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Structural Equation Model of the Factors Affecting Construction Industry Innovation Success

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ABSTRACT

Innovation is seen as one of the major factors to improve construction industry despite conventional structure of the industry impede implementation of its practices. A convenient solution to promote innovation or force the companies to adopt it, is the legal regulations that can be set forth by the decision makers of whom aware and prevailed of the macro benefits of innovation practices. However, the impact of innovation practices on industry indicators was not defined adequately to understand those benefits. This study aims to reveal the relationship between company-level innovation success measures and industry-level innovation success indicators. Therefore, a comprehensive literature review was performed to determine those success measures and indicators and the results were validated with an illustrative case study. The outputs of the case study was used to construct structural equation model exhibiting the interdependencies between factors. The study results approved that there is a significant relationship between the innovation practices of construction companies and construction industry innovation. According to the results, increase in competitive advantage among rivals and improved reputation were seen as the two highest indicators in the company-level. Additionally, the study showed that the most important innovation success indicator at the industry-level was found as "employment and new job opportunities".

Keywords: Innovation, structural equation modeling, building information modeling, construction industry.

1. INTRODUCTION

The improvements in process, technology, and organization in the construction industry so-called -construction innovation- accelerate economic growth and productivity [1]. One of the major driving factors behind the development of construction industry is the globalization leading companies to take strategic innovative decisions in terms of -employee, technology,

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marketing, knowledge, and relationships- to survive and maintain their competitiveness [2,3]. The construction industry correspondences 15 percentages of gross domestic production (GDP) in the World [7]. Therefore, nation-wide innovation strategies will not only contribute to the profitability of construction companies, but will also increase construction industry figures and indirectly nations' GDP. For example; Utterback and Suarez [8] stated that a couple of firms could dominate the industry with product technology obtained by innovations. Such instances can be especially seen in information technology (IT) industry where high tech companies' annual turnover exceeds many countries' GDP [9].However, construction innovations such as "improvements of construction methods or sequences, application or extension of methods, application of new equipment or tools, and existing methods" have not been reported or recorded explicitly [4-6].

In the literature, construction innovation related studies were performed under five categories such as "construction innovation diffusion", "organizational factors' impact on construction innovation", "the origin of innovation (technology-push or pull)", "commercialization of construction innovations" and "national efforts for construction innovation" [10]. The literature review parallel to Toole [10]'s findings showed that the studies were mainly performed on developments of guidelines, construction innovation drivers, organizational structure and cultural factors, process identification with successful innovations, owner role, manufacturers' role, innovation sources, innovation models, diffusion, root causes for construction innovations, national approaches/government role, academia-industry cooperation, industry level innovation factors, innovations at project level, barriers, innovation management system, development of framework, and case study implementations with successful example [11-37]. . The literature indicated that many authors attempted to determine innovation success indicators on the company or project level, however, construction industry-specific performance studies were rare.

For instance, Lim et al. [38] used annual turnover of construction companies, annual research and development expenditure, the percentage change in construction value-add per person employed, the research and development capacity and the number of responsible personnel, to measure innovation activities and their impact on the construction industry. Also, Zhang et al. [39] not specific to construction industry contended that innovations are essential to enable national competitive advantage, resource optimization, workforce, and social welfare. Furthermore, Bygballe and Ingemansson [40] stated that there was a debate about the compatibility of existing measures for the construction industry that was stated in Lim et al.'s study [38]. According to Zubizarreta et al. [41], these measures were not appropriate for the construction industry. Additionally, Loosemore [5] agreed that measurement of innovation in the construction industry was provided with data adopted from other industries since construction innovations are not identified or detected in the project level [35]. However, Brockmann et al. [42] stated that "innovation in construction is defined as changes leading to an improved input-output relationship for products and processes as well as within the technical, management, or legal organization of a project that can be evaluated monetarily." which in turn have tremendous impacts on cost, time and quality issues inevitable for the construction industries' success.

Moreover, some authors claimed that construction innovation is an added value activity for the construction industry [35]. However, neither more comprehensible innovation success indicators of the construction industry have been identified, nor the relationship between the measures of construction companies innovation success and the indicators of the construction industry innovation success have been investigated. Therefore, this study aims to fulfill the gap by developing indicators which could be used or employed the boost innovation performance of construction industry and to reveal the relationship between the measures of construction company innovation success and the indicators of construction industry innovation success. From this perspective, first of all a comprehensive literature review was conducted. To validate findings of the literature review and to set hypothesis, an illustrative case study was performed. Finally, a measurement model indicating the innovation-related factors specific to the construction industry and a structural model representing the interrelationships between those factors were proposed to assess the impact of innovation in the construction industry. In this context, data collected from 52 construction companies were analyzed using Structural Equation Modeling (SEM) to verify the proposed measurement and structural model. The findings of the study, and set forth relationships between construction industry indicators and companies' innovation success measures showcased, would reveal a roadmap for new developments that make sense for construction industry professionals and decision makers.

2. RESEARCH METHODOLOGY

The research methodology followed in this study consists of "*identification of model variables with a comprehensive literature review, validation of literature review results with illustrative case study, and questionnaire survey to construct model, analysis of data, and model creation with SEM methodology*". In this study, two research methods were used. Firstly, findings from literature review were verified with an illustrative case study. In the illustrative case study, two type open-ended questions were asked to three high level executive manager interviewees working in the companies placed in Engineering News Record 2018 Top 250. In the first question, it was asked from the respondents to associate identified indicators given under the measures of construction company innovation success with BIM implementations in their companies. Secondly, it was asked, whether they observe the implications of indicators of the construction industry innovation success as the representatives of leading companies in construction industry. After that, the proposed model was verified with SEM to enable the measurement of unobservable parameters by observed parameters. In the questionnaire, the questions -"Please indicate importance level indicators which are given under the measures of construction company innovation success according to your company implementations" and "Please indicate importance level variables which are given under the indicators of the construction industry innovation success according to your companies' innovation results"- were asked to the participants. The proposed model consists of two constructs: the measures of construction companies' innovation success, and the indicators of success in terms of the construction industry. In order to measure these constructs, indicators were evaluated by respondents according to a 1 to 5-point Likert scale. The questionnaire was sent to 141 construction company members of the Turkish Contractors Association (TCA) via e-mail and conducted to 52 companies accepting to perform face-to-face interviews (37% response rate). The respondent companies are specialized mainly on buildings 85%, waterworks 15%, transportation 21%, industrial 23% and infrastructure 17%. The respondents' average experience is approximately eight years.

3. PROPOSED MODEL VARIABLES

The measures of "Construction Company" success such as, "increase in higher perceived value", "decrease in costs", "time savings", "increase in competitive advantage among rivals", "improved reputation/company image", "productivity enhancements", "increase in growth, market share and profit", "improved learning and development process", "increase in satisfaction of customer/consumer"; and indicators of "Construction Industry" such as, "contribution to the development of supporting industries", "employment and new job opportunities", "opening up new markets (exporting construction services)", "increase in turnover and production", and "decrease in material and labour wage" were determined with a comprehensive literature review and presented in Table 1.

Table 1 - Measures and indicators

Factors	Indicators	References
The measures of construction company innovation success	Increase in higher perceived value	[1, 11, 13-15,20, 22-25, 27-28, 33, 37-38, 50, 55, 60-61,63]
	Decrease in costs	[1, 4-5 10-11, 13, 15-17, 21-23, 28, 30, 35, 38, 42-43, 45, 47, 50-52, 54-55, 57, 60-61, 63]
	Time savings	[4-5, 10-11, 13-15, 22, 28-30, 35, 38, 50, 54, 57, 60-61]
	Increase in competitive advantage among rivals	[1, 4, 11, 13, 17, 19, 22-24, 27-28, 30, 33-37, 38, 43-44, 48, 50, 52-54, 58-60, 63-64]
	Improved reputation/ company image	[1, 15, 17-18, 23, 28, 30, 38, 50, 54, 57, 60, 63]
	Productivity enhancements	[1, 10-11, 13, 16-17, 21, 25, 28, 30, 33, 35, 38, 42, 44-45, 47, 50-52, 54, 57, 59-60, 63]
	Increase in growth, market share, and profit	[1, 3, 10-11, 17-18, 20-24, 28-30, 35, 38, 44-45, 50, 52, 56-57, 59-60, 63]
	Improved learning and development process	[3, 13, 27-28, 30, 46, 50, 52, 54, 56-60]
	Increase in satisfaction customer/consumer	[10-11, 15, 20, 23-24, 28, 38, 43-44, 50, 55-57, 60, 63]
The indicators of the construction industry innovation success	Decrease in material and labour wage	[1, 10-11]
	Increase in turnover and production	[1, 21-22, 35, 50]
	Employment and new job opportunities	[1, 3, 11, 15, 17-18, 25, 27, 58]
	Contribution to the development of supporting industries	[10-11, 13, 15-16, 23, 35, 49-50, 53-54, 58, 62-63]
	Opening up new markets (Exporting construction services)	[3, 12-13, 17, 22, 27, 30, 38, 43-44, 48, 63]

4. THE ILLUSTRATIVE CASE STUDY

In this research, an illustrative case study methodology was employed to gain a better understanding of the effect of innovation outcomes on the construction industry. Thus, the validation of literature review results were tested to gather more meaningful results with a practical implementation related to innovation indicators in the construction industry. Gerring [65] defined case study methodology as "the intensive study of a single unit for the purpose of understanding a larger class of (similar) units". Barlish and Sullivan [66] stated that a case study is more beneficial to understand the advantages of innovative information technologies such as Building Information Modeling (BIM) since it highlights the issues that are difficult to describe based on only empirical data. Eisenhardt [67] stated that collocation of qualitative and quantitative data in the case study method provides an increase in the creativity and the reliability of the study. The qualitative part of the study is to conduct illustrative case study. Results of the case study give insights about reliability of the literature review, hypothesis creation and relationships used in the model. As for the quantitative part of the study, the SEM method was introduced to analyze results of the illustrative case study.

4.1. Building Information Modeling (BIM) as a Disruptive Technology

BIM is an example of radical innovation for the construction industry [67]. The benefits of BIM use in an organization cannot be limited to solely as a technological improvement since it also changes the way how operational processes will be handled [68]. The literature clearly stated a lot of definitions for BIM; Aranda- Mena et al. [69] stated innovative characteristics of BIM as; "a new software application; a process for designing building information; a whole new approach to practice and advancing the profession which requires the implementation of new policies, contracts and relationships amongst project stakeholders". In the construction industry, it is believed that BIM is a remedy for problems because it enables them to be modelled prior to construction. For example, when BIM softwares are used, it is seen that they have the capability of manipulating a geometric representation of building elements and generating locations for these elements due to its parametric object-oriented architecture [70]. This enables realistic calculations and accurate planning in advance. BIM offers companies a variety of opportunities to get better results in their projects. Moreover, some of these opportunities show parallels with the gains from innovation actions that was mentioned in previous sections. Therefore, BIM technology was chosen as a case topic. Also, BIM adoption with different level requirements (Level 0, Level 1, Level 2, and Level 3) introduce new technological applications and challenges to construction companies. Additionally, BIM obligations, BIM utilization mandate for the projects, BIM standards, BIM Guides and different level requirements for BIM utilizations by countries trigger construction companies in terms of innovativeness increasing technology transfer capability [71]. Therefore, BIM is a hot topic to adapt it in the companies. Moreover, Becerik-Berber and Rice [72] stated that construction companies have problems with cost, time, conflicts etc. and they cause loss of 3-4% of total industry turnover. Also, the authors stated that BIM as an innovation can be a remedy of the productivity of construction industry.

In the literature, Papadonikolaki [37] handled BIM as an innovation and the author investigated BIM diffusion in the companies. However, the study was only focused on BIM adoption and its implementation in the companies. In this study, BIM was used to validate indicators comprehended from a literature review. The indicators used in the proposed framework is general and they are applicable to different innovations.

4.2. Illustrative Case Study Implementation

The three companies chosen for the illustrative case study hold a significant market share in the domestic and international market as being placed in Engineering News Record 2018 Top 250 International List. The chosen companies are the leading companies in terms of sustainable construction implementations, energy investments, hotel, hospital, factory, residential housing, infrastructure, office and shopping mall projects. Another reason for choosing these companies is that they are multinational companies. They deliver service in European and Middle East countries. Furthermore, market leadership of these companies is not limited with national industry, but the companies are also open to new markets, technological advancements, innovations and demonstrate a high capability and adaptability. When conducting the three case studies, face-to-face interviews were performed at the managerial level. The case study was conducted with open-ended questions. The questions asked were designed to find out the impact of the company's innovation success on the company's output since industrial figures are the collective results of a company's performance. Interviewees have top management tasks in their companies and have experience of more than ten years.

BIM technologies have been used actively for five years by Company A. They have preferred Allplan and Revit BIM software in their company. In the project history of Company A, BIM technologies have been implemented in five projects. Furthermore, the company has provided employment for ten white-collar workers in order to perform the BIM-related work. The company has used BIM technologies heavily within the bill of quantities for projects and for mechanical, electrical and plumbing (MEP) coordination. In addition to the bill of quantities and MEP implementations, they have started to use BIM technologies for projects developed in the national market. In Company B, BIM technologies have been used more than ten years. BIM has been used in both facilities management and in the planning phase. Through the BIM technologies, they can perform 3D modeling of the project, detection of clashes, MEP implementation, energy analysis and bill of quantities. Company B has exploited BIM technologies actively through facilities management. Company C had experience of BIM over more than five years and started to use BIM as a project contract necessity. They have used BIM technologies in the design phase and in MEP implementations. They have also benefited from 3D modeling, bill of quantities and detection of clashes.

According to Company A's bill of quantities implementation, BIM has provided opportunities to more accurately control working hours and material quantities. This process helped to reduce "material and labour wage" compared to classical methods in the company process because it was stated that construction sequencing and parametric modeling of building components can be seen easily with BIM. This prevents mishandling of projects and wastage in terms of material. In other words, rework activities can be reduced with BIM by helping design quality improvements [73]. As a common comment from participant companies, BIM, with quality increments and a well-organized operational structure, helps companies achieve "increase in profit and production". For example, Company B used BIM for a project they were awarded in order to increase expected concession periods by virtue of improved quality in minimizing the construction process.

Also BIM implementation in the companies increased workers' qualifications. With the help of BIM, the companies employed more qualified workers for the bill of quantity works. Furthermore, in Company C, the project owner demanded project planning with BIM. Therefore Company C had to launch a BIM department specific to the project. This led to new job vacancies in the company. In contrast to Company C, Company B has a permanent department for BIM due to its facilities management. The capability of BIM utilization with different level of details has led to "increase in competitive advantages between the companies" within the international market. The quality increments achieved through BIM implementation helped the company to be awarded, and take part, in international projects. For example, in the Middle East countries, BIM has been used as a qualification requirement for contractors because this qualification is the representation of quality in design, construction and operational stages of projects. As stated before, Company C started using BIM as a result of this contract clause.

As stated in Azhar's [74] study, BIM technology helps towards cost savings in projects. In parallel with Azhar's [74] findings, the case studies acknowledged that innovation such as BIM helps to "decrease in costs". Therefore, cost and time wastage are eliminated by the help of BIM. Company A clearly stated that BIM technologies help to monitor and eliminate unnecessary "material and labour wages" in the management of the projects [75]. Also, elimination of the unnecessary costs helps to "industry turnover". Additionally, Company C stated that a clash of MEP designs is a costly problem in conventional project management. However, BIM, with Navisworks tools, helps them to save significant monetary resources in projects. This utilization of BIM directly affects "decrease in costs". Company B also stated that these tools helped them to observe the financial status of the project. If they have to take corrective action, it helps them in the decision-making process. As a common view among the case study companies, "decrease in costs" reflects directly on the "increase in turnover and production" of the companies. Usage of BIM technolgy also leads to an increase in the company's competitive position. For example, Company B benefited from BIM in estimating yearly expenditures and revenue in the operational phase [76]. Therefore, they can use BIM as a competitive tool against their rivals. This provides more accurate historical data when bidding for new projects. All companies agreed that the tools have helped companies to win projects in the international arena since they were able to plan more accurately. According to Company C, the company's BIM competence provided them with the means to participate in the tender process, and provides more advantages to help them win bids. This also helped to protect the company's position in the international market, to provide job vacancies or attract more talented workers and to "increase in industrial turnover and production".

Latiffi et al. [77] stated that BIM applications help to monitor work sequence, equipment and materials in companies. According to their findings, the authors advised their government to develop BIM technology in order to increase their efficiency and effectiveness industry-wide. Following on from the literature review, interviewees were asked to judge what impact "time savings" – by using BIM technologies – had on industrial indicators. In Company A, the impact of "time savings", and of "material and labour wage", was seen as very limited because a subcontracting method was extensively used in their projects. However, an interviewee from Company A stated that BIM-based technologies for MEP projects provided a more effective solution for coordination and production in the projects. Also MEP applications using BIM provided time savings in project planning and execution. In contrast to Company A, the manager of Company B said that BIM technologies helped them reduce change orders [74]. Also, Company C stated that these tools can be used in claims and that they proved their claims with these tools. Therefore some problems can be solved without requiring a court or using arbitration procedures [75]. In addition to these findings, Company C stated that BIM helps to coordinate project partners. This enables efficient and effective communication between project stakeholders. All managers agreed that "time savings" with BIM helps "increase in turnover and production". Therefore, this can help protect their position in international markets.

The findings related to the impact of “reputation and company image” on industrial output in the literature were supported by Qian’s [75] study. According to that study, BIM technologies provide them with a better company image, help them make less mistakes and errors and provide strategic competitive advantages. Interestingly, the manager of Company A stated that the reputation and company image gained through implementing BIM helped the company to get more projects in the international market, and the technology helped with the company’s international project strategies. In addition to the view of Company A, Company C has used technologies like BIM to improve their company image in order to be a bidder in some tenders, and this helps protect their international market position and “exporting construction services”.

“Productivity improvements” with BIM can be observed at the company level. Here, BIM implementations help with project documentation, estimating “cost and time savings” in productivity during the operational phase [74]. The manager of Company A stated that BIM helps to keep employees more satisfied than with classical methods. To explain this, he gave an example of where white-collar workers now called themselves 3D modellers, even though they had already previously been performing the same tasks. This also helps lead to an increase in worker productivity. This impact was also observed in the bill of quantities, which became easier and was more accurate. This has helped with “material and labour wage”. Therefore BIM implementation can deliver productivity advantages in the international market arena. It was also stated that integrated project planning with BIM provides the flexibility to easily implement project change orders, using the example of implementing column size changes on an existing project. In parallel to Azhar’s [74] study, the manager of Company B stated that BIM helps to effectively document the project. It also helps to decrease architectural expenditure because it minimizes the time for the project design. This reflects directly on a company’s profit and production.

The financial benefits of BIM technologies on a company’s output attracts lots of companies to use it. As stated in Becerik-Gerber’s [72] study, BIM helped staff requirements and enabled changes to be identified and implemented at the design phase, which is cheaper than changes at the construction phase. Interestingly, the manager of Company A stated that being innovative with BIM technologies increases the financial creditability of the company. Therefore the company had a “competitive advantage” in the international market. Moreover, the manager of Company C stated that earnings at the project level helped to sustain the financial status of the company. So Company C can deliver services in the international market and provide” new job opportunities” by way of international projects. Also, they used some construction material from Turkey such as marble etc., which therefore contributed to the development of supporting industries.

The another result obtained from literature review is increase in learning and development with innovation implementations. According to the manager of Company A, BIM cannot be implemented in every company’s projects because of customer requirements, profitability of the project and competitiveness of the company awarded the project. Therefore, the company appealed for know-how about BIM technologies to improve their ability to run a BIM-based project. This provided capability for both learning and development of the company and qualification of its workers. Therefore, any acquired know-how and technology can be used when tendering for projects requiring new technologies like BIM. Company B gained an advantage with BIM in the prefabrication of some construction elements. Therefore, Company B can contribute to the development of supporting industries in the prefabrication phase. However, the process cannot be fully utilized for prefabrication features of BIM when comparing with other international company counterparts. This finding also acknowledged Azhar's [72] study findings about future BIM utilization in prefabrication.

"Increase in satisfaction of customer/consumer" is an important criterion for companies in a project. In this context BIM technology provides promising features for companies. For example, in the literature, it was stated that BIM provides better customer services with visual representation [78]. However, the projects Company A conducted with BIM technology belonged to the company's real estate property, so this question wasn't answered. Company B has actively used BIM in the operational phase. This helps management of facilities by both considering customers' expectations and their numbers.

5. IMPLEMENTATION OF STRUCTURAL EQUATION MODELING (SEM)

The SEM, connecting observable variables to unobservable variables, is a method in which causal relationships between unobservable variables are examined. It consists of a combination of a measurement model (confirmatory factor analysis) and a structural model (regression or path analysis) [79]. In the SEM methodology, various statistical methods are used together to create a validated model. These methods are factor analysis, multiple correlation, regression and path analysis [80]. The distinguishing specialty of the SEM method compared to other statistical methods is that it enables the use of unobservable variables. This allows problem representation to be accurately handled by variance and covariance analysis [81]. Moreover, the SEM method gives researchers an opportunity to research or test whether collected data supports a model designed by the researcher or not. Also SEM is a comprehensive methodology since it considers multiple relationships between factor structures [80]. The SEM methodology contains two steps. In the first step, factor structures are tested with bidirectional impacts to reveal the reality of the relationships between factors [82,83]. The structural model is the second step in which causal relationships between latent variables are investigated. In other words, defined relationship in measurement model is defined in the structural model [83]. In the structural model, every relationship corresponds to a hypothesis. And these relationships are tested to validate asserted model. Basically, in this study, hypothesis that -there is significant relationship between indicators of construction companies' innovation success on the indicators of success of the construction industry- was tested.

Table 2 - Fitness indices for measurement and structural models

		Measurement Model		**Structural Model**
Fit indices	**Allowable range**	**F1**	**F2**	**Final model**
Non-normed fit index (NNFI)	0 (no fit) to 1(perfect fit)	0.973	0.969	0.848
Comparative fit index (CFI)	0 (no fit)-1(perfect fit)	0.980	0.985	0.873
RMSEA	< 0,1	0.048	0.050	0.090
$\chi 2$/degree of freedom	< 3	1.118	1.1258	1.4088

The Goodness of Fitness Indices (GFI) and construct validity were used to verify the model since it investigates fitness between the model and the collected data. In this study, GFI were chosen to be the non-normed fit index (NNFI), the comparative fit index (CFI), the root mean square error of approximation (RMSEA) and the chi-square model due to their common use in the literature. The measurement and structural model structures (F1- indicators of construction companies' innovation success, and F2- indicators of the success of the construction industry) presented a nearly perfect fit as seen in Table 2.

Table 3 - Latent and observed variables of the model with factor loadings

F1	The measures of construction company innovation success	Factor Loadings	F2	The indicators of the construction industry innovation success	Factor Loadings
V1	Increase in higher perceived value	0.605	V10	Decrease in material and labour wage	0.632
V2	Decrease in costs	0.770	V11	Increase in turnover and production	0.578
V3	Time savings	0.769	V12	Employment and new job opportunities	0.773
V4	Increase in competitive advantage among rivals	0.784	V13	Contribution to the development of supporting industries	0.519
V5	Improved reputation/company image	0.779	V14	Opening up new markets (Exporting construction services)	0.419
V6	Productivity enhancements	0.718			
V7	Increase in growth, market share and profit	0.567			
V8	Improved learning and development process	0.672			
V9	Increase in satisfaction of customer/consumer	0.595			

Construct validity consists of content validity, scale reliability, convergent validity and discriminant validity. Content validity testing was performed with a literature review without making a statistical analysis. In the study, 14 variables were specified and they were acknowledged with a pilot study. Scale reliability is measured with Cronbach's alpha value, which gives information about the relationship of observed variables to their latent variables. This value must be 0.7 as a minimal condition [84]. According to the analysis of the model, the value was found to be 0.891 for the measurement model of the measures of construction company innovation success. The value for the measurement model of the indicators of the construction industry innovation success was found to be 0.718. As can be understood from these values, this constraint was met. Convergent validity is examined with factor loadings. In order to fulfill convergent validity, observed variables must be statistically significant at $\alpha = 0.05$. As a result of the convergent validity analysis, all variables and factors were found statistically significant. Furthermore, variables that have a value less than 0.3 are eliminated. In our model, the nearest value was 0.419. Therefore, no variable was excluded from the model. The results are given in Table 3. For discriminant validity, correlation between the variables under the same latent variable is investigated. The correlation value between variables must be less than 0.9 [85]. According to the analysis, all values stayed below 0.9. After the implementation of the structural analysis, the model results gave acceptable values. An interpretation of the findings is presented in the following discussion part.

5.1. Discussion of SEM Results

According to the analysis of the measures of construction company innovation success, and the indicators of construction industry innovation success, the path coefficient is 0.862. This shows that the relationship between the two is very strong. (See Figure 1)

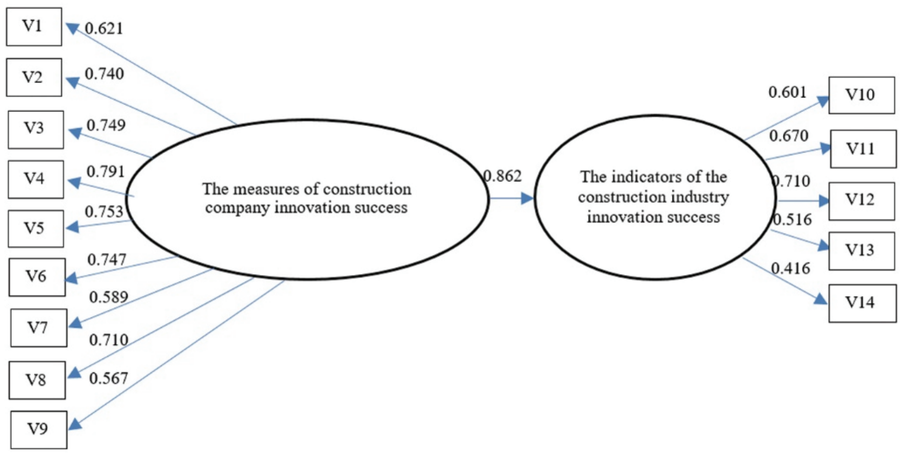

Figure 1 - The measures of construction company innovation success impact on the indicators of construction industry innovation success

5.1.1. The Measures of Construction Company Innovation Success

In the study, nine observed variables were taken into consideration in line with the literature review. All considered variables were found to be significant as a result of the SEM analysis. According to the analysis, factor loadings of the structural model were found to be 0.621 for increase in higher perceived value (quality), 0.740 for decrease in costs, 0.749 for time savings, 0.791 for increase in competitive advantage among rivals, 0.753 for improved reputation/company image, 0.747 for productivity enhancements, 0.589 for increase in growth, market share and profit, 0.710 for improved learning and development and 0.567 for increase in satisfaction of customer/consumer. As the findings were compared with Ozorhon et al.'s study [57], variables show compatibility with their findings – except for quality and competitive advantage among rivals which weren't considered in their study. In contrast, the increase in competitive advantage among rivals was found to be the most significant factor affecting a companies' innovation success. Additionally, this relationship was also confirmed by the study of Lim et al. [38]. Another difference between the studies involved increase in higher perceived perception or quality. Arditi et al. [45] stated that innovative developers in the construction equipment industry provide advancements in quality when they simultaneously compete for market position. Furthermore, findings showed compatibility with the study by Xiaolong et al. [86]. According to their study, outputs of innovation provide a time savings and decrease in costs, productivity enhancements and improved corporate image. As was mentioned in the definition of indicators of construction companies' innovation success, no surprising results emerged.

5.1.2. The Indicators of the Construction Industry Innovation Success

The indicators of the construction industry innovation success were evaluated in terms of five factors. These factors were chosen according to the relationship between the innovation efforts of companies and the industry. The factor loadings of these variables were found to be 0.601 for decrease in material and wage costs, 0.670 for increase in turnover and production, 0.710 for employment and new job opportunities, 0.516 for contribution to the development of supporting industries and 0.416 for opening up new markets (exporting construction services). According to the data analysis, employment and new job opportunities were found to be the highest variable, followed by decrease in material and wage labour, increase in turnover and production, contribution to the development of supporting industries, and the opening up new markets, respectively.

The study revealed that there is a positive correlation between innovation and employment and new job opportunities. To achieve positive outcomes which are presented in Table 3, the construction companies should recruit new graduates or open new employee positions in the company so that innovation or creative ideas can be enhanced and facilitated within the company. Therefore, the companies contribute an increase in employment rate in the industry [3, 11].

Another important finding from this study is that "decrease in material and wage costs" via innovations was found to be the most critical second indicator. Toole [10] stated that by the help of innovations, building product could be moved from on-site production to off-site production (factories). Slaughter [1] mentioned the intangible benefits of innovations and stated that technological improvements provided achievable construction productions for customers. This demonstrated that competition for equipment and materials, and new methods of innovation, exert pressure to decrease in costs.

The third highest score belonged to an increase in turnover and production. This can be explained by the importance given to innovations by governments [35]. They have constituted new regulations and incentives to attract new developments in the construction industry since the industry represents a significant proportion of the economy. Therefore, industrial savings and production efficiency through new developments benefit government earnings simultaneously. Also, Koellinger [87] investigated relationship between innovation and turnover development, and employment development. The study results approved that there is positive relationship between innovation and turnover and employment growth.

The fourth highest score was found as contributions of innovations to the development of supporting industries. Some authors expressed that the contractor has an intermediary role between manufacturers and clients since the contractors provide adaptation of innovations or new components in the project to meet the requirements [54]. Furthermore, Rundquist et al.

[53] expressed that supporting companies are not represented at the construction sites. Therefore, the problems which arise from site needs to be conveyed to supporting companies such as material companies via contractors. It means that collaboration for new developments between stakeholders are facilitated. In other words, the construction industry directly affects the development of local material industries.

Technological improvements or developments can be used as a leverage to help companies expand abroad. Edum-Fotwe [48] expressed that the competition between companies is not limited to nationwide. To maintain competitive advantage, the companies need to consider foreign companies' competitive advantages (innovations, technologies, etc.) as well [38]. Also, Podmetina et al. [88] performed a study which investigate relationship between innovation activities and exportation activities for all industries. The study results showed that there is a significant relationship between them. Therefore, the result of the SEM analysis acknowledged that innovation activities of the construction companies aid export activities as an industry outcome indicators positively.

Thus, the construction industry success provided with innovation related success of the companies was validated with the SEM model developed, as well as the findings of the literature review and illustrative case study.

6. LIMITATIONS OF THE STUDY

This study involves limitations as summarized below:

1. Though most of the respondents of the questionnaire and all the interviewees of illustrative case study were representatives of leading companies listed in international indexes, the study results represent more the dynamics of companies and industry in developing countries since data were collected from companies located in a developing country. To comprehend the model, the study can be implemented in developed countries' construction industries as well which can give more insight about the innovation process in the construction industry.
2. The study focused on measuring the impact of company related innovation success on industry related innovation success. Therefore, macro-economic related policies, relationships, intra-company, or environmental impact on companies were not considered. Further studies can be extended by considering these factors.
3. Moreover, findings from the study includes the idea for different project types. Therefore, the further studies can be performed by focusing on separate project types.

7. CONCLUSIONS

Technological and innovative advancements open new perspectives for any industry. The technological improvement of companies gain importance also in the construction industry since construction industry significantly affects a country's economy due to its huge share in national income. These improvements are not only restricted to the construction industry, but also impact other supporting industries interacting with the construction industry, such as the material manufacturing industry. Therefore, this study aims to contribute innovation performance measurement framework for construction industry and its implementation with well-known IT technology to existing innovation literature. In this context, this study tried to measure the effect of the indicators of construction companies' innovation success, and the indicators of success of the construction industry. Accordingly, nine measures for construction company innovation success, and five indicators for the construction industry innovation success, were defined as a result of a comprehensive literature review.

An illustrative case study was performed to validate literature review findings and construct the theoretical structure of the structural equation model. According to the case study findings, BIM provides an opportunity for contractors to keep projects within the approved budget [90]. Also, BIM enables an analysis of the energy performance of a building which provides opportunity for development in the construction material industry in terms of energy saving materials promoting also new sub sectors and employment opportunities in the industry [91]. Additionally, the growing popularity of BIM is likely to lead to an increased number of innovative job opportunities via professional BIM consultancy according to Wong and Fan [92]. Wong and Fan [92] also stated that BIM helps reduce the use of materials and energy, and helps waste reduction. This discourse was also supported by Fernandes [93] since BIM enables easier material and equipment tracking. These requirements also reflect on industrial indicators as positive turnover and production. When Eastman et al. [94] mentioned the future of BIM, they stated that lack of trained professional staff leads to difficulty in implementing BIM. This indicates that BIM requires trained staff providing new job opportunities such as building modeller or model manager in the industry. Experience and de facto rules play an important role in traditional construction and architecture. However, this situation has started to lose its importance since BIM provides opportunities to make sound judgments with analysis tools.

After performing the illustrative case study, SEM methodology was conducted to model relationships between company-level and industrial-level. In this context, the literature findings were tested by a questionnaire conducted to 52 companies. As a result of this modeling method, the proposed model stayed in statistical allowable limits. Furthermore, it enables an important framework for company performance measurement using industrial indicators. According to the SEM results, competitive advantage and reputation as a result of innovation activities were found to be the two highest scores at the company-level. It shows that the construction companies believe that embracing new technologies helps to increase their competitiveness and reputation. It was stated in the illustrative case study, new technologies can open the way for new projects by meeting participation requirements for the tenders. Also, the respondents believed that increasing innovation implementations in their companies helps to eliminate iron-triangle and productivity problems. Additionally, the companies thought that requirements which comes with innovations lead to change either organization or necessity for human resources. Therefore, the highest score was found as "employment and new job opportunities". Besides, they believed that increase in their profitability with innovations also reflect on industry-level turnover and production. Besides, these indicators, the participants believed that innovations aid to "decrease in material and wage costs", "contribution to the development of supporting industries", and "opening up new markets (exporting construction services)".

Main contribution of this study for construction industry professionals is that the government bodies and professional chambers can use identified innovation success factors to measure and boost innovation performance of the construction industry, since the government bodies use incentive mechanism or new regulations (i.e. BIM technology to participate tender process) to enable productivity increase and eliminate wastes in the construction industry Therefore, the innovations which have positive outcome on the industry are identified with the application of the proposed model and their adaptations or spread of innovation can be facilitated industry-wide. Also, the government side can incentivize by identifying technological implementations which help to increase or improve the factors given in innovation success factors of construction companies by performing pilot projects for special innovations. Another contribution of the study is that the study will be helpful to increase awareness of the construction practitioners about innovation success factors and BIM implementations. It should be noted that the proposed indicators in this study must be measured, analyzed, reported, and stored by the decision makers periodically to implement effectively.

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