levels. For example, the International Organization for Standardization (ISO) published the first set of global BIM standards in 2018 [22]. Since then, the ISO has continuously updated global BIM standards, with the most recent update being in 2020. This is also true for some developed countries. The United Kingdom (UK) adopted three different levels of UK BIM standards that were mandated to be followed during the implementation of all public sector projects by 2016 [23], and the United States published its national 3D-4D BIM program in 2003. Other countries, such as Finland, Norway, Singapore, and South Korea, have all published their own national standards for BIM utilization to support and assist a more successful BIM working environment.

If BIM is an effective tool to support the construction industry and to change the ways in which we design facilities, then its advantages in terms of costs should be studied in a more detailed manner. This study aims to provide insight into such obstacles in BIM research. By investigating real projects that have utilized BIM during the design phase for railway construction, the authors examine the possible advantages and disadvantages of BIM implementation. To do so, the authors have selected three projects in which BIM was implemented during the design process, as well as three non-BIM projects: those that implemented a traditionally designed working environment. Similar-scale projects were carefully chosen, and the differences in costs, man-hours, and labor forces were analyzed quantitatively. In addition, an in-depth interview was conducted with four firms implementing BIM to provide a more comprehensive perspective on the advantages and issues of BIM implementation.

2. Materials and Methods

2.1. Implications of BIM

In less than 10 years, more than 900 studies focusing on BIM application have been published as academic papers, and most of them illustrate how BIM could change the construction industry [1,2,4,18,20,21]. Many of these studies have shown a great interest in the effectiveness of BIM, and a large amount of effort has been made to identify the benefits and obstacles of using BIM [3,5,16,24–26]. BIM is a widely acknowledged term, and most relevant professionals accept the effectiveness of using BIM in the construction process. The problem is that we are not fully aware of how we should accelerate such advantages and how to support the BIM environment in quantitative and qualitative ways [27–29].

Some studies have identified that BIM technology can provide benefits in resource management and in real-time cost control [4,8,18,30]. This can be regarded as a great advantage, because difficulties in achieving real-time solutions are often experienced in traditional, non-BIM environments. In addition, some studies have discovered that the benefits of BIM include design quality, the ability to share information, reduced construction and design errors, a faster working environment, enhanced efficiency, improved operational efficiency, and so on [3,31]. These abundant benefits have been categorized into five categories by previous researchers: (1) lifecycle cost control; (2) effective construction processes; (3) design and quality improvement; (4) decision-making support; and (5) risk management. Some categories are more abundant in specific cases, such as facility management [1,7,32,33].

Studies have identified that knowledge management is also an important issue in automated construction environments. A significant increase in the level of influence of coordination and integration, strategic direction and intention, and organizational learning create changes in knowledge management in a BIM environment. Statistical results have revealed that coordination and integration are effective during engineering processes. Clash detection, model updates, integrated logistics, soft landing plans, and as–built models for trade coordination or on-site construction represent a few advantages of BIM [21,34–36].

It can be seen that there are some studies demonstrating the importance of using BIM. However, most of these studies mainly focus on its overall implementation and greater management areas. A more specific understanding of the use of BIM is necessary. This is especially true for rail industries, as they tend to receive less attention in terms of BIM implementation. Traditionally, architectural, mechanical, and electronic projects have a long history of using 3D modeling. Railway projects, on the other hand, still tend to remain in 2D working environments because of their longer duration, greater work scope, and other bureaucratic issues. To this extent, this study tries to identify what the demands to achieve a better BIM working environment for the rail industry are, especially during the design process.

2.2. Research Framework

To properly understand the BIM working environment in railway construction, the authors conducted a comprehensive survey on the BIM design process. The first part of the survey involved quantitative measures, such as man-hour changes, labor charges, and other factors. The other part of the survey was designed to capture qualitative measures, such as difficulties in the BIM working environment, or the benefits of using BIM. To collect the surveys, two professionals from each of the selected firms A, B, and C were chosen: a BIM manager and a BIM coordinator. A total of 6 experts spent approximately 2.5 h answering the questions related to the quantitative measures, and the authors reorganized the survey answers so that they could be properly input into equations. Some firms had access to very specific records that allowed them to answer each of the questions referring to the quantitative measures, but some had to answer those items based on manager memory, meaning that more scrutiny was required when interpreting the answers. In addition to those 6 professionals, a BIM manager from firm D participated in an in-depth interview to determine the qualitative measures. In-depth interviews took about 5 h (during a two-day visit) to complete.

To properly conduct comparative research, the authors selected similar-scale BIM and non-BIM projects. All of the projects are subway line extensions. Three of them are located inside of the Seoul Metropolitan area, whereas two are in the vicinity of Seoul, and one is located in the Daejeon Metropolitan area, the 6th largest city in Korea. It can be seen that firms A and D indicated a similar project length, duration, number of engineers, and location. Firms B and E and firms C and F can be matched according to their similar characteristics. Because all of the projects are still under construction, other information, such as the total budget, exact location, and specific participants, is considered confidential and cannot be disclosed at present. Table 1 summarizes these results.

Table 1. Basic information about the 6 selected firms and projects.

BIM Use	Firms	Project Type	Total Project Length	Total Project Duration	Total No. of Professional Engineers	No. of Professional BIM Engineers	Project Location
BIM	A	Subway Extension	1.96 km	60 months	51	15	Seoul Vicinity
	B		5.21 km	95 months	78	18	In Seoul
	C		1.73 km	60 months	48	12	Seoul Vicinity
Non-BIM	D		2.15 km	60 months	60	N/A	Daejeon Vicinity
	E		4.97 km	95 months	85		In Seoul
	F		1.81 km	60 months	50		Seoul Vicinity

2.2.1. Quantitative Measurements

Quantitative measures were divided into 4 categories of 14 different questions, whereas the qualitative measures were divided into 5 categories of 16 questions. The four categories for the quantitative questions were: (1) planning stage; (2) BIM modeling; (3) education and support; and (4) relevant meetings, and the qualitative questions were divided into: (1) the Level of Detail (LOD) of the products; (2) design errors and difficulties; (3) budget changes during BIM application; (4) satisfaction rate; and (5) the use of BIM guidelines. Table 2 shows the quantitative and qualitative survey questions.

Table 2. Survey questions for quantitative and qualitative measures.

Quantitative Measures	
Categories	Areas of Questions
Planning Stage	Planned budget for design and planning stage
BIM Modeling	Man-hours for creating BIM modeling based on different LODs
	Error-processing time and labor force required for BIM modeling
	Man-hours and the amount of labor required for the design phase
	Labor charges for BIM coordination
	Man-hours for model checks and quality management
	Total working hours to create BIM models
Education and Support	Hours of education for BIM utilization
	Initial investment for BIM adoption
	Types of software and the cost of maintaining it
Relevant Meetings	Additional meetings required when using BIM
	Meetings required for error and interference checks for BIM models
Qualitative Measures	
Categories	Areas of Questions
Product LOD	LOD of the final model compared to the initial plan
	Final LOD of the BIM model
	LOD for BIM utilizations
Design Errors and Difficulties	Reasons for errors during BIM modeling during design stage
	Expected problems during BIM modeling during design stage
	Coordination issues
Budget Changes during BIM Application	How to achieve a successful BIM working environment
	Satisfaction rate from client side
	Benefits of using BIM compared to a traditional working environment
	Types of BIM experts inside firms
Guidelines	Existence of guidelines for BIM utilization
	Utilization process for BIM in design stage

Note: The same questions were delivered to non-BIM firms.

Subsequently, fundamental equations were set up to properly compare the effectiveness of BIM and non-BIM working environments. For example, questions for planning stages can be estimated with three different inputs: (1) base budget + (2) labor charges based on different skill levels × (3) man-hours. Using this method, the initial budget for the planning stage was calculated. Table 3 indicates all of the cost estimation results. It can be seen that there was a slight difference between the BIM and non-BIM calculations because the input items for the cost calculation were different, and for that reason, some questions were not applicable for the non-BIM firms. For example, the education and support costs were only applicable to projects using BIM, because BIM education is necessary due to the use of new software and hardware. In addition, the support costs for maintaining BIM are not mandated cost items for non-BIM projects.

Table 3. Equations for quantitative measures.

Measurement Equations	
Categories	Areas of Questions
Planning Stage	Planned budget = base cost + (labor charges × man-hours)
BIM Modeling (Design of non-BIM)	Drawing and scheduling = labor charges based on LOD × man-hours
	Design cost = labor charges based on skill level × man-hours
	Modeling cost = labor charges based on skill level × man-hours
	Model check and quality control = labor charges based on skill level × man-hours
Education and Support (Not applicable to non-BIM)	BIM education = number of education × instructor fees
	BIM initial cost = software charges + hardware charges + upgrade costs
	BIM maintenance cost = (software + hardware maintenance) × number of years
Relevant Meetings	Emergency meetings = number of unexpected meetings × unit price × number of participants
	Model check meetings = number of unexpected meetings × unit price × number of participants

The authors were dispatched to each firm and met with the BIM managers and coordinators to properly collect the survey results. In addition, in-depth interviews were conducted with the BIM managers to obtain answers to the qualitative questions. All of the projects were for subway extensions, with the design process beginning between 2019 and 2020; thus, price inflation was not a consideration for the cost estimates. Table 4 shows the measurement results for projects applying BIM. The total costs, man-hours, and estimated labor fees for each survey question were estimated.

As can be seen in Table 4, each project required about 200~300 days for the design stage. The longest duration for the design stage was required by a project implementing BIM modeling. Firms A and C spent about 160 days on model design and another 30 days on coordination, whereas firm B spent 270 days on modeling and another 90 days on coordination. According to the BIM manager, the project for firm B was a larger-scale project and experienced challenges due to its difficult geographical location, requiring more in-depth modeling and additional checking time for the BIM model. As a result, even though the total amount of labor input was the smallest, BIM costs and man-hours were the highest. Due to the different size of the project and the geographic situation, firm B generally showed higher costs in the project-planning and BIM-modeling phases.

As for the BIM modelers, coordinators, and managers, each firm provided different labor charges based on the level of experience and contract details. Therefore, the average among the three firms was implemented to calculate the BIM modeling costs. BIM education and urgent meetings were not major parts of the total estimates (16.5% for firm A, 22.1% for firm B, and 21% for firm C). However, a large difference was seen in BIM investments. Firms A and C mainly used AutoDesk Revit for BIM modeling, but firm B used a number of different packages combined, paying higher fees for the licensing charges.

Table 5 shows the man-hours and labor charges for the non-BIM projects. According to the results, firm E had higher costs than the other two firms. The chief designer indicated that firm E's project was relatively large in size and more complicated compared to general projects, requiring more time and labor during the design and detail drawing stages. Firm F consumed more man-hours than firm D (349.8 days vs. 247 days), but the project difficulty was relatively low, and for that reason, the number of laborers and the level of expertise of the engineers were lower than they were for firm D.

Table 4. Man-hours and the number of laborers for BIM projects.

Item	Code	Descriptions	Firm A			Firm B			Firm C		
			Man-Hours (days)	**No. of Laborers**	**Cost Estimates (USD)**	**Man-Hours (days)**	**No. of Laborers**	**Cost Estimates (USD)**	**Man-Hours (days)**	**No. of Laborers**	**Cost Estimates (USD)**
Planning	(a)	Plan management	3.3	1	8000	5	2	17,000	3.3	1	15,000
BIM Modeling	(b)	Drawing and scheduling	70	4	14,000	60	2	40,000	70	4	26,500
	(c)	Design stage	30	2 *	94,000	60	1 *	168,000	30	1 *	70,000
			30	3 **		90	2 **		30	2 **	
			30	2 ***		60	2 ***		30	2 ***	
	(d)	Model coordination	30	10	50,000	90	4	72,000	30	7	70,000
	(e)	Model checks and quality control	7	2	10,000	30	2	12,000	1.6	2	5000
Education and Support	(f)	BIM education	0.2	5	3000	0.3	2	900	1.6	6	2500
	(g)	BIM initial investment	N/A		10,000	N/A		68,000	N/A		10,000
	(h)	Maintenance costs			20,000/yr			20,000/yr			30,000/yr
Relevant Meetings	(i)	Emergency meetings	0.4	2	600	0.1	2	600	0.1	2	1200
	(j)	Model check meetings	0.5	2	1200	0.1	2	1200	0.3	2	4800
Total			201.4	33	210,800	395.5	21	410,500	196.9	29	235,000
Average for three firms			263.6 days/27.7 men/USD 283,285								

*: BIM manager; **: BIM coordinator; ***: BIM modeler. 1. Labor charges for BIM managers differ, but the average among the three firms was USD 10,000/month. 2. Labor charges for BIM coordinators differ, but the average among the three firms was USD 14,000/month. 3. Labor charges for BIM modelers differ, but the average among the three firms was USD 16,000/month.

Table 5. Man-hours and the number of laborers for non-BIM projects.

Item	Code	Descriptions	Firm D			Firm E			Firm F		
			Man-Hours (days)	**No. of Laborers**	**Cost Estimates (USD)**	**Man-Hours (days)**	**No. of Laborers**	**Cost Estimates (USD)**	**Man-Hours (days)**	**No. of Laborers**	**Cost Estimates (USD)**
Planning	(a)	Plan management	1.0	1 *	11,000	2	2 *	11,000	4.5	2 *	12,000
Design Drawings	(b)	Drawing and scheduling	90	2 *	24,000	80	2 * 1 **	28,000	60	2 **	16,000
	(c)	Design stage	100	10 *	159,000	300	6 * 2 **	270,000	210	7 * 1 **	175,000
	(d)	Detail drawing	40	12 *	63,600	100	2 ** 1 **	35,000	60	4 * 1 **	32,000
	(e)	Drawing checks and quality control	10	10 *	13,300	20	5 *	10,000	10	3 *	3000
Relevant Meetings	(i)	Emergency meetings	3	1 ** 1 ***	1250	2	2 **	600	3	1 * 2 **	1100
	(j)	Drawing check meetings	3	2 * 1 ** 1 ***	2050	3.3	1 * 2 **	1330	2.3	2 **	1230
Total			247	41	274,200	507.3	26	355,930	349.8	25	240,330
Average for three firms			368.1 days/30.7 men/USD 290,153								

*: Entry-level professional engineers. **: Intermediate-level professional engineers. ***: Experienced professional engineers. Engineer fees were calculated based on national labor standards for the Korean construction industry.

According to the results, the average number of man-hours required for the three firms to complete their design tasks was 368.1 days, requiring 30.7 workers and costing USD 290,153. The non-BIM projects took longer than a year to complete the design process.

We can see that the average man-hours required for BIM projects was 263.6 days, whereas the non-BIM projects took about 368.1 days. This means that the non-BIM projects required about 105 more days to complete the project. In addition, the BIM projects required 27.7 laborers for the projects, and the non-BIM projects required 30.7 laborers to finish the projects, a difference of three laborers. Lastly, the average costs of the projects that adopted BIM were USD 283,285/year, and similar non-BIM projects cost USD 290,153/year, a difference of about USD 6868. This may not be a significant difference, but considering that man-hours and input labor also varied based on BIM utilization, the effectiveness of using BIM can be understood in a greater magnitude.

2.2.2. Qualitative Measurements

For comprehensive results, the authors conducted an in-depth interview with BIM managers from four design firms. The interview was conducted to ask about the potential advantages and disadvantages of using BIM. In addition, the authors looked at any difficulties and other risks of using BIM. Aside from the three firms selected for data collection, one more firm was contacted for an interview. All of the firms had more than 7 years of experience in BIM design, especially in the field of civil engineering, and for that reason, they all employed the relevant BIM professionals.

Five different categories of topics were covered in the interview: (1) the LOD of BIM models; (2) issues during the BIM design process; (3) financial risks of using BIM in a design environment; (4) benefits experienced using BIM; and (5) the use of BIM guidelines. Outside of confidential topics, the BIM managers provided the most appropriate answers. Some of the questions required more sensitive information in terms of the firm's design strategy, and those questions were answered in a more general manner.

As can be seen in Table 6, most of the firms ended up with an LOD higher than 300 for their final products, and their initial plan for the model was generally higher than an LOD of 300. The biggest reason for errors occurring during BIM modeling was design errors, and those errors could cause process delays and quality control issues for the final design product. The main reason for man-hour changes was due to clients requesting design changes, and the initial investment in the BIM working environment was about USD 7000/year for software and hardware combined. In most cases, the clients were satisfied with the BIM products because of their instant visualization and modification capability, and the biggest advantage of using BIM was the reduction in human error.

Interestingly, almost all of the firms expected more mutual understanding of the BIM working environment from the participants. Because traditional CAD-oriented and BIM-oriented working environments are largely different, the design firms had difficulty explaining the differences to the relevant stakeholders. Finally, some firms established their own guidelines for BIM design, but others utilized national standards, asking for more support and assistance from administrative entities, such as the national governments or municipalities.

Table 6. Interview results from four different BIM design firms.

Items	Descriptions	Results			
		Firm A	Firm B	Firm C	Firm D
Product LODs	BIM utilization rate based on the initial plan	- 100% based on the initial plan (client request)	- 90% compared to the initial plan	- 100% based on the initial plan (client request)	- 80% compared to the initial plan
	Planned LOD	- Different based on the purpose of BIM models	- Schematic design: LOD 200~300 - Detailed design: LOD 300~400	- Schematic design: LOD 200~300 - Detailed design: LOD 300~400	- LOD 300~350
	Final LOD	- LOD 350	- LOD 350	- LOD 300	- LOD 300

Table 6. *Cont.*

Items	Descriptions	Results			
		Firm A	Firm B	Firm C	Firm D
Issues in BIM Designing	Main reasons for BIM errors	- Drawing errors - Unsolved issues during design process	- Drawing errors - Interface errors in software	- Drawing errors - Design differences compared to the actual site - Unsolved issues during design process	- Drawing errors - Design differences compared to the actual site
	Expected problems with BIM errors	- Process delays - Quality control	- Process delays	- Cost inflation - Process delays - Quality control	- Quality control
	Coordination issues	- No issues	- No issues	- Inter-organizational coordination required	- Software competitiveness issues
Financial Risk in BIM Use	BIM coordinating costs	- Different based on project scale - Coordination required throughout design process	- At 70~80% completion of BIM model - Different costs based on experience level	- Two coordinators/month/project	- Different based on project scale
	Reasons for changes in man-hours	- Work scope/level change from clients	- Work scope/level change from clients	- Work scope/level change from clients	- Labor increase compared to the initial plan
	Initial investment in BIM implementation	- Cost varies based on the level of expertise	- Hardware: USD 3000/person - Software: USD 4000/year	- Hardware: USD 4000/person - Software: USD 3000/year/person - Upgrades: USD 1000/year	- Approximately USD 6000/year
Benefits and Advantages of using BIM	Requests for more effective BIM usage	- Understanding of BIM implementation from all sectors of design industry	- Understanding of BIM work environment from client side	- Strategic support in terms of policy and regulation of national standards	- Automation for scheduling and budgeting
	Satisfaction level of clients	- Very satisfied	- Satisfactory	- Very satisfied with 3D visualization and instant model modification	- Very satisfied
	Advantages of using BIM	- Reduction in drawing errors and man-made mistakes	- Increased mutual understanding based on 3D working environment	- Reductions in redundant design work	- Increased mutual understanding based on 3D working environment
	Types of BIM experts in firms	- BIM managers - BIM coordinators - BIM modelers - BIM consultants - BIM educators	- BIM managers - BIM coordinators - BIM modelers - BIM consultants	- BIM managers - BIM coordinators - BIM modelers - BIM consultants	- BIM managers - BIM coordinators - BIM modelers - BIM consultants - BIM researchers
BIM Guidelines	Guidelines for using BIM	- Have own standards and guidelines for BIM works	- Following client and national standards for BIM working environment	- Following client and national standards for BIM working environment	- Have own standards and guidelines for BIM works
	BIM implementation point	- Anytime during the project	- At the point of 70% schematic design process	- Generally use BIM for detailed design stage	- At the point of 70% schematic design process

This is a notable result because all of the firms understood the benefits of using BIM in the design process, but most of the other associated partners, such as the construction industry and the clients, did not fully understand the changes induced by BIM application. As a consequence, semi-contractors or clients perceived BIM as a service rather than a key decision-making tool. This misunderstanding between stakeholders created a confusing working environment in terms of costs, final products, etc.

3. Results

3.1. Quantitative Measures Results

Table 7 explains cost differences between BIM and non-BIM projects. It can be seen that firms with BIM implementation required an average of USD 13,333, and that non-BIM firms spent USD 11,333, resulting in a USD 2000 difference in the planning stage. During the design phase, firms using BIM spent an average of USD 210,500 on design and modeling, whereas the non-BIM firms spent an average of USD 276,300, a difference of about USD 65,800. This is a notable difference, as the firms that used BIM spent additional money to purchase software and hardware. The average cost for BIM education and support was USD 54,800 annually. However, the total costs of the BIM projects were not significantly different.

Table 7. Cost comparison between BIM and non-BIM projects.

(In USD)		Planning Stage	BIM Modeling	Design Drawings	Education and Support	Relevant Meetings	Total
BIM Projects	Firm A	8000	168,000	N/A	33,000	1800	210,800
	Firm B	17,000	292,000	N/A	88,900	1800	399,700
	Firm C	15,000	171,500	N/A	42,500	6000	235,000
	Average	13,333	210,500	N/A	54,800	3200	281,833
Non-BIM Projects	Firm D	11,000	N/A	259,900	N/A	3300	274,200
	Firm E	11,000	N/A	343,000	N/A	1930	355,930
	Firm F	12,000	N/A	226,000	N/A	2330	240,330
	Average	11,333	N/A	276,300	N/A	2520	290,153

Note: All costs are calculated on a yearly basis.

According to the average costs, although the BIM firms invested more in education and support, the planning stage, and relevant meetings, the entire design work cost USD 65,800 less than in the non-BIM firms, compensating for all other spending. This is an interesting result, because once a BIM model is set up, there are not many associated costs for other related work, such as detailed design, 3D modeling, and so forth. Therefore, BIM may require more investments upfront, but the durability and utility of the products are more versatile, and the costs can be compensated for via the subsequent work.

Table 8 indicates labor and man-hour differences between the BIM- and non-BIM firms. According to the results, firm B spent the highest number of man-hours in BIM projects, but the number of laborers was the smallest. The difference between firms A and B in terms of man-hours was about 194 h, and firm C required the lowest number of man-hours during the design phase. Firm A shows the highest number of laborers required for its project, about 12 more than firm B and about four more than firm C. The average revealed that BIM projects required about 264.6 man-hours and 27.7 laborers.

Table 8. Man-hour and labor comparison between BIM and non-BIM projects.

			Planning Stage	BIM Modeling	Design Drawings	Education and Support	Relevant Meetings	Total
BIM Projects	Firm A	Man-hours	3.3	197	N/A	0.2	0.9	201.4
		Laborers	1	23	N/A	5	4	33
	Firm B	Man-hours	5	390	N/A	0.3	0.2	395.5
		Laborers	2	13	N/A	2	4	21
	Firm C	Man-hours	3.3	191.6	N/A	1.6	0.4	196.9
		Laborers	1	18	N/A	6	4	29
	Average	Man-hours	3.9	259.5	N/A	0.7	0.5	264.6
		Laborers	1.3	18	N/A	4.3	3	27.7
Non-BIM Projects	Firm D	Man-hours	1	N/A	240	N/A	6	247
		Laborers	1	N/A	34	N/A	6	41
	Firm E	Man-hours	2	N/A	500	N/A	5.3	507.3
		Laborers	2	N/A	19	N/A	5	26
	Firm F	Man-hours	4.5	N/A	340	N/A	5.3	349.8
		Laborers	2	N/A	18	N/A	5	25
	Average	Man-hours	2.5	N/A	360	N/A	5.5	368.1
		Laborers	1.7	N/A	23.7	N/A	5.3	30.7

Firm E spent about 500 h on design drawing using 19 laborers, representing the highest number of man-hours among the non-BIM projects. Firm D used the highest number of laborers during the design stage, and firm F used the lowest number of laborers during its design process. The average results show that non-BIM projects required about 368.1 man-hours to complete projects with 30.7 professionals. Compared to the BIM projects, the non-BIM projects spent about 103.5 more man-hours and required three more laborers. This could be a significant result because the average cost difference between BIM and non-BIM projects was about USD 65,800, but the number of man-hours differed to a greater degree. Observing the average, the non-BIM projects took about 103.5 days longer than the BIM projects to complete the design process. Although USD 65,800 may not be a significant difference in terms of investments per year, the time difference seems to be a noteworthy result.

According to the cost comparison, firm A spent USD 210,800 on project design, whereas firm D spent USD 274,200 on the same process. It can be understood that BIM utilization may increase productivity by roughly 23.1%. On the other hand, based on the results of firms B and E, BIM implementation did not increase the productivity of the design process; rather, productivity decreased by about 11%. This cannot be a complete measure to judge BIM efficiency for larger scale projects, but we can understand that the education and support costs create a slight difference. Lastly, the difference in productivity between firms C and F was about 2.2%, meaning that BIM improved efficiency by about 2.2% in terms of the total costs. On average, using BIM for a similar-scale project could induce cost differences, resulting in a 2.9% increase in productivity. Figure 1 illustrates the results.

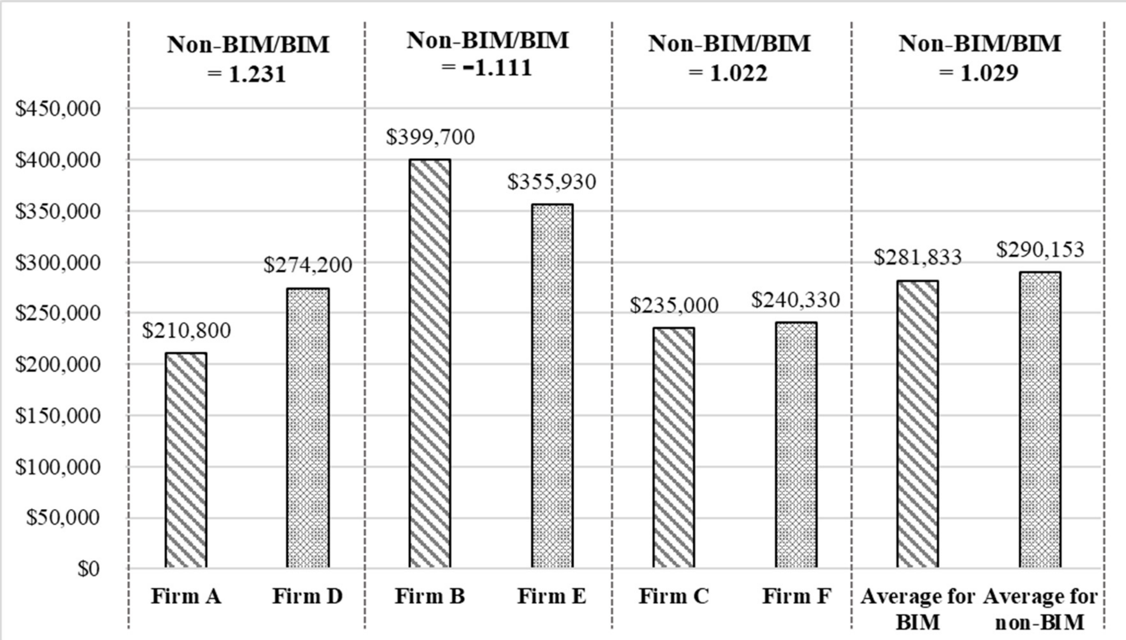

Figure 1. Productivity differences between BIM and non-BIM projects.

3.2. Qualitative Measures Results

Based on in-depth interviews with four firms, the results can be summarized in five categories. The first category refers to the LODs for the design process, and most of the firms achieved 100% LOD compared to their initial plan. Most of the firms used 200~300 LOD for schematic design, and 300~400 for detailed design, and the final product's LOD was in between 300~350. The second category refers to issues in BIM implementation. Four main issues in BIM use during the design process can be identified: (1) drawing errors; (2) interface compatibility between software; (3) unsolved issues during design decision-making; and (4) differences between the design product and the actual site. Third, there are some expected financial risks involved in BIM, and the biggest change in the number of man-hours was due to the scope of the work and design conversion from the client side. In addition, the initial investment in BIM varied from USD 4000/year to USD 6000/year. Most of the firms reported that coordination was required for BIM utilization throughout the design process.

There are certain advantages of using BIM, and almost all of the firms asked for a better understanding of BIM working environments from stakeholders. Clients were mostly satisfied with the BIM products because of their ability to be instantly modified and visualized in 3D. All of the firms agreed that BIM provides advantages such as reductions in human error, thus minimizing drawing errors compared to traditional design environments. Additionally, all of the firms hired BIM managers, coordinators, modelers, and consultants. Some firms required BIM educators and researchers for a better implementation. Finally, two firms had their own standards for BIM working guidelines, whereas the other two followed national standards. The point at which BIM was utilized depended on the schematic design process, but all of the firms gradually expanded their use of BIM from the beginning of the design stage.

4. Conclusions

This study was designed to understand the advantages and issues of using BIM in the design process. Specifically, similar-scale projects were selected for BIM and non-BIM utilization. As the analysis results indicated, BIM can provide certain benefits in the design process. The average results show that the projects that implemented BIM spent about USD 65,800 less than their counterparts, increasing productivity by about 2.9%. More importantly, the difference between BIM and non-BIM projects was in their man-hours. The projects that adopted BIM spent 103.5 days less than non-BIM projects on average and required three less professional laborers during the entire design process.

This could be an interesting point because the BIM-utilizing firms invested more in hardware and software. In addition, BIM education resources were mandatory for a more effective working environment. Due to these reasons, the upfront costs for the BIM projects were higher, but the final analysis showed lower costs, fewer laborers required, and fewer man-hours than the traditional working environment. If BIM can be a continuous effort for these selected firms, then the initial investments could be minimized and could eventually pay off the additional charges.

Based on in-depth interviews with the relevant BIM professionals, most of them agreed with the point that BIM is a necessary tool for a better and more effective design environment. Additionally, all of them have experienced certain benefits of using BIM during their career. However, a mutual understanding of BIM adaptation in the construction and design industries is still in demand, with a request for a more collaborative decision-making environment for BIM utilization. Specifically, understanding the differences between the traditional design environment and BIM application are needed on the client side. Semi-contractors and other partners should also embrace the new challenges induced by the BIM working environment. Finally, more systematic and administrative support from the central government or municipalities regarding BIM guidelines, working protocols, and product standards could ease such obstacles.

It is certain that results from only six firms cannot be generalized to determine the effectiveness of BIM. However, this study provided a holistic view on the differences between BIM and non-BIM projects for the railway design process. Based on the survey and in-depth interviews, the authors tried to identify possible benefits and hurdles to BIM utilization and possibly suggest a future direction for a smarter and more sustainable construction environment.

Author Contributions: M.-H.S. prepared the entire funding and in-depth interview; J.-H.J. conducted quantitative analysis; and H.-Y.K. prepared the overall research process and the manuscript. All authors have read and agreed to the published version of the manuscript.

Funding: This study was funded by the Ministry of Land, Infrastructure, and Transport in South Korea (Grant number: 22RBIM-C158185-03).

Data Availability Statement: The data that support the findings of this study are available from the corresponding author, Hwan Yong Kim, upon reasonable request.

Conflicts of Interest: There are no conflicts of interest.

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