Drivers of Innovation in Construction Projects

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Abstract: Analysis of the innovation process should take into account the characteristics of the sector under investigation. In construction, there are multiple stakeholders and, therefore, innovation is codeveloped at the project level. However, innovation is driven by a high number of factors that could be distinguished at the industry, firm, and project levels. The major objective of this research is to investigate the role of different factors in driving innovation in construction projects. In this respect, a framework has been proposed, in which the main components of innovation are identified as the drivers, inputs, and outputs. The relationship between those components are analyzed using structural equation modeling based on data collected from 110 construction projects. The findings of the study suggest that the innovation decision is governed mainly by project-related factors that are followed by firm- and industry-related factors. Project complexity, innovation policy, and environmental sustainability are found to be the main motivations behind construction innovation. Research findings are expected to help project managers devise proper strategies to effectively implement innovation. **DOI: 10.1061/(ASCE)CO.1943-7862.0001234.** *© 2016 American Society of Civil Engineers.*

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Introduction

The Organization for Economic Cooperation and Development (OECD 2005) defines innovation as "the implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization or external relations." Mention (2011) stated that innovation is "an interactive process between the firm and its environment, as the result of the collaboration between a wide variety of actors, located both inside and outside the firm." Project-based firms need to manage innovation across organizational boundaries, within networks of interdependent suppliers, customers, and regulatory bodies (Gann and Salter 2000). Innovation has a context-sensitive nature; for instance, patterns of innovation in manufacturing differ from those in services (DTI 2007). Therefore, analysis of innovation in a specific sector should take into account the sector's characteristics. Construction is a diverse and project-based industry. It is partly manufacturing (materials, components, equipment) and partly services (engineering, design, surveying, consulting, and management) (Blayse and Manley 2004). Unlike other industries, construction involves production of unique projects on-site by a variety of teams brought together temporarily. Although more emphasis is put on the firm level, much of construction innovation is codeveloped at the project level (Ozorhon 2013).

Measuring innovation is crucial in order to determine innovation performance of firms. However, measurement of innovation is a complicated process since there is no agreement on a set of variables. Traditionally, innovation is measured in terms of inputs [e.g., research and development (R&D) expenditure] and outputs (e.g., patent or trademark applications) (Archibugi and Pianta 1996). Although extensively used, these two components are not sufficient to measure the innovation process as a whole. The underlying reasons of why companies innovate should also be investigated. Being project-based, construction is known to be among the less innovative industries (NESTA 2007). In addition, the organizational context of construction innovations differs significantly from a great portion of manufacturing innovations (Slaughter 1998). Construction is a very diverse sector and there is no one single way in which innovation occurs. According to Lansley (1996), the occurrence of innovation within the construction industry is often characterized by the widespread adoption of new practices as a result of advances in technological and business processes. In this respect, previous research investigated innovation diffusion (e.g., Taylor and Levitt 2004; Kale and Arditi 2005, 2010) among the members of the construction industry. There are a high number of drivers that lead companies to invest in innovation. In construction, these drivers could be distinguished at project, firm, and industry levels.

This study identifies the components of the construction innovation process, including the drivers, inputs, and outputs, and examines the interrelations among the proposed components of innovation. In this respect, a questionnaire survey was designed and data were collected from construction professionals in Turkey, who have been involved in a total of 110 projects that have adopted innovation. The study is expected to provide a better understanding of the innovation process in a project setting.

Innovation Process

Although numerous studies have investigated the implementation and management of innovation, more research is required to develop appropriate metrics for understanding the underlying reasons for innovation in construction projects. Construction companies invest less in R&D but rather adopt new technology and new ideas to improve their operations. Therefore, such innovations are difficult to capture with the standard indicators used for technology-intense sectors. Innovation measurement tended to focus on products and

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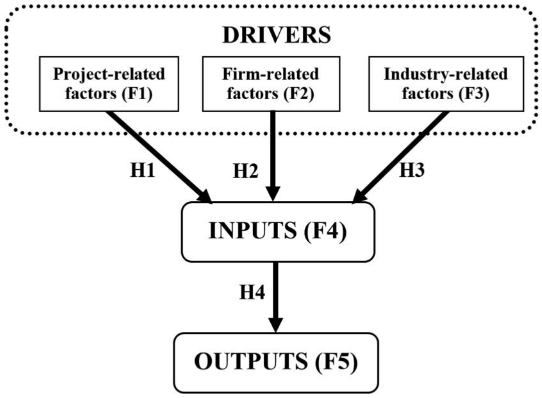

Fig. 1. Research framework

related production systems that are based on measuring inputs to innovation (R&D expenditures, education expenditures, capital investment) and intermediate outputs (publications, patents, workforce size and experience, innovative products) (Milbergs and Vonortas 2004). The construction industry provides an example of a sector within which traditional measures do not reflect the true extent of the innovative activity that is taking place (NESTA 2006; Barrett et al. 2007).

The aim of this research is to propose a framework to analyze the innovation process in construction. Fig. 1 presents the proposed innovation framework that models innovation based on three main components, including the drivers, inputs, and outputs. The figure also shows the hypotheses of the research that are discussed in subsequent sections.

In this framework, drivers represent the main motivations for the innovation process to initiate. Drivers are further grouped under three categories, namely the project-(F1), firm-(F2), and industry-related factors (F3). These three groups of drivers collectively affect the decision to innovate. Inputs (F4) represent the resources utilized to implement innovation. This investment in innovation is expected to result in project-level outcomes that are named as outputs (F5). These five factors are the latent variables of the model. An extensive literature review was conducted to identify relevant components of innovation. An initial list was prepared to include all relevant factors without any overlaps. Then a pilot study was conducted to establish the content validity of the variables that are used to construct the model. The initial list was refined through the pilot study that involved interviews with a team composed of three professors of civil engineering and three highly experienced engineers (one business development manager, one project manager, and one R&D manager) from the construction sector. Each variable of this framework is explained below.

Project-Related Factors (F1)

Client Requirements

Client requirements are considered as the major drivers of innovative activities in the construction industry (Brandon and Lu 2008). They encourage project participants to develop well-set strategies to deal with unpredictable changes (Gann and Salter 2000). The clients also have the ability to foster innovation by increasing the demand for high standards of work and they adopt a role as a leader in bringing up new ideas for a supportive work environment (Barlow 2000; Mitropoulos and Tatum 2000; Blayse and Manley 2004; Ozorhon et al. 2014).

Improving Project Performance

Construction companies believe that innovation improves project success especially in terms of time, cost, quality, and client satisfaction (Goodrum and Haas 2000; Ozorhon 2013). Therefore, project performance improvement is regarded as a key driver of innovation.

Approach of the Project Team

Egan (1998) identifies integrated design and build arrangements, including partnering and supply chain management, as one of the key drivers for excellence and innovation in construction. In a project setting where all members are willing to create new ideas and implement these to find solutions to the problems, innovation is more likely. As Aronson and Lechler (2009) suggested, a project culture that is constructive entails a risk-taking, trusting, and proactive approach that encourages experimentation and open dialogue among the members.

Project Complexity

Problems faced during construction projects generally require innovative solutions. Therefore, innovation might occur based on a necessity as well. Construction firms often innovate at the project level as their work is always unique, always delivered to bespoke designs, and always achieving something new (Keegan and Turner 2002).

Firm-Related Factors (F2)

Improving Firm Performance

Innovation is the key source for gaining competitive advantage in the construction industry (Slaughter 2000). Given the increasing competition level in the construction business, companies aim to innovate and thereby enhance their performance.

Corporate Social Responsibility

Corporate social responsibility (CSR) plays a critical role in achieving higher client satisfaction and improving corporate image of companies. Green (2008) states that CSR is mostly seen as a source for sustainability. Borger and Kruglianskas (2006) reported that there is a strong link between the adoption of a CSR strategy and an effective environmental and innovative performance (project- and company-level benefits).

Leadership

Leadership was defined as one of the main facilitators of innovation in the construction literature (Tatum 1987; Ozorhon et al. 2014). Previous studies have shown that leadership plays a critical role in shaping the project's spirit (Aronson et al. 2013). In another study, it was also demonstrated that effective leadership is critical for innovation (Nam and Tatum 1997).

Innovation Policy

A construction firm's policies and philosophy might influence construction innovations (Tatum 1989). Existence of an innovation strategy helps creativity in companies and plays a significant role in the performance of innovative activities (DTI 2007). According to Davies et al. (2014) an innovation strategy should enable firms to learn new ideas and practices outside of their sector and exploit external resources such as suppliers, universities, and other organizations. A successful strategy depends on an innovation culture that is tolerant, supportive, and encourages learning from failure (Dodgson et al. 2008).

Industry-Related Factors (F3)

Competition Level

Communication technologies, new materials, and wider use of information are among the main ingredients of innovation. Previous research also suggests that advances in technology help construction companies devise innovative solutions to their problems (Nam and Tatum 1992).

Regulations and Legislations

The influence of institutional-level factors on innovation implementation in project networks is reported to be critical (Alin et al. 2013). Regulations involving performance standards have a considerable effect on stimulating and fostering innovations through exerting pressure on construction companies (Reichstein et al. 2008).

Technology/Design Trends

Design plays an important part in the innovation process since it combines technical capabilities, market demands, and opportunities (Faulkner and Senker 1995; Salter and Torbett 2003). There is an increasing pressure on designers to create more innovative and competitive designs (Steele and Murray 2004). Clients expect designers to use advanced levels of integrated technology and to create more complex designs, which bring new insight into the construction technology (Winch 1998; Murphy et al. 2008).

Environmental Sustainability

Environmental innovation consists of the use of sustainable production equipment, techniques, procedures, products, and product delivery systems (Miozzo and Dewick 2004). The construction industry has recently been pushed to decrease its environmental effects. Therefore, construction of sustainable structures has a significant effect on the development of innovative solutions.

Reward Schemes

Successful innovation is achieved in the existence of a reward system for the recognition of innovators and innovation promotion in companies (Dulaimi et al. 2002). Ozorhon et al. (2010) suggested that industry-wide schemes are effective in driving construction innovation. These include research grants, awards, funds, and government programs. Chen (2015) also suggests that firms should establish reward systems to stimulate learning efforts of the project members while minimizing their perceived risk.

Previously mentioned drivers of innovation consist of a total of 13 variables at three different levels: project-related (4), firm-related (4), and industry-related (5). These three factors are the reasons why a company initiates and thereby invests in the innovation process.

Inputs of Innovation (F4)

Investment

Innovative capabilities of construction firms might be increased and extended through investing in adopting new knowledge, R&D, and organizational practices (Teece and Pisano 1994). Construction projects are complicated in nature and they require large capital investments. Similarly, financial resources are needed for designing new tools or specialized equipment (Tatum 1987). Construction is treated as a less innovative industry based on its limited commitment to R&D expenditure, which is one of the main indicators of innovativeness.

Human Resources

The importance of human resources for success in the construction industry has been underlined in several studies so far (Warszawski 1996; Sun and Pan 2011). Similarly, existence of an R&D or innovation team is critical. Innovation success could be ensured by increasing the number of people on the innovation team. Effective composition of innovation teams is critical in innovation implementation (Warszawski 1996).

Internal Knowledge Generation

Knowledge is one of the major ingredients of innovation. Companies learn from their own experiences and staff as well as from external sources. Problems arising at construction sites might foster innovation. Therefore, the role of the project management team and site personnel in the innovation process is critical. In addition, managers also have an important role in facilitating internal coordination and gathering feedback to generate ideas. Firms organize meetings for bringing up innovative solutions (Ozorhon et al. 2014).

Knowledge Transfer

Construction projects involve multiple parties such as suppliers, designers, engineers, constructors, clients, and end-users. Knowledge might be shared among the project parties to implement innovation. Most of the construction firms do not develop new technology; they might transfer technology from outside the construction industry (Veshosky 1998). A typical example is knowledge transfer between companies and research institutions/universities (Ozorhon 2013).

Consultancy

Consultants have an important role in providing valuable information for their clients. To foster innovative competencies, consultants establish working relationships with the clients, partnering with technology suppliers to absorb new technologies; formalize strategic engineering methodologies; and accumulate previous experience in archives, knowledge management systems, or expertise directories (Rogers 2003). As Barlow (2000) indicated, the regular use of external organizations with different knowledge bases is beneficial provided that the collaborating firms recognize the value of knowledge and apply it strategically.

The previously mentioned five inputs of innovation represent different types of essential resources used to facilitate innovation. The inputs factor is an essential ingredient of innovation and leads to the outputs that are explained below.

Outputs of Innovation (F5)

Decrease in Project Duration

One of the most important indicators of project success is meeting the preset schedule. Innovation may provide a significant advantage in the early completion of projects (Gann 2000; Ozorhon et al. 2014).

Decrease in Project Cost

Completing a construction project within budget is one of the most important expectations of both clients and contractors. Innovation in the construction industry is likely to reduce project costs (Gann 2000; Ozorhon 2013).

Increase in Productivity

Slaughter (1998) and Goodrum and Haas (2000) explain that companies foster innovations mainly to increase productivity and efficiency.

Increase in Client Satisfaction

Innovations are implemented in a company to satisfy client expectations. To achieve those client expectations, significant factors, which have considerable effect on innovation success, must be managed and controlled (Ling 2003).

The previously mentioned four outputs of innovation are related to the project-level benefits of the innovation process. This factor is critical to observe the contribution of the innovation process to project success.

Given this background on various components of construction innovation, the following hypotheses are developed and tested in the study:

H1: Project-related drivers have a positive influence on the inputs.

H2: Firm-related drivers have a positive influence on the inputs.

H3: Industry-related drivers have a positive influence on the inputs.

H4: Inputs have a positive influence on the outputs.

Data Collection and Analysis

Based on the proposed framework, a questionnaire was designed and administered to construction companies in Turkey via e-mail and face-to-face interviews. The questionnaires were sent to 152 members of the Turkish Contractors Association (TCA), 127 members of the Association of Turkish Consulting Engineers and Architects (ATCEA), and 56 members of the Turkish Employers' Association of Construction Industries (TEACI). These associations represent a major portion of the civil engineering professionals in Turkey. A total of 110 questionnaires were returned out of 335 sent out, resulting in a 33% response rate. The respondents were required to fill in the questionnaires based on a specific innovation that they have implemented in a project. The collected data represent 110 different construction projects that were undertaken by 101 different firms, with a small portion of these firms providing multiple project data sets. The survey consists of two main parts: (1) general information about the company and the innovative project and (2) variables related to the innovation model. A sample of the questionnaire can be found in the Appendix (as supplemental data). The respondents were asked to evaluate their innovations based on the listed variables using a 1–5 point Likert scale [(1) very low, (2) low, (3) medium, (4) high, and (5) very high]. It would be helpful to report on some hard data regarding the outputs of innovations (such as decrease in cost, decrease in duration, and increase in productivity). Unfortunately, it was not possible to collect such data from all respondents. Hard data could be collected and more detailed analysis could be performed based on some case studies.

The average age of the respondent companies was 39 years; they had an average turnover of US$480 million. The average size of the projects was US$460 million. The majority of collected data involved transportation projects (35%), buildings (32%), and infrastructure projects (22%), followed by industrial (10%) and energy (2%) projects. In terms of the clients, there was a nearly equal distribution between public clients (53%) and private clients (47%). Upon evaluating 110 projects, it was observed that the main innovation types are modern methods of construction (i.e., off-site manufacturing and prefabrication) (26/110); project management tools [i.e., web-based project management, enterprise resource planning (ERP), intranets, and extranets] (20); strategic partnering (17); and supply chain partnership (14). The remaining innovation types such as energy efficiency and sustainability (i.e., green buildings and sustainable solutions) (10); building information modeling (BIM) (7); advanced materials (6); lean construction (i.e., lean production and waste management) (5); automation (3); and marketing (2) were rarely observed in construction projects. According to the business area of the respondents, the majority were contractors (77%), followed by subcontractors (7%), project management consultancy firms (6%), engineers/designers (4%), clients (3%), and suppliers (3%).

The data collected from 110 questionnaires were analyzed using a software package called *EQS 6.2*, a structural equation modeling (SEM) tool. SEM is a multivariate statistical technique, which uses a confirmatory approach to analyze a structural theory based on a phenomenon and which tests hypotheses among observed and latent variables (Kline 1998; Byrne 2013). In other words, SEM analyzes direct or indirect relationships between one or more independent variables and one or more dependent variables. The reason why SEM was chosen as the analysis method in this study is that SEM goes beyond the conventional multiple regression, factor analysis, and analysis of variance (ANOVA). In addition, SEM can carry out factor analysis and path analysis simultaneously unlike the factor analysis and multivariate regression (Xiong et al. 2015).

A typical SEM has two parts, the measurement and the structural models (Kline 1998). The measurement model represents the extent to which latent variables or the hypothetical constructs are measured by means of the observed variables, while the structural equation model represents the causal relationships among latent variables (Byrne 2013). A measured variable might be simply defined as a variable that might be observed directly and is measurable. A latent variable is a variable that cannot be directly observed and must be inferred from the measured variables.

In a structural equation model, the relationships among the latent variables need to be specified and the hypothesized constructs' validity should be tested. Validity refers to the extent to which an instrument measures the construct (Byrne 2013). Construct validity can be tested by means of numerous methods and is achieved when a construct passes all tests of content validity, reliability, and convergent and discriminant validity. Content validity is a qualitative method, whereas the other methods can be categorized as empirical methods.

Content validity refers to the degree to which the construct is represented by the indicators, which are in the domain of the construct (Dunn et al. 1994). In this study, content validity is achieved by the researchers' judgment and insight since there is no statistical test for achieving content validity (Garver and Mentzer 1999). The indicators of each proposed construct were determined through an in-depth literature review. Those indicators were then discussed and finalized with the industry practitioners and academic experts to establish content validity for the constructs.

The components of construct validity are convergent validity, discriminant validity, and reliability. In convergent validity, it is tested whether a construct converges in terms of its indicators showing the items' variance. Convergent validity might be assessed by the examination of factor loadings and goodness-of-fit indices. Discriminant validity tests whether two measures differ statistically in terms of indicating a construct as opposed to the convergent validity and it is assessed by the evaluation of intercorrelations among the measures of a construct (Byrne 2013). Reliability refers to the internal consistency of the constructs in the traditional sense (Xiong et al. 2015). However, in a structural model, reliability is defined as the magnitude of the direct relations of all the variables with the measure for which reliability is assessed, excluding the error terms (Bollen 1989).

Results

Examination of factor loadings constitutes an important part of assessing confirmatory factor analysis (CFA) for the purpose of

Table 1. Latent and Constituent Variables of the Model with Factor Loadings

Identifier	Variable	Factor loading
F1	Project-related factors	—
V1	Client requirements	0.497
V2	Improving project performance	0.482
V3	Approach of the project team	0.439
V4	Project complexity	0.562
F2	Firm-related factors	—
V5	Improving firm performance	0.565
V6	Corporate social responsibility	0.234[a]
V7	Leadership	0.561
V8	Innovation policy	0.683
F3	Industry-related factors	—
V9	Competition level	0.387
V10	Regulations and legislations	0.243[a]
V11	Technology/design trends	0.625
V12	Environmental sustainability	0.908
V13	Reward schemes	0.322
F4	Inputs	—
V14	Investment	0.611
V15	Human resources	0.518
V16	Internal knowledge generation	0.565
V17	Knowledge transfer	0.584
V18	Consultancy	0.456
F5	Outputs	—
V19	Decrease in project duration	0.464
V20	Decrease in project cost	0.379
V21	Increase in productivity	0.796
V22	Increase in client satisfaction	0.721

[a]Factor loading not significant at $\alpha = 0.05$.

including significant factors and deleting the insignificant ones from the model. Factor loadings corresponding to the latent and constituent variables of the model are shown in Table 1. It was observed that some factor loadings are not significant at $\alpha = 0.05$. Therefore, these variables (*corporate social responsibility* and *regulations and legislations*) were removed from the initial model.

Table 2 presents the reliability values and fit indices of the constructs. The reliability is assessed by using Cronbach's α coefficient. In a reliability test, which is the measure of internal consistency, the reliability of the constructs is satisfied when Cronbach's α coefficient exceeds 0.7 for all the constructs (Nunally 1978). Table 2 also presents the nonnormed fit index (NNFI), comparative fit index (CFI), root-mean square error of approximation (RMSEA), and the ratio of χ^2 to the degrees of freedom (DOF). The goodness of fit for each construct was assessed through these measures. Table 2 shows that the reliability of all constructs was greater than 0.7 and, therefore, satisfactory. It also indicates that fit indices were in the acceptable ranges since all of them approach 1, which is the measure of good fit of the measurement model with the data. Finally, χ^2 to the DOF ratio values less than 3 demonstrate an acceptable fit between the hypothetical model and the sample data (Kline 1998) and, therefore, the ratio of χ^2 to the DOF in this study was also in the acceptable ranges for all constructs.

In the second step of the structural model, the influences of each driving factor on innovation inputs and the influence of inputs on outputs were computed. The arrows in Fig. 2 represent the direction of influences between model parameters, and the numbers on the arrows represent the path coefficients. Path coefficients are the equivalents of regression weights. A path coefficient ranging from 0.1 to 0.3 shows a weak association, 0.3 to 0.5 a moderate association, and 0.5 to 1.0 a strong association, as suggested by Murari (2015). The analysis of the model reveals that project-related factors are the most significant driver of innovation with a path coefficient of 0.516, which indicates a strong association. This is followed by firm-related (0.441) and industry-related factors (0.438). Inputs have a positive and moderate effect on outputs (0.498). The analysis results show that all hypotheses proposed in this study were accepted.

Table 3 presents the reliability values and fit indices for the initial and modified model. Table 3 shows that χ^2 to DOF ratios were in the acceptable ranges ($\chi^2/\mathrm{DOF} < 3$) as recommended by Kline (1998). CFI and NNFI values were also satisfactory since they were found to be around 0.9, representing a good fit of the model to the data. The RMSEA values were also below the recommended value of 0.10 (Kline 1998). The evaluation of the correlation matrices for all constructs also demonstrated that intercorrelations were below 0.90, which proves that there is no multicollinearity (Hair et al. 1998). The final model's Cronbach's α coefficient (0.894) was slightly better than the one obtained in the initial model (0.862). The NNFI and CFI were found to be 0.964 and 0.954, respectively, for the final model whereas these were lower (0.935 and 0.896) for the initial model. These values provide evidence that the fit between the final model and the data is quite satisfactory.

Discussion

In this study, a framework was proposed to measure innovation performance in construction. The validity of the model was tested based on data collected from 110 projects undertaken by Turkish firms. The initial model was revised based on hypothesis testing and the final model was found to be satisfactory in terms of content and construct validity and fit indices. This section discusses the analysis results.

Drivers

Data analysis suggests that project-related factors are the governing drivers of innovation in the Turkish construction industry (path coefficient of 0.516). Firm-related factors (path coefficient of 0.441) and industry-related factors (path coefficient of 0.438) are almost equally important in driving innovation. Previous studies do not distinguish between innovation drivers at different levels; in that respect, this study is the first to quantify the influence of these factors in terms of stimulating innovation. However, it might be stated that this is somehow expected, since construction is a project-based

Table 2. Reliability Values and Fit Indices

Index	Recommended value	F1	F2	F3	F4	F5
Cronbach's alpha	>0.7	0.832	0.919 (0.905)	0.824 (0.806)	0.737	0.809
NNFI	0 (no fit) to 1 (perfect fit)	0.901	0.964 (0.916)	0.961 (0.905)	0.916	0.892
CFI	0 (no fit) to 1 (perfect fit)	0.974	0.969 (0.843)	0.981 (0.915)	0.918	0.948
RMSEA	<0.10 indicates good fit	0.082	0.084 (0.093)	0.024 (0.046)	0.095	0.090
χ^2/DOF	$\chi^2/\mathrm{DOF} < 3$	1.472	1.778	1.154	2.346	2.015

Note: Numbers in parentheses belong to the initial analysis before the model improvement.

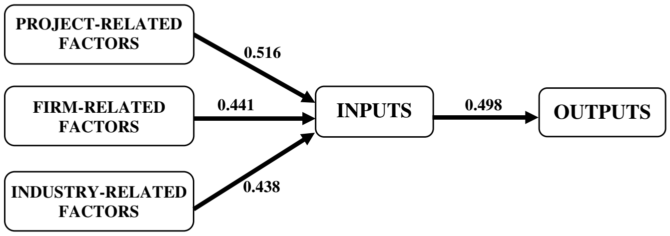

Fig. 2. Analysis results

Table 3. Fit Indices for the Model

Index	Recommended value	Initial model	Final model
Cronbach's alpha	>0.7	0.862	0.894
NNFI	0 (no fit) to 1 (perfect fit)	0.935	0.964
CFI	0 (no fit) to 1 (perfect fit)	0.896	0.954
RMSEA	< 0.10 indicates good fit	0.092	0.084
χ^2/DOF	χ^2/DOF < 3	1.512	1.416

industry and project requirements shape the overall construction process and, therefore, the innovative activities.

The primary driver within project-related factors is project complexity (factor loading of 0.562). This was evident in Ozorhon's (2013) study, which reported innovative and cost-effective solutions to the technical problems encountered throughout the investigated project. However, this parameter has not been referenced as often as client requirements, which is the second most important indicator among the project-related factors. Previous studies highly emphasize the importance of clients in driving innovation (Gann 2000; Hakkinen and Belloni 2011). This finding points out the fact that daily problems at the construction site are the major source of innovative solutions. For example, low productivity has been overcome by adopting lean construction principles and difficulties regarding weather conditions have been resolved through off-site manufacturing. Client requirements, on the other hand, is still a noteworthy driver, and they provide guidance for contractors to develop innovative ideas. Improving project performance and approach of the project team have similar but slightly lower factor loadings. All indicators within this factor are crucial drivers, and in order to increase the effectiveness of the innovation process, integration of team members is advised. Successful innovation requires effective cooperation, coordination, and integration among contractors, subcontractors, suppliers, architects, engineers, and clients in construction projects (Gann and Salter 2000; Ling 2003; Blayse and Manley 2004; Robichaud and Anantatmula 2011; Sun et al. 2015). Korczynski (1996) indicates that contractors' contribution to the design stages might be enhanced by early contractor involvement to create a cooperative work environment. In addition, Barlow et al. (1997) and Briscoe et al. (2004) also state that early contractor involvement might inspire team members to create efficient and value-adding solutions.

Among the indicators of firm-related factors, innovation policy is the most notable (factor loading of 683). This is evident in previous studies as well. For example, Slaughter (2000) reported that as part of innovation policy, on-site training and learning are essential to change existing skills and competencies of personnel implementing innovation. As Blayse and Manley (2004) stated, effective innovation performance requires a formal innovation strategy. This is followed by improving firm performance and leadership. In this respect, the findings are similar to those reported in previous studies (Aronson et al. 2006; Ozorhon et al. 2014). Corporate social responsibility has not been found significant and it was deleted from the model. This suggests that improving their public image through CSR is not a leading factor for the Turkish firms to invest in innovation. When this group of factors is analyzed, commitment should be brought out as an important issue. A construction firm must show necessary commitment to innovation for successful implementation (Ozorhon 2013).

Within the industry-related factors, there has been a growing emphasis on environmental sustainability (factor loading of 0.908) as a response to climate change and its effects on the environment. Bossink (2004) stated that institutions and organizations affect other institutions and organizations in that environmental pressure is exerted and innovativeness is increased. This statement was also supported by other researchers in the literature (Robichaud and Anantatmula 2011; Ogunbiyi et al. 2014). Environmental concerns are followed by technology/design trends, competition level, and reward schemes, respectively. An interesting finding of the analysis is that regulations and legislations are not significant, although this parameter is cited among the key drivers of especially green innovation (Ozorhon et al. 2014). This might be associated with the fact that regulations in Turkey have not been enforced so far. There have not been clear rules and guidelines on innovation. Besides, industry-wide environmental consciousness might have been regarded as more important than legislation.

Inputs

Among the six indicators of inputs, based on the factor loadings, investment (factor loading of 0.611) was found to be the leading one. Allocating a certain budget for R&D and innovative activities is already reported as the main input of innovation in previous studies as well (Archibugi and Pianta 1996; NESTA 2006). Following the financial resources, knowledge resources are observed to be critical. Internal knowledge generation is a key input. This is also mentioned by Dikmen et al. (2005), who reported that innovations usually result from internal sources. Similarly, knowledge transfer is among the most significant inputs of innovation. Gann and Salter (2000) stated that knowledge is distributed through channels and innovation is managed through those channels and networks of interdependent suppliers, customers, and regulatory bodies. Therefore, integrity of those channels is essential in external idea generation and achievement of innovation. Human resources and consultancy are found to be the other valid but less significant inputs of innovation. This might be attributed to the fact that financial and knowledge resources are the main ingredients, but the persons who provide new ideas and knowledge are not regarded as crucial.

Money has always been the most central issue in business. Therefore, companies should allocate a certain amount of their financial resources to enable innovative solutions. Another issue is related to knowledge management, the vehicle through which innovation and improved business performance is possible (Kamara et al. 2002). According to Mention (2011), managers should put in place the mechanisms and tools that foster knowledge sharing within a group in order to facilitate innovation. In a study by Ozorhon et al. (2014), effective knowledge sharing was found to be essential not only in bringing the right ideas into the project, but also in ensuring that these ideas are communicated to the entire project team and diffused to future projects.

Outputs

According to data analysis, increase in productivity (factor loading of 0.796) was found to be the most prominent outcome that occurs through innovation. As evidenced by Slaughter (1998) and

Goodrum and Haas (2000), innovations take place when companies aim to increase their productivity and efficiency. The results showed that increase in client satisfaction is another crucial output of innovation. Decrease in project duration and decrease in project cost were also found as significant indicators. In this respect, findings are in parallel with what has been reported previously in the literature by Gann (2000), who stated that innovation is driven by clients' pressure to improve quality, reduce costs, and speed up the construction processes. As the least important outcome of innovation, cost reveals an important fact about innovation. Companies need money to produce innovation; however, the return on their investment is not guaranteed. Benefits are most likely achieved in the long run, if similar innovations are implemented in future projects (Ozorhon 2013).

Conclusions

Various factors drive innovation in construction, both individually and in a combined manner. Despite the high number of studies mentioning innovation drivers, no study has empirically tested the relationship among different categories of drivers and innovation inputs. This study presents an innovation framework within which drivers are distinguished at three levels, including project-, firm-, and industry-related factors. The influence of those drivers on innovation inputs and that of inputs on outputs were investigated. The validity of the model was tested using SEM based on 110 construction projects undertaken by Turkish construction companies.

The findings of the study suggest that project-related factors are the major drivers of innovation. There are moderate or strong links among all three groups of drivers and inputs. Effect of inputs on outputs is also validated by the analysis. Further analysis on the indicators of innovation components reveal the significance of (1) project complexity, (2) innovation policy, and (3) environmental sustainability as the main reasons behind construction innovation. The findings also point out that the essential resources necessary to implement innovation are financial and knowledge resources. The most significant outcome of the innovation process is increased productivity.

A deeper assessment of the results brings about a main issue, which is commitment. Cost is an integral component of the innovation process. In terms of innovation inputs, financial investment is the most critical one. However, achieving cost-effective solutions is not easy and not guaranteed. Firms should be aware of the fact that innovation is a risky activity and the returns may only be obtained in the long run. They should devise appropriate strategies to implement innovation. Innovation might be more suitable for those companies that carry out similar projects and therefore have the opportunity to apply the same innovations in their future projects. Since innovation is costly and risky, project stakeholders should be devoted to the innovation process, and team integration should be ensured.

This study adopted a broader definition of innovation and investigated the components of the innovation process accordingly. However, more specific studies may be conducted to have an enhanced understanding of how certain types of innovations (such as modern methods of construction, BIM, and lean construction) are managed. Also, innovation has a dynamic nature and the subcomponents of the innovation process interact with one another. New models may be developed to investigate the feedback loops and observe how the process evolves at different phases of the project life cycle.

The data used in this study were collected from Turkish contractors and therefore reflect their projects and experiences. The findings may vary depending on different project data. However, the study provides a complete list of drivers, inputs, and outputs of innovation. The same model can be applied to investigate the innovation process using data from other countries and analysis results may be used for comparison. Similar frameworks can also be developed to investigate the innovation process in other project-based industries. The study is also expected to increase the awareness of construction professionals about their attitude toward innovation. The findings suggest short-term benefits at the project level, but highlights the long-term nature of innovation at the firm level.

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Supplemental Data

A sample questionnaire is available online in the ASCE Library (http://www.ascelibrary.org).

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