Title:

Benefit-Cost Analysis of Building Information Modeling (BIM) in a Railway Site

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Keywords:
Building Information Modeling (BIM); Benefit-Cost Analysis (BCA); Railway construction; Liquidated damage; Infrastructure; Planning and design

Abstract:
Recent technological improvements have made abundant changes in construction industry. In specific, some technical applications, such as Building Information Modeling (BIM) opens up many possibilities. Some studies have articulated the use of BIM and its advantages in construction, but most of them are theoretical, not practical. This study is to provide an insight to such obstacles in BIM research. By investigating a real project that could utilize BIM in planning and construction phases, the authors try to investigate a possible outline of advantages in BIM implementation. The study area was set to a railway construction site in South Korea. The site covers a multiple railway tracks, stations, telecommunication facilities, infrastructure facilities, railway structures, and so numerous. In the site, the authors have identified 12 errors in 7 projects that could be prevented if BIM was utilized before the construction. The total upfront costs required to provide a BIM for 7 projects were $116,348. On the other hand, the total costs required to fix the errors in 7 projects were $166,486. This can be regarded as the benefits of using BIM because if BIM was implemented then the associated errors are easily replaced. Therefore, the benefit-cost ratio can be estimated as 1.32 for one-month delay and 1.36 for a three-month delay.

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4303; doi:10.3390/su10114303

1. Introduction

Recent technological improvements have made abundant changes in construction industry. This is especially true in database management and data sciences. In specific, some technical applications, such as Building Information Modeling (BIM) opens up many possibilities for construction control and management. BIM is an effective tool to manage construction process and this is especially true in schematic design and planning stage. With its 3-dimensional ability along with versatility to control a vast amount of associated data, BIM is supported by many industry professionals.

However, despite the fact that many experts advocate BIM and support for its utility, not many studies have identified the true effectiveness of BIM in reality. Some studies have articulated the use of BIM and its advantages in construction, but most of them are theoretical, not practical. The majority of studies have adopted the utility of BIM in theoretical projects, giving a possibility for future use. However, its practical use and the impact of using BIM are still vague and unclearly identified.

This study is to provide an insight to such obstacles in BIM research. By investigating a real project that could utilize BIM in planning and construction phases, the authors try to investigate a possible outline of advantages and disadvantages in BIM implementation. Conducting a benefit-cost analysis (BCA) would suggest a holistic view to similar BIM environment and articulating the sensitivity of BC ratio based on construction period difference may suggest more precise impact of BIM utilization to construction industry.

2. Background

There have been a large amount of studies elaborating the benefits of using BIM in construction industry. In less than 10 years, more than 900 studies regarding BIM utilization are published as academic papers and most of them illustrate how BIM would change the construction industry and the world at large (Volk, Stengel et al. 2014, Yalcinkaya and Singh 2015). Among various studies, many showed great interests on how effective BIM is and a large amount of efforts have been put to identify the benefits and obstacles in using a BIM (Li, Hou et al. 2014, Volk, Stengel et al. 2014, Yalcinkaya and Singh 2015, Dakhil, Underwood et al. 2016).

Some studies have identified that BIM technology can provide high benefits in resource management and real-time cost control. This can be regarded as a great advantage because the traditional non-BIM environment experienced difficulties in real-time solutions (Li, Hou et al. 2014). In addition, some studies have discovered that the benefits of BIM are in improvement of design quality, information sharing ability, reduction in construction and design errors, faster working environment, enhancing efficiency, operational efficiency, and so numerous (Doumbouya, Gao et al. 2016). With abundant benefits, BIM utilization and its possible benefits can be divided into five categories: 1) life cycle cost control; 2) effective construction process; 3) design and quality improvement; 4) decision-making support; and 5) risk management, and some are more abundant in specific cases, such as facilities management (Tomek and Matějka 2014, Terreno, Anumba et al. 2015, Enshassi, Hamra et al. 2018).

However, by closely observing the recent pattern in BIM studies, the vast majority of the existing literature relies on surveys, case studies, and interviews (Tomek and Matějka 2014, Cao, Wang et al. 2015, Ghaffarianhoseini, Tookey et al. 2017). This is acceptable as a precise BCA

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may require higher standards and amounts of data and thus, sufficient information may not be feasible. Also, closely investigating the existing cases could enhance the validity of BIM benefits and thus, still play an important role in expanding the uses of BIM in construction industry. Nonetheless, many have identified that more precise cost-benefit analysis should be performed to capture the true benefits of using BIM (Ding, Zhou et al. 2014, Volk, Stengel et al. 2014, Wong and Zhou 2015). In addition, more attention is now being paid that organizational and legal framework need significant adjustments to adopt BIM processes (Volk, Stengel et al. 2014, Wong and Zhou 2015).

If we think about the benefits of BIM utilization, however, then some financial benefits and associated advantages should be elaborated. There are studies describing benefits in risk management, construction time reduction, error management, and some other issues that may involve costs (Love, Matthews et al. 2014, Terreno, Anumba et al. 2015, Dakhil, Underwood et al. 2016). But in many cases, precise measurements on financial costs of BIM utilization can be hardly accessible. As mentioned earlier, it may be due to data security as cost data generally involve greater scrutiny. Accessing to cost data often times require private information and in many cases, it makes hard for a researcher to conduct a proper analysis. If what we want is expanding the utilization of BIM and its operating environment to make construction industry more sustainable and healthy, then precisely capturing the financial benefits of BIM needs to be assessed. This study is intended to cover such gaps.

3. Research Framework

3.1 Study Area and Data Analysis Procedure

This study is conducted in four steps. First, the authors make surveys and in-depth interviews with specific experts who worked in the study site to acquire how BIM would change their work experience in construction. By doing so, the authors discover some projects that may have done a better job if BIM was utilized. During construction, some projects involved additional costs because of errors in design and construction. By conducting interviews with relevant experts, the authors identified the errors that are relatively easy to be fixed if BIM is utilized beforehand. After that, each project is scrutinized with their existing datasets. Doing so allows the authors to take a close look on what errors have made, and among which error can be eased with BIM utilization. In third, the authors estimate expected costs that may have increased due to BIM work to prevent the errors. Finally, a BCA can be conducted with the existing cost data that are associated with the errors and the estimates that may have arouse to build a BIM.

The study area was set to a railway construction site in South Korea. Due to the regulatory requirements, a test bed was under construction to provide a more effective research environment for Korean railways studies. The site covers a multiple railway tracks, stations, telecommunication facilities, infrastructure facilities, railway structures, and so numerous. For that reason, BIM could be utilized to enhance the construction experience and receive financial benefits in construction and planning phases. The planning and design stage was conducted by a consortium of 8 different engineering firms and the construction was carried out by a consortium of 9 different semi-contractors. The total budget is approximately $25 million and the expected duration of completion is about 51 months. Since the construction is in its last stage and expected to be finalized in December, 2018, many details cannot be revealed at this moment. The authors selected this site because this test bed could become an important data generator providing more specific outcomes of BIM utilization in a real world project.

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To precisely capture the benefits of using BIM in a railway construction project and to prevent any misinterpretation of BIM implementation, the authors conducted a series of meetings with the relevant professionals. Using a Delphi survey and an in-depth interview, experts are divided into three different stages, planning, design and construction. In fact, if the use of BIM in a project should be fully captured, then maintenance and operating stage have to be incorporated as these two are probably the biggest benefits that BIM could create. However, since the test bed site is still under construction and thus, only planning, design and construction phases are feasibly inclusive, the authors only considered the three aspects of BIM utilization. As this will become a longitudinal study, the authors think more data will be available once the site is done with construction and into its operation stage.

Based on meetings and interviews with relevant experts, the authors understood that capturing BIM's benefits in a project has limited capabilities. It means the advantages of using BIM can be diagnosed by a small number of indicators. This is understandable, as construction involves a large number of people with diverse work steps and for that reason, the data availability could become a critical factor. In addition, construction involves a number of unpredictable events, such as natural disaster and man-made mistakes. Hence, detailed documentation about planning, design, and construction is not always available in many cases. Therefore, including all details and elaborated measures in BIM BCA is not handful in general. This study is not far from such circumstances, the authors have included a few selected measurements to estimate BIM benefits in railway construction site.

Figure 1 illustrates data mining process in this study. As can be seen, although planning, design, and construction stages involve a large number of work flows, the study mainly focuses on three areas: 1) design review; 2) reorder and reconstruct; and 3) delayed construction. Design review is to assess if there is any cost reductions or increase in fixing design errors. BIM is an effective tool to capture any interference in design elements as it supports 3D capability. This can be done even with a simple model checker. Hence, design errors could decrease when BIM is implemented at the planning and design stage. After that, reorder and reconstruct is measured to gauge any build orders are permitted with errors associated with it. If this happens, then construction process can be delayed and other relevant costs could move up because of a possibility of rework. Finally, if errors are carried out throughout planning, design and construction stages, then the entire construction period could delay which in return affects the liquidate damage. Although these three measurements are not holistic measurements to cover the entire benefits of BIM, estimating the three would provide an insight about the utility of BIM implementation in a real project.

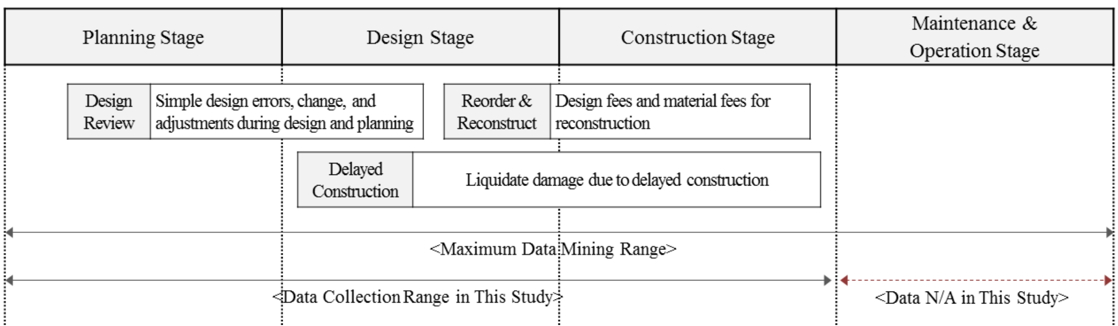

Figure 1 - Three measurement categories used in this study

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After the initial BCA elements boundary is set, the authors collected possible data for corresponding workflows. In this case, there are 7 construction projects that may heavily require BIM. Table 1 depicts 7 projects that are carried out with errors and for that reason, reworks and associated costs were increased. There are more errors in railway construction site, of course, but based on interviews and surveys with the relevant experts, below 7 are identified as the closest projects that could be easily fixed with BIM. It means below 7 projects could be the potential works that can minimize errors if BIM was implemented beforehand.

As can be seen, most of them are bridge construction and only two projects involve tunnel and railway tracks. This is plausible as BIM generally requires physical figures and bridges are the most common structural component in railway construction. Tunnels and railway tracks are possible construction components for BIM utilization but as the experts noted, it sometimes is a hard job as tunnel and tracks should be customized at a site scale, requiring different works in different circumstances. Therefore, it could be noted that most of BIM utilization is inclined to structural elements.

7 projects with BIM implementation						
The 1st Bridge	The 5th Bridge	The 7th Bridge	The 8th Bridge	Test Bed Bridge	The 6th Tunnel	Railway Tracks

Table 1 - 7 projects inducing errors

3.2 Cost and Benefit Elements Standards

During the data mining process, the authors have identified 12 errors that could be prevented if BIM was utilized before the construction. Most of them are dimension errors or interference, and they are relatively easy tasks for BIM modelers to deal with. In this sense, the authors estimated possible costs that are required to fix these issues and estimated possible benefits that can be assessed if those errors are fixed beforehand. Table 2 illustrates all of the 12 events that happened during the construction process and possible benefits that could be provided if BIM was implemented at the beginning of design phase.

Project Names	Errors	Category	Benefits when Fixed
The 1st Bridge	Retail wall and bridge interference	Drawing change	Prevent rework
The 1st Bridge	Railway location mismatch	Dimension change	Prevent rework
The 1st Bridge	Girder and column level mismatch	Dimension change	Prevent rework
The 5th Bridge	Column elevation mismatch	Dimension change	Prevent rework
The 7th Bridge	Site elevation and drawing mismatch	Dimension change	Prevent rework
The 7th Bridge	Plan and side elevation mismatch	Dimension change	Prevent rework
The 7th Bridge	Section slope errors	Dimension change	Prevent rework
The 8th Bridge	Dimension errors	Dimension change	Prevent rework
The 8th Bridge	Girder and column mismatch	Dimension change	Prevent rework
The 6th Tunnel	Site boundary and entrance circulation interference	Interference simulation	Prevent rework and code violation
Test Bed Bridge	Structural interference	Redraw	Prevent rework
Railway Tracks	Girder elements miscalculation	Recalculate	Prevent rework

Table 2 – 12 errors in 7 projects without BIM utilization

 doi:10.20944/preprints201810.0019.v1

Peer-reviewed version available at *Sustainability* **2018**, *10*, 4303; doi:10.3390/su10114303

4. Analysis and Results

4.1 Cost Estimate

The first step in cost estimation is calculating the costs that are expected to increase if BIM is applied to fix the above issues. To do so, the authors have divided the work force into two types and two processes. In general, BIM can be carried out by single person, whereas some cases demand multiple experts. Hence, BIM labor is divided into two types: single and multiple labors. After that, implementation process is also divided into two: 1) making BIM itself, and 2) site investigation for BIM implementation.

All 7 projects are diagnosed if BIM was conducted before construction. Using the information from 8 engineering firms who are contracted to do design and planning, man-hour and unit fees are estimated. In table 3, each project is investigated to decide the proper type and process of labor it demands. First, the process of each project is diagnosed, and as can be seen, BIM implementation requires two processes: BIM work and site investigation for BIM implementation. BIM work requires BIM experts, whereas site investigation demands professionals from engineering field and thus, the labor cost should be distinguished. According to the interview with professionals, BIM experts are generally divided into three levels, BIM manager, BIM coordinator, and BIM modeler, where the manager is the highest paid and the modeler is the novice. In addition, professional engineers in Korea are divided into 3 three levels: beginner, intermediate, and professional, where the beginner is paid as the lowest and the professional is the highest. Subsequent to process determination, type decision was carried out to provide if the work should be done with single labor force or a collaboration of multiple workers. In some cases, both modeling and site investigation could be done with multiple labors, whereas in some other cases, BIM works need just single labor and site works need multiple labor forces. Table 3 depicts the detailed work forces, processes, and types.

Labor Cost Division	**Types**	Single Labor	(Daily labor fee) x (man-hour/8hr) x (No. of labor)
		Multiple Labor	(Daily labor fee) x (man-hour/8hr) x (No. of labor)
	Process	A-1	BIM work at office
		A-2	Site investigation for BIM implementation

Projects	**Process**	**Type**	**Level**	**Man-hour**	**No. of labor**	**Daily fee**	**Estimates**	
The 1st Bridge	A-1	Multi	BIM Manager	30	1	$873	$3,274	
			BIM Coordinator	60	1	$729	$5,468	
			BIM Modeler	120	1	$551	$8,265	
	A-2		Professional	26	1	$977	$3,175	
			Intermediate	26	1	$669	$2,174	$22,355
The 5th Bridge	A-1	Single	BIM Coordinator	100	1	$729	$9,113	
	A-2		Intermediate	26	1	$669	$2,174	$11,286
The 7th Bridge	A-1	Single	BIM Coordinator	100	1	$729	$9,113	
	A-2	Multi	Professional	26	1	$977	$3,175	
			Intermediate	26	2	$669	$2,174	$16,636
The 8th Bridge	A-1	Single	BIM Coordinator	100	1	$729	$9,113	
	A-2	Multi	Intermediate	26	2	$669	$2,174	$13,461
The 6th	A-1	Multi	BIM Manager	30	1	$873	$3,274	$17,006

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Tunnel			BIM Coordinator	60	1	$729	$5,468	
			BIM Modeler	120	1	$551	$8,265	
Test Bed Bridge	A-1	Single	BIM Coordinator	100	1	$729	$9,113	$9,113
Railway Tracks	A-1	Multi	BIM Coordinator	100	2	$729	$18,225	
			BIM Modeler	120	1	$551	$8,265	$26,490
Total								**$116,348**
Total with 10% additional allowance								**$127,983**

Table 3 – Types and process of labor and cost estimates

Table 3 illustrates the entire cost estimates for BIM implementation in this study. As can be seen, the total amount of the cost that would arouse if BIM was done before construction is about $116,348. This is based on type and process of works that are devised from interviews and surveys from 8 engineering firms. Man-hours and number of labor are also identified by the experts in engineering firms. Daily fees for BIM workers and professional engineers are published by the national government. In addition, the authors would like to note that this estimate is a relatively conservative measure as the calculation is based on the assumption if BIM was utilized for each project that was not actually placed in reality. Therefore, a 10% of allowance was added to provide any margins that may happen in reality. As a result, the total cost estimate for BIM utilization in 7 projects is about $127,983 with the marginal 15% allowance.

4.2 Benefit Estimate

To calculate benefits that come from using BIM in this case, the authors closely searched how much reworks in terms of planning and construction have occurred as described in table 2. After that, the authors have calculated the additional costs that arouse due to the reason that BIM was not implemented at the beginning. These costs are relatively easy to be prevented if BIM was used in model checking during planning stage. Because the 8 engineering firms did not implemented BIM, errors in table 4 occurred and these are simple processes if model checker function in BIM was used beforehand. In addition, the authors have divided benefits into two sections: benefits during BIM work, and benefits during construction. In some cases, because drawing check was not done appropriately, rework did happen and for that reason, increased construction fees were observed. In other cases, simple BIM work could have significantly reduced reorders in drawings.

Table 4 illustrates the total possible benefits if BIM work was conducted before construction. This cost is purely for BIM work, meaning that associated construction costs need to be estimated separately. As can be seen, the 1st bridge project demanded 4 experts with 35 days of work, resulting in about $13,850 additional costs in redrawing orders. In terms of re-dimensioning orders, about 8 experts with 14 days of reworks were placed resulting in about $3,080 extra fees. As a consequence, the total incurred costs that could have been prevented if BIM works was carried out at the planning and design stage is about $16,930.

Incurred reconstruction costs based on redrawing orders					
Estimates = (No. of labor) x (Man-hour/8hr) x (Daily fee based on level)					
Project	**No. of Labor**	**Level**	**Man-hour**	**Daily fee**	**Estimates**
The 1st Bridge	1	Manager	40	$650	$3,250

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	2	Coordinator	160	$420	$8,400
	1	CAD operator	80	$220	$2,200
Total redraw benefits that could be saved if BIM was implemented beforehand					$13,850
Incurred reconstruction costs based on re-dimensioning orders					
Estimates = (No. of labor) x (Man-hour/8hour) x (Daily fee based on level)					
The 1st Bridge	2	CAD operator	24	$220	$660
The 5th Bridge	1	CAD operator	16	$220	$440
The 7th Bridge	2	CAD operator	40	$220	$1,100
The 8th Bridge	2	CAD operator	32	$220	$880
Total re-dimension benefits that could be saved if BIM was implemented beforehand					$3,080
Total benefits that could be saved if BIM was implemented beforehand					**$16,930**

Table 4 – Total possible benefits that could be saved during BIM work

Because of the above rework orders, there have been reconstruction orders as well. To properly estimate the associated costs in reconstruction orders, the authors divided reconstruction into two phases: labor costs and material costs. Because reconstruction involves multiple processes, it is relatively hard to precisely capture all the associated works and calculate the costs. Therefore, the authors decided to simplify the associated costs of reconstruction into two. In addition, because this estimate is based on just physical amount of labor and materials, delayed construction due to rework needs to be inclusive. It means delinquency in the entire construction process should be calculated to properly reflect all the associated risks that incurred because of reconstruction orders.

As can be seen in table 5, the total amount of labor fee incurred by rework in the bridges 1, 7, and 8 cost about $71,417 and the total amount of associated materials fee is about $78,139. As a result, the total amount $149,556 could have been unnecessary if BIM was utilized at the planning stage and model check was performed. If so, minimal errors such as interferences and mismatches could be easily replaced before construction, making it much less costly and require less time to finish the work order.

Projects	**Errors**	**Solution**	**Estimates**	
The 1st Bridge	Retain wall and bridge interference	Rework	Estimate = (Volume) x (Unit fee)	
The 1st Bridge	Girder and column level mismatch	Rework		
The 7th Bridge	Site elevation and drawing mismatch	Rework		
The 8th Bridge	Girder and column mismatch	Rework		
Labor fee estimate because of reconstruct				
Projects	Construction	Unit fee	Volume	Estimates
The 1st Bridge	Retaining wall	$47	1,016M3	$47,752
The 7th Bridge	Sound-proof wall	$40	540M3	$21,600
The 8th Bridge	Concrete casting	$93	22.2M3	$2,064.6
Subtotal				$71,416.6
Material fee estimate because of reconstruct				
The 1st Bridge	Retaining wall	$3	1,016M3	$3,048
The 7th Bridge	Sound-proof wall	$139	540M3	$75,060
The 8th Bridge	Concrete casting	$1.4	22.2M3	$31.08
Subtotal				$78,139.08
Total construction fees because of rework				**$149,555.68**

Table 5 – Total possible benefits that could be saved because of avoided reconstruction

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As mentioned earlier, to properly capture the benefits that a BIM could bring to the case, delayed construction days should be considered as well. Because of reorders in drawings and construction, there surely have been delays in the entire construction schedule. However, as the construction process does not occur independently, precisely capturing the delayed schedule due to the reorders is often times a very difficult task. The authors have reviewed all the construction schedules and daily notes on the site, but it was impossible to pinpoint the delays that appeared to be responsible because of the above reorders. Therefore, the authors decided to implement liquidated damages instead.

In general, construction industry in Korea includes the maximum of 15% of the total construction costs as a liquidated damage and the maximum legal delay in construction is up to 300 days. It means the liquidate damage is calculated based on 0.05%/day, and if there is any delay in construction schedule, 0.05%/day could be applied to calculate the liquidated damage. In this case, because capturing the precise delay due to the errors is a hard task, the authors calculated an estimate in terms of sensitivity of liquidate damage. If redrawing and reconstruction could have generated a month delay in construction schedule, then 1.5% of damage could have been added to the total costs. In other words, if BIM was implemented and could have captured all the errors defined in the previous calculations, then 1.5% liquidated damage could have been saved in a month, reducing the risk of construction uncertainty. Therefore, 1.5% could be regarded as benefits of using BIM in this case.

Table 6 illustrates possible liquidated damage based on different lengths. Since the cost of this study only involves cost for each error, liquidated damage is applied only to the errors that are covered in this study. This may be a very conservative approach in calculating opportunity costs. However, to enhance the validity of the research outcome, the authors decided to include liquidated damage to rather smaller areas, not to the full contents in construction costs. As can be seen, a month delay could increase about $2,500 in liquidated damage and a 3-month delay could make the total costs up to $173,978. This means if BIM was utilized at the beginning of planning and design, then the range of savings in liquidated damage could be $2,500 in a month to $7,492 in three months.

Delay	Initial costs	Damage %	Liquidated damage	Total
+1 month delay	$166,486 ($149,556+$16,930)	+1.5%	**$2,497.3**	**$168,983.3**
+2 months delay		+3.0%	**$4,994.6**	**$171,480.6**
+3 months delay		+4.5%	**$7,491.9**	**$173,977.9**

Table 6 – Liquidated damage based on different length of construction delay

4.3 Benefit-Cost Analysis

Based on three estimates, BCA can be conducted. The cost can be identified as where BIM was utilized in planning and design stage. The total upfront costs required to provide a BIM for 7 projects were $116,348 and if a 10% margin is added, then the cost goes up to $127,983. This is the necessary costs to construct a BIM to fix the errors in 7 projects of the site. On the other hand, the total costs required to fix the errors in 7 projects were $166,486. This can be regarded as the benefits of using BIM because if BIM was implemented then the associated errors are relatively easy to capture. In addition, because of these errors, there could have been delayed construction and this risk was calculated based on the liquidated damage. If 12 errors have caused a one-month delay, the liquidated damage would be $2,498. In this extent, the total benefits could be

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regarded as $168,984 to $173,978 depends on the length of delayed construction. Therefore, the benefit-cost ratio can be estimated as 1.32 for one-month delay and 1.36 for a three-month delay. Table 7 illustrates the final result.

BIM cost	Design rework benefits	Construction rework benefits	Liquidated damage benefit	Total benefits	B/C
$127,983 (10% allowance)	$16,930	$149,556	$2,497.3(1.5%)	$168,984	**1.32**
			$4,994.6(3.0%)	$171,481	**1.34**
			$7,491.9(4.5%)	$173,978	**1.36**

Table 7 – Benefit-cost ratio based on different liquidated damage

5. Conclusions

This study is intended to capture possible financial benefits that a BIM could bring to a real project. Although the railway test bed did not applied BIM into its construction cycle, the authors were successful to identify 12 errors that could be solved if BIM was implemented at the beginning of design and planning phases. Similar to previous studies, adopting surveys and interviews with the experts could have provided an in-depth observation in BIM application. All 12 errors are relatively simple ones that could be detected if BIM was adopted. Using a model checker or model reviewer, interference, dimension mismatch, and dimension errors can be easily resolved in the BIM environment. However, because the project did not imply any BIM environment at the beginning, rework was carried out in two phases, rework in design and rework in construction. Eventually, these two created additional costs and risks.

Those 12 errors are found where actual reconstruction was placed and rework on drawings has occurred. It means benefit calculation in terms of CAD rework and construction rework are actual investments that were made due to the 12 errors on the site. BIM cost was the only segment that did not occurred in this project, requiring data from 8 engineering firms in their BIM experiences. It means although this study is not purely realistic, it indeed is founded on a real project. As mentioned earlier, all the experts from 8 engineering firms have agreed that if BIM was supplied at the beginning, then the 12 errors and associated costs could have reduced significantly. It means the use of BIM at the planning and design stage could have played more important roles in cost reduction and eventually risk management as a whole.

B/C ration over 1.3 may sound too promising, nor does it guarantee all projects using BIM will enjoy the same benefits. Nonetheless, providing an alternative perspective that could suggest a foundation in benefits of using BIM may enable a new opportunity for future applications. BIM was introduced in less than 40 years. If we are to judge whether the success of BIM in construction industry, then shouldn't we have more diversity in real cases? More empirical studies should be followed to robust the findings in this study about the effectiveness of BIM in a real project. In addition, not only for architectural projects, but some other projects in urban and infrastructure scale should be tested to provide more fruitful outcome in this area.

Acknowledgments: This study is supported by national research grants *"15RTRP-B104239-01-000000: Development of BIM-based standard management technology for railway infrastructure"* from the Ministry of Land, Infrastructure, and Transport in South Korea. The authors would like to appreciate our deepest gratitude for support from the government.

Author Contributions: Min Ho Shin prepared the entire research framework and managed the manuscript; Hwan Yong Kim has prepared initial data, analysis check, and manuscript submission. Hye Kyung Lee prepared for interviews and surveys with the professionals.

Conflicts of Interest: There is no conflict of interests.

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