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Road map to BIM use for infrastructure domains: Identifying and contextualizing variables of infrastructure projects

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Abstract. Nowadays, construction activities and projects are becoming much more challenging to manage. Getting involved with different stakeholders is a difficult task to which Information and Communication Technology (ICT) has been addressed as a solution. In parallel, Building Information Modeling (BIM) has already taken the first steps towards this big revolution and secured a place in the sector. Upon inspiration from modality of BIM, it has been adopted for use in other sub-branches of construction industry such as infrastructure domain. Since BIM has proven beneficial in the case of buildings, infrastructure projects might gain similar advantages through proper implementation. This study proposes a new description for the purpose of BIM adoption for infrastructure projects, namely Infrastructure Building Information Modeling (I-BIM). The main objective of conducting this research is to identify and prove the lack of using BIM for infrastructure projects. In this context, a questionnaire survey was designed and distributed among 187 participants. These respondents were mostly located in the United States of America and Turkey. Authors point to the preponderance and impediment components that constrain I-BIM utilization and discuss five main categories to cluster the selected 26 variables as either benefit of or barrier to I-BIM.

1. Introduction

Architecture, Engineering, and Construction (AEC) represents one of the largest industries in the world [1]. Construction projects are particularly made by a municipal agency as a public property or privately by a property owner. Construction is a process of building any structure that may result in its remodeling or completion. All construction projects involve strong financial parties and manpower to make the project done. The labors risk their lives using dangerous materials, construction equipment, and gears and work in different conditions. Minor neglect may result in too dangerous and costly circumstances. There are multiple types of construction projects and they can be divided into four main categories:

1. Residential Building;
2. Commercial and Organizational Building;

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3. Specialized Construction;
4. Heavy Construction and Infrastructure.

Oxford dictionary defines infrastructure as basic physical and organizational structures and facilities needed for the operation of a society or enterprise. Therefore, infrastructure assets can be broken down into 5 main domains, as illustrated in Figure 1 [2].

To deliver any construction project including infrastructure, there should be a financial benefit as an advance incentive. However, profit taking is not guaranteed for a project. There are three main objectives in completing a project successfully including time, budget, and compliance with requirements, but the main barrier to overcoming these objectives is project environment. Project management is an effective approach to anticipating the probability of project success and effective time and cost control is the key to any construction projects. To achieve the aforementioned parameter and to resolve the management information issue, establish a strong link among different related parties, and accomplish progressive practices, Information and Communication Technologies (ICT) have been developed and utilized in the construction industry [3].

In 1997, a researcher claims that the Information Technology and Construction (ITC) is a synonym for ICT [4]. Furthermore, ITC has been considered as domain of study in information technology and defined as a collective reference to the integration of computing technology and information processing [5]. The original belief behind this philosophy is to prove that ITC is not a standalone technology; on the other hand, a wide range of technical approaches remain to resolve different types of issues. Therefore, any type of artifact that has the ability to store or retrieve and transmits or receives data electronically can be defined as ICT.

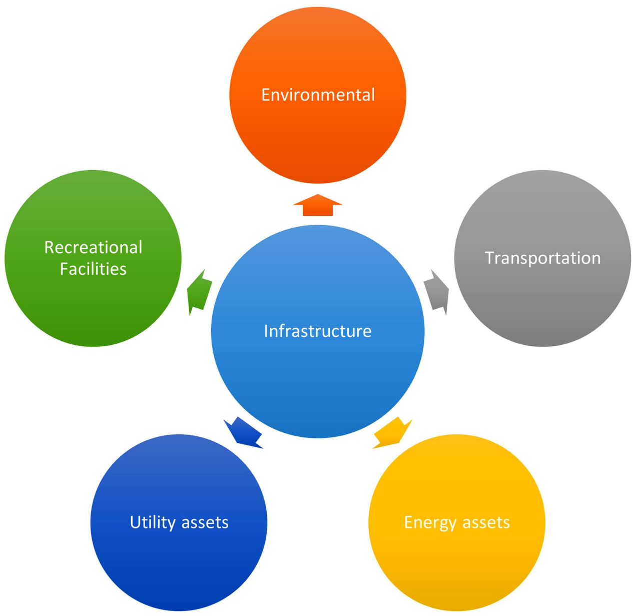


Figure 1. Infrastructure assets domains.

Adwan and Al-Soufi [6] identified 21 sets of ICT technologies, including Web-based, BIM-based technologies, computer-based training and learning, virtual reality, knowledge and information management, wireless and mobile technology, information systems, decision-based, tracking technologies, optical recognition, simulation analysis, etc. These ICT technologies have been compared based on different construction tasks and among all technologies, BIM-based has been identified as one of the most frequent technologies among more than 30 other ICT technologies. Thus, amongst different sorts of ICTs, Building Information Modeling (BIM) provides a model-based cooperative approach that allows teams to manage projects in a better condition [7]. According to ISO 29481-1, BIM provides a digital technology for describing and displaying information of a built object (including buildings, bridges road process plants, etc.) to facilitate design, construction, and operation processes to form a reliable basis for decision-making process of any construction works [8]. Also, Azhar [9] introduced BIM as a process to stimulate the planning, design, construction, and operation of any facility by a computer-generated model that could be used for different construction stages such as design, modeling, energy analysis, clash detection, project scheduling, health and safety, and cost estimate and Bill Of Quantity (BOQ) plans. There are several divisions of BIM technology and these subsets are commonly described as dimensions including 3D modeling, 4th dimension as project scheduling, 5th dimension as cost estimating, 6th dimension as sustainability and green energy, and 7th dimension as facility management.

The main aim of conducting this research is to identify and prove the lack of BIM utilization for infrastructure projects. In order to justify this issue, a questionnaire survey is selected as a major data collection tool. In this context, respondents of the conducted questionnaire are selected from USA and Turkey/North Cyprus considering that these two countries represent good cases of being an advanced country (USA) and developing country (Turkey/North Cyprus). This questionnaire seeks to determine and prioritize the concerns of professionals for not adopting BIM utilization for infrastructure projects within the context of 5 main categories, namely Managerial (M) concerns, Contractual Relations (CR), Public Authority (PA), and Financial (F) and Educational (E) reasons. For this purpose, 26 variables are obtained subject to a critical review of the existing body of knowledge and these are correlated with the aforementioned 5 categories and diverted as questions for professionals' review. Performed analysis and obtained results are critically discussed. Necessary reliability

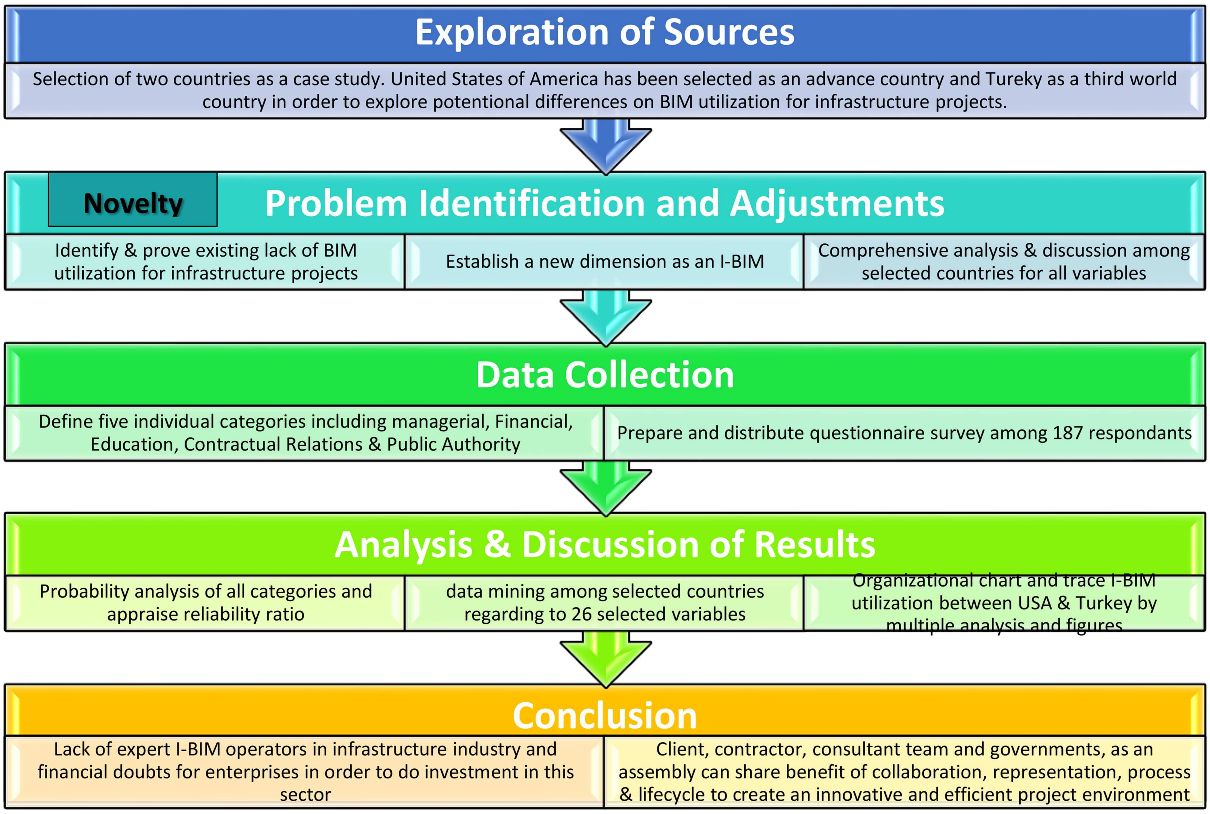


Figure 2. Proposed approach flow chart to define BIM for infrastructure projects.

analysis, data mining of all variables, and necessary charts for compared countries are presented in the next sections of the paper.

As depicted in Figure 2, this research is composed of 5 sequential processes. Research process begins by selecting two different countries that are in different leagues in terms of adoption of latest trends, technology, and processes in construction. Therefore, the United States of America represents an advanced country in terms of existing construction practices, while Turkey is selected as a developing country for the same purpose. Determination and evaluation of the difficulties associated with minor or no use of BIM adoption in infrastructure projects in these two countries, observation of similarities/dissimilarities, and analysis of the reasons for the difficulties pave the way for proposing an action plan to mitigate these difficulties, if elimination is not an option. In this way, authors strongly believe that theoretical proof and findings create a necessary motive for industry professionals to adopt BIM for infrastructure projects.

2. Building Information Modeling (BIM)

Over the last decade, BIM has continued to be one of the most important technological improvements in the structure design and construction industry. AEC industries have received much attraction through this significant technology. This technology roadmap can be drawn dating back to the 1960s by computing applications and the need for solid modeling programs to achieve a more proper design [10]. BIM is establishment through the development of the ArchiCAD and Revit software plays an important role in BIM utilization in the construction industry. This technology was introduced to determine the potential problem of construction project to analyze and simulate any influences. To achieve this goal, BIM presents the building process of a construction project virtually at the preliminary stage and before even construction tasks get started. Generally, BIM is more than just a simple application of 2D and 3D techniques. It is more descriptive as a system which helps companies organize the right people with accurate information together, efficiently and effectively. Therefore, as a highlight, BIM is a combination of information, technology, people, and processes.

By the mid-1990s and through the reduction of demand for and other obstacles to construction projects faced by the construction industry, BIM has been introduced as a solution to overcome these obstacles. A variety of direct and indirect benefits of BIM are undeniable, and construction phases including prefabricated buildings are to adopt BIM in a new framework [11]. In the past two decades, the AEC industry owes its reinvention to BIM. As mentioned earlier, the main concept of BIM is 3D modeling; however, over time, it has been expanded and improved to 4D programming connected to the construction process. Later on, it is developed even more through 5D modeling integrated with cost data. According to Jung and Joo [12] and Biancardo et al. [13], the effectiveness and benefits of implementing the BIM may reduce construction time duration and costs and in some cases, decrease the delivery time of projects by 7%, eliminate unbudgeted changes in projects by 40%, and make the process of cost estimation faster by 80%. Furthermore, different phases of any construction projects including demolition, maintenance, design, and construction information are merged into a solid and single higher-level phase and all participants follow improvements in costs reduction, monitoring risks, and waste management, as well as carbon emissions and efficient performance.

BIM contains rich structured data that are represented by an easily visualized 3D object database. Moreover, it can be functional so that building costs, schedules, sustainability, and performance can be analyzed [14]. This technology was initially applied only to the construction phase of building projects; however, nowadays, it is known as a tool that can contribute to most of construction projects including airports, stadiums, or even bridges at operation or maintenance phase and, more generally, to most of well-known infrastructure domains to advance and expand it; this is sometimes referred to as Civil Information Modeling (CIM) [15].

Basically, CIM is a term commonly used to refer to the application of BIM to civil infrastructure like tunnels and bridges, but there are other terms like construction information modeling, civil information management, or civil integrated management used by various institutions to define CIM. This variety of CIM definitions may lead any users to errors when working on a project with other members who work for different companies; this issue makes collaboration difficult. Furthermore, upon moving from paper-based workflow to a computer-aided workflow, there are other terms in infrastructure domains such as Bridge Information Modeling (BrIM) causing greater complexity in gathering all infrastructure projects such as bridges, roads, railways, tunnels, airports, harbors, and other infrastructure domains within a single framework. To resolve this issue, the authors of this paper suggest using a new description for the purpose of BIM adoption for infrastructure projects, namely Infrastructure Building Information Modeling (I-BIM).

2.1. BIM implementation

2.1.1. North America

According to Wong et al. [16], the North America region is leading the construction industry in BIM implementation and development. McGraw Hill Construction [17] found that the rate of BIM adoption was only 17% in the North American industry by the end of 2007 and later on, in 2012, it was increased to 71% by project team professionals who provided data including satisfaction of more than %60 of BIM users on companies' turnover through investments in BIM. This proves that BIM is playing a key role in the development of construction industry. This increment proves the fact that this region is on top of BIM ladder on a global scale. The improvement of BIM went back to 2003 when the General Services Administration established a new 3D and 4D BIM based program to contribute as an accelerator of Public Buildings Service Office and because of a large number of buildings for this public sector across the United States, this program has had its own role in BIM adoption. Consequently, this fact demonstrates the importance of major governments and client leadership for the construction industry. In the United States, there are two significant publication reports by the National Institute of Standards and Technology which quantified the cost subsequences of insufficient interoperability in the capital facility sector of the U.S. construction industry.

2.1.2. Turkey

One of the leading industries in Turkey is construction and its success in the long term can be ensured through increased awareness on green building, energy efficiency, and sustainability [18]. Since the year 2007, the legislations and law about energy efficiency have been implemented in the Turkish construction industry by the energy efficiency law number 5627 and regulation of energy performance of building. Therefore, many contractors realize that BIM application promotes collaboration of different working parties, computation of material qualities, visualization of project to stakeholders, positive impact on green design in terms of daylight analysis and energy saving, LEED documentation, and reduction of the carbon emission of projects. It can also be applied for different purposes such as lifecycle asset management, condition monitoring, and sustainability [19].

2.2. BIM benefits

The approach to designing, constructing, and maintaining any building has been modified through the introduction of BIM technologies to the construction industry. According to Eastman et al. [20], owners appear to have a better grasp of a sequence of construction activities of the base of their project in their anticipated duration. An innovative framework was proposed by Schade et al. [21] based on a decision-making system that is used based on the design performance at the design phase stage. This method was developed in order to inform decision-makers by making the best choice regarding the life cycle performance of a building. This BIM-based model includes a variety of information such as building geometry, materials, structure, functional, and installation which lead the project to reduce time and cost for the analysis of energy performance [22].

Contractors use BIM to support several construction management tasks [23,24]. Furthermore, Farnsworth et al. [25] investigated the notion of BIM as being part of commercial construction processes in recent years. Scholars have found that the advantages of using BIM include variables such as better communication systems among different involved parties, provide more accurate scheduling, improve coordination of project teams, enhance visualization and accurate clash detection, provide a cost estimation in a short time, and increase in the accuracy of quantity takeoffs. Weygant [26] concluded that both clients and contractors had the benefits of 4D and 5D modeling of BIM by increasing the awareness of coordinating, estimating, and scheduling of any project aspects.

Management of existing facilities for any project can be considered as another advantage of BIM, which should be achieved by modeling any structure and fully linking it to the computer-generated model. In this manner, all operational errors and energy consumption can be monitored by selected team members for management purpose [27]. Likewise, other potential benefits of BIM implementation include increased productivity through cost and time saving, enhanced information sharing, improved quality management, supported decision-making, and high sustainability. Similarly, through a quantity survey done in Australia, researchers found that the time saving factor was the most significant perceived benefit of using BIM and they determined the benefits associated with BIM implementation data through questionnaire survey and the highest-ranking benefits to reduce conflicts, improve visualization, and enhance productivity.

Upon increasing BIM software interoperability among team members, more than 65% of the overall annual costs paid by clients, operators, and building users have been saved. Also, different parties like software vendors have more benefits from their investment in BIM [28–30]. Furthermore, BIM is capable of making multiple parties, and team members in a project are guaranteed additional benefits such as 3D visualization, full understanding of project requirements, time saving, reduction of time duration for construction activities, and reduction of design problems [31–33]. Even so, to gain these benefits in any projects, there are various factors that play significant roles in the success of BIM implementation of any projects. These factors are collaboration among different team members, expert team members, legal contractual issues of projects that involve BIM usage, project budget and Project Type (PT), and geographical location. It is noteworthy that if any of these components are not handled properly in a BIM project, they certainly turn into barriers to BIM adoption of any projects [34–39].

2.3. BIM barriers

BIM implementation requires development of a national strategy and standardization of the BIM process. To this end, a related organization needs to provide proper guidance and set out national priorities for the whole industry. Moreover, there is a need for classifying all types of work in the construction industry accordingly. However, there is no clear general consensus on BIM implementation and usage. Over the previous decade, although some guidelines were developed, there is still no formal standard to organize industry practice. Despite the existence of some standards applicable to the AEC industry, development of new standards for BIM implementation is a must.

The inconsistency between data and the data compatibility for exchange and sharing are the most noticeable data-related problems [40]. Further, the inclination of information sharing among project parties is considered a critical factor and this issue illustrates the fact that BIM needs the capability to transmit embedded information in a graphical model. Consequently, lack of information sharing could be considered a BIM implementation barrier.

BIM as a new technology with all the provided significant benefits for the AEC industry requires funds to be implemented. The main common costs of BIM adoption involve education and training costs as well as initial and development costs of this innovative technology. Generally, the implementation cost is recognized as an obstacle to BIM. According to Ganah and John [41], large companies with most resources are mainly in charge of BIM implementation in the industry. Two of the critical requirements of BIM implementation include data storage and specific related software, and these two factors can raise the costs significantly for any firms. Depending on the IT facility of companies, the costs of purchasing new software are considered as a challenge for smaller companies and this could easily force investors to reconsider BIM options more carefully due to nature of the project and its requirements.

Generally, education and training costs can be quite influential. For instance, education is ensuring that a firm has either the right personnel by retraining existing ones or hiring new staff in order to integrate BIM into its operational phase and again, by retraining the majority of existing staff to support the behavioral and organizational changes required to fully adopt BIM technology within a business model. The fundamental of BIM evolution is training and education which can be considered as the best solution to improving the BIM learning procedure. Lack of adequately trained BIM professionals hinders BIM implementation and use in the AEC industry. Similarly, lack of skills remains to be another barrier to implementation of BIM in the future. This condition is going to get worse by the persistent shortage of capable BIM professionals over the following decade [42].

The issues including process problems, liability, and trust are categorized as an organizational problem on the way of BIM implementation [43]. Senior managers of any firm are usually quite unwilling about new technology and its processes while the management system needs more support in order to adopt BIM implementation quicker. A bottom-up approach is considered more efficient in dealing with resistance to change [44]. Moreover, lack of knowledge about the differences between conventional construction methods and use of BIM by some managers is identified among the other obstacles to BIM implementation.

Legislation aspect of BIM development is one of the concerns held by scholars and governments. Data ownership is subject to risk in terms of the legal aspects of BIM because if clients pay for the design phase of construction projects, they have the right to claim ownership of the documentation. Likewise, there would be a significant chance for conflict to occur among other stakeholders rather than owners and architects in case they are involved in the project. Additionally, it is extremely important to determine who will access data and be responsible for any inaccuracies in the project, and this point of view could bring about a considerable risk. Although stakeholders prefer to have the confidentiality of data and documents in the BIM model, a range of legal issues that have been identified in connection with the administration aspect of projects exist.

Table 1 provides a comprehensive assessment of critical variables of BIM implementation including CR, E, F, M, and PA. A detailed assessment of each category is added to explain their sub-factors like availability of expert personnel (E1) or responsibility for inaccuracies (CR3). Correspondingly, these variables are correlated with each other and the associated relations are to be shown in more detail after presenting data mining.

3. Research methodology

To demonstrate how the industry professionals can efficiently adopt BIM for infrastructure projects, a comprehensive review of the existing body of knowledge from many different sources (academic journals, dissertation and conference databases, web, e-books, etc.) is performed. Through this critical review, the benefits of and barriers to BIM implementation are identified in terms of 26 variables, where these variables are later assessed and rated by the professionals through conducted questionnaires. As illustrated in Figure 3, these variables are correlated and clustered under 5 different headings as suggested by the authors.

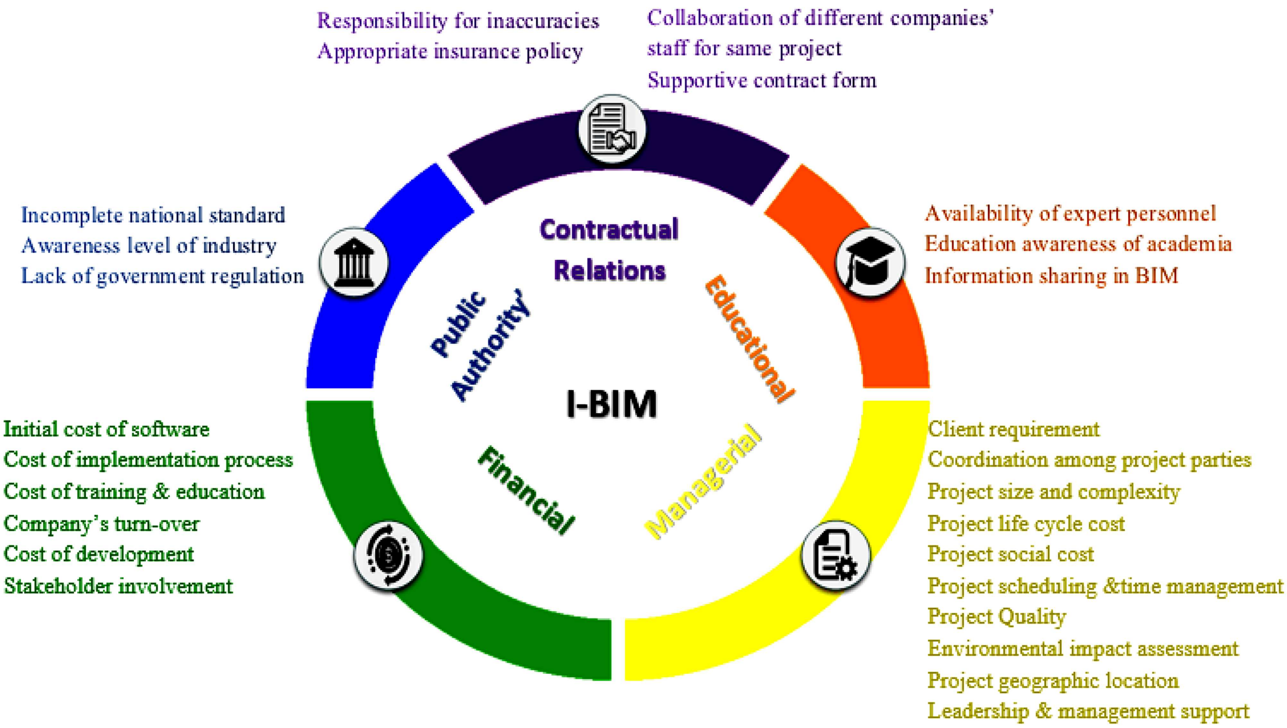


Figure 3. I-BIM variables.

Table 1. Summary of I-BIM benefits and barriers.

Primary factor	Sub-factor	Sources	Summary and assessment
Contractual Relations (CR)	CR1: Collaboration of different companies staff for the same project CR2: Supportive contract form for I-BIM CR3: Responsibility for inaccuracies CR4: Appropriate insurance policy for project	[9] [36] [38] [46] [47] [48] [49] [56] [57] [59]	Currently, there are different software tools available and this variation causes problems to the user. This issue can lead any enterprise to conflicts with other involved parties. Therefore, a supportive management plan with an international software package can help overcome this barrier.
Education (E)	E1: Availability of expert personnel E2: Education awareness of academia E3: Information sharing in I-BIM	[29] [38] [44] [55] [56] [57] [60]	Regarding the project's nature, it is difficult to find expert users who handle all aspects of project and due to variation of software tools, sharing information is sometimes difficult between users. These issues can be resolved by educate conversant engineers.
Financial (F)	F1: Initial cost of software F2: Cost of implementation process F3: Cost of training and education F4: Company's turn over F5: Cost of development F6: Stakeholder involvement	[9] [28] [38] [39] [41] [50] [51] [54] [56] [58]	Adoption of BIM promises returns for any construction business but due to high down payment, it could be a burden for small and medium sized enterprises. Part of industry professional believed that in the long term, there will be a huge capital outlay for any enterprise by reducing design errors and increasing productivity.
Managerial (M)	M1: Client requirement M2: Coordination among parties M3: Project size and complexity M4: Project life cycle cost M5: Project social cost M6: Project scheduling and time management M7: Project quality M8: Environmental impact assessment of project M9: Project geographic location M10: Leadership and management support	[9] [28] [37] [38] [39] [41] [42] [49] [51] [52] [54] [56] [57] [58] [59] [60]	Construction management of any project always involves knowledge areas such as risk, time, cost, quality, procurement, etc. BIM is a great asset to distinguish these pieces of knowledge from one another and introduce features such as clash detection in early stages of planning for better coordination and collaboration among staffs, saving time in scheduling (4D) and wealth in cost estimation (5D), etc. Moreover, there will be a potential for quantification of social cost through the BIM platform.
Public Authority (PA)	PA1: Incomplete national standard PA2: Awareness level of the industry PA3: Lack of government regulation	[9] [27] [38] [46] [48] [51] [53]	There has been a lack of guidelines so far in standardizing the process of adopting BIM for infrastructure projects. Lack of legislation is making stakeholders concerned about the ownership of data or models within the digital assets. Therefore, there is a need for clearer standards.

Table 2. I-BIM implementation components.

Indicators	Variables	Mean score	Ranking
CR1	Collaboration of different companies staff for the same project	7.109	9
CR2	Supportive contract form for I-BIM	6.161	13
CR3	Responsibility for inaccuracies	7.483	3
CR4	Appropriate insurance policy for project	6.005	16
E1	Availability of expert personnel	4.360	21
E2	Education awareness of academia	5.050	19
E3	Information sharing in I-BIM	7.441	5
F1	Initial cost of software	4.015	22
F2	Cost of implementation process	3.997	23
F3	Cost of training and education	3.879	24
F4	Company's turn over	5.387	18
F5	Cost of development	4.891	20
F6	Stakeholder involvement	6.452	12
M1	Client requirement	6.942	10
M2	Coordination among parties	7.110	8
M3	Project size and complexity	7.129	7
M4	Project life cycle cost	7.932	1
M5	Project social cost	7.473	4
M6	Project scheduling and time management	7.862	2
M7	Project quality	7.341	6
M8	Environmental impact assessment of project	6.144	14
M9	Project geographic location	6.006	15
M10	Leadership and management support	6.509	11
PA1	Incomplete national standard	3.489	26
PA2	Awareness level of the industry	5.488	17
PA3	Lack of government regulation	3.817	25

Subsequent to identification and classification of the 26 variables, it is quite important to obtain opinions and feedbacks of the professionals as well as the benefits of their experiences of BIM adoption. This is the reason why a questionnaire survey is selected as an instrument for collecting data in this respect. After about 4 months of efforts, 187 experts working in USA and Turkey are reached. For participants with whom the authors have personal communication, questionnaires are conducted face-to-face in an interview-based environment. The rest of the respondents are reached through newsletters, professional organizations, and academic networks and they have participated through online tools.

Our research team considered two main principles to detect and screen an invalid questionnaire: first, if some answers are missing; second, if answers are of the same score pattern from the beginning to the end. In this respect, 12 invalid questionnaires are detected and participation of 175 respondents is considered through analysis. On the other hand, it is worth highlighting in this stage that 44% of the respondents are from USA where the remaining are from Turkey and North Cyprus.

The questionnaire comprises two main parts. In the first part, general information of the participants concerning the type of firm they work for, their affiliation, their level of proficiency in BIM, work experience, and knowhow in using BIM software is investigated through 15 questions. In the second part, the 26 variables identified from literature review are diverted to participants under 5 different headings for their classification of those variables either as a barrier or benefit, and participants have prioritized these variables so that a relative important index of the variables can be obtained. Table 2 shows the final ranking of variables upon respondents' opinions.

4. Results and discussion

4.1. Respondent profiles

This questionnaire survey had 175 complete responses.

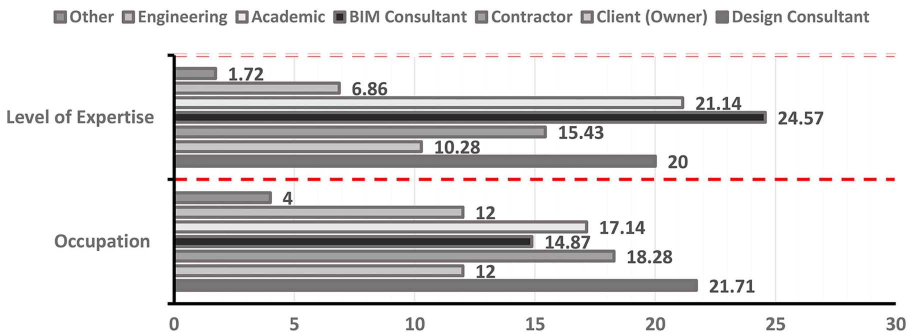


Figure 4. Respondent's profile charts.

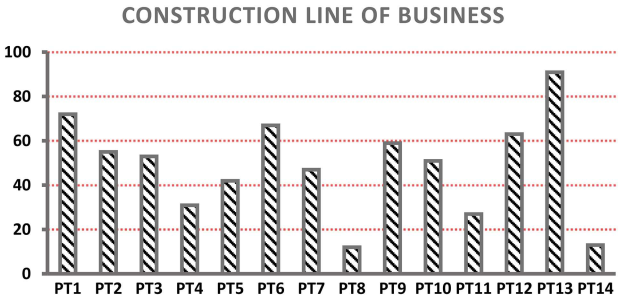


Figure 5. Respondent's project types.

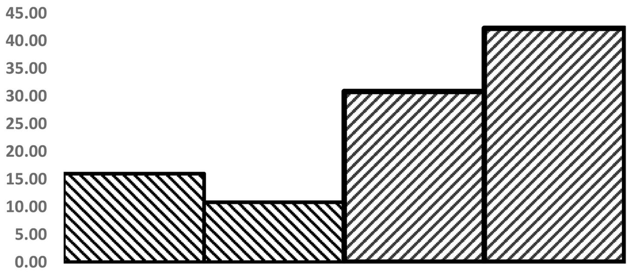


Figure 6. Operated project's value by respondents.

Figure 4 categorizes all the respondents in terms of their occupation and expertise level in the construction industry and in this case, an attempt is made to conduct a survey of the infrastructure experts in firms. Of note, 77 out of 175 participants were located in the United States of America being equivalent to 44% of the entire survey. The remaining number of participants who helped conduct this scientific research were located in Turkey and Republic of Northern Cyprus.

4.2. BIM project profiles

Respondents were asked to select PT in their firm by using BIM in order to make a construction line of business for the following research. As is shown in Figure 5, all 175 participants of the survey were involved in 683 projects, as shown by PT1 to PT14 indicators. These indicators are represented by commercial (PT1), residential (PT2), educational (PT3), industrial (PT4), airport (PT5), transportation (PT6), public and government (PT7), sports & entertainment (PT8), water supply & resources (PT9), bridges (PT10), power generation & transmission (PT11), tunneling (PT12), pipeline infrastructure (PT13), and none (PT14). According to Figure 5, there are many residential and commercial projects that utilize BIM. The current usage of heavy construction and infrastructure based on BIM is growing fast all around the world, but it still needs raising concerns in the industry. On the other hand, there is another way to categorize selected respondents in terms of the values of firm projects, as illustrated in Figure 6. According to the survey data elicited, most of the involved firms fall in the range of more than \$50 million (42%), followed by \$30–\$50 million (31%). Therefore, these results show that I-BIM is more applicable to large invested projects.

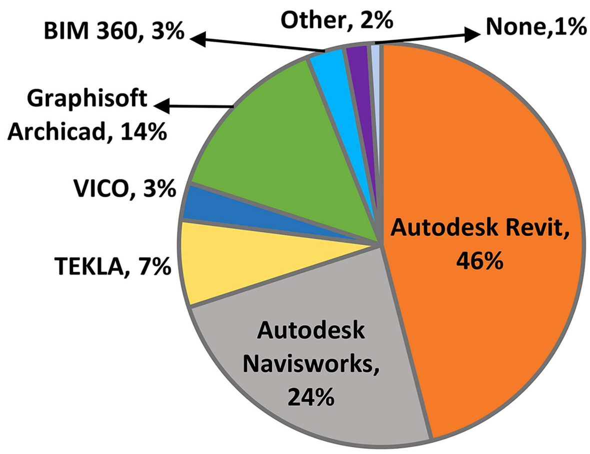


Figure 7. BIM software used by firms.

4.3. Adoption of BIM for different dimensions

During the previous decade, several BIM analysis and authoring tools were employed to design and monitor different aspects of the construction industry. Due to survey results, as illustrated in Figure 7, AutoDesk programs such as Revit and Navisworks are widely used in the selected country. Afterward, Graphisoft ArchiCAD by 14% and Tekla by 7% are the most common BIM tools used in industry. Also, around two-thirds of the architecture firms are using AutoDesk and Tekla is a popular tool among the engineering firms according to the respondents.

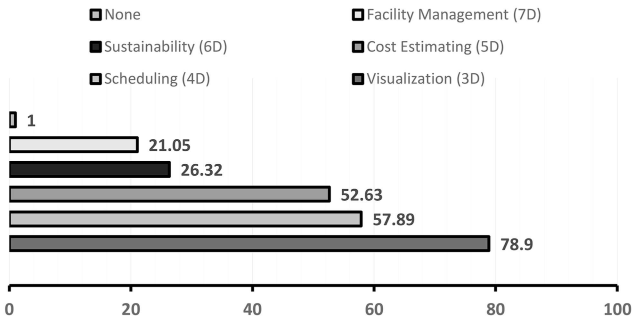


Figure 8. BIM dimensions used by firms.

To investigate BIM adoption more, respondents were asked about using the BIM dimension (task) for their firm projects. According to Figure 8, visualization (3D) and scheduling (4D) were the most important BIM dimensions used in projects. Likewise, cost estimation is one of the most critical tasks to finalize any project phases on time and on budget. It is a raising concern that the 5th dimension of BIM needs much attention and there is a high potential impact that can be investigated by researchers; for instance, the social cost effect in today's construction activities can be evaluated using BIM as a quantification tool.

4.4. Contractual Relations (CR)

The agreement among all the involved firms during the construction of any structure is one of the most important parameters of any successful project. With the introduction of BIM to construction industry, the accuracy level of any construction activities increased. In this section, authors selected four parameters for I-BIM utilization for evaluation. According to respondents' opinions, the collaboration of different companies' staff for the same project and responsibility for inaccuracies in project tasks are the most important beneficial aspects of I-BIM. Currently, contractors and architecture firms are applying it to their projects. In these cases, each person involved in a project has access to online cloud system to create, modify, and monitor any tasks, depending on their roles. This system clearly reduces any inaccuracies and makes the quality and control management of the project at a higher level.

In contrast to the first two parameters, supportive contract forms for I-BIM and appropriate insurance policy for projects are considered as underdeveloped parameters, not as barrier nor benefit, which need a deeper understanding by related parties. For instance, in the United States of America, there are some advantageous insurance policies that motivate customers to use those technologies. In the construction industry, there are different types of insurance. Considering that technology is finding its own way to the industry, lack of a beneficial insurance policy for the firms that are using I-BIM in their projects can be felt because, as mentioned earlier, use of I-BIM achieves much revenue for everyone including the public by saving a notable amount of tax payment to the government. Even as a solution, there could be a clause in contract agreements between the clients (or, the consultant firm on behalf of clients) and contractors, showing that the responsible firm is using I-BIM in the project and by using it, there would be exemptions for contractors and subcontractors due to its advantages.

As a matter of fact, BIM easily helps segment CR of the construction industry by making a more proper collaboration among involved companies in the same project. Moreover, it facilitates investigating any inaccuracies at any stage of any project and simply realizes the responsible role who leads the task to error. Thus, in this manner, any aspect of a project could be easily managed. Of note, uncertainty in these matters in third-world countries should be considered because, as stated in CR2 and CR4 analogy given in Figure 9(b) and (d), around 40% of the respondents are not sure how these two variables could help their firms. However, hopefully, in the near future, there is an appropriate insurance policy for the projects that are using BIM and I-BIM by the legislation experts all around the world.

4.5. Education (E)

The relation between education and I-BIM is irrefutable because any new technology needs to be taught by experts and learnt by an apprentice to be more applicable. According to the respondents' opinions, lack of expert personnel around the world causes high costs of training and education. This is easily one of the strongest barriers to BIM utilization in any sector including infrastructure. As a solution of E1 variable, industry and government as an assembly need to put much effort into bringing I-BIM to reality by changing university curriculums and organizing workshops to promote the awareness of all related parties in addition to those already in Figure 10(b), because this is the future of construction industry.

Afterward, it is noticeable to discuss background education of academia about I-BIM as another barrier. Due to respondents' comments, there are not enough must-take courses at universities which precisely focus on different aspects of BIM. Most of the interested apprentices need to attend high-cost workshops to learn a new program or to get familiar with the concepts of this technology. However, if the mentioned assembly gathers and works properly to overcome E1 variable, both academia and engineers are going to be more familiar with I-BIM. Therefore, given availability of expert personnel, all related costs including workshops are reduced because of a highly insensitive contest among parties.

Information sharing in I-BIM is the third parameter, which has been asked. This factor is easily

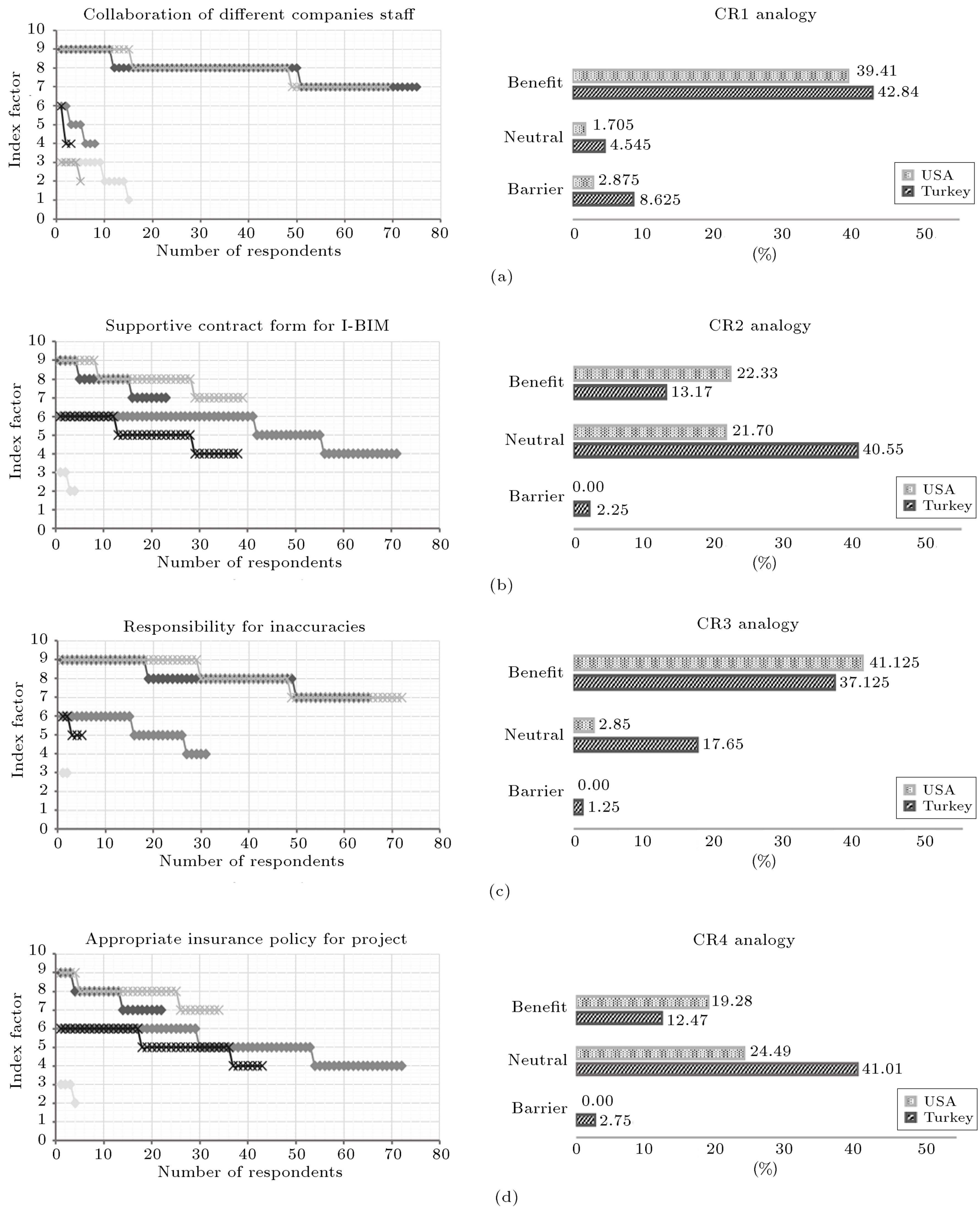
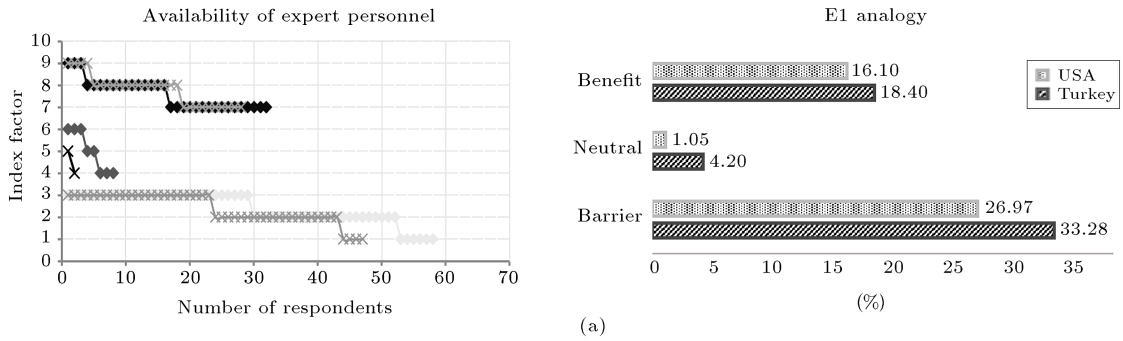


Figure 9. Contractual relation variables for I-BIM utilization.

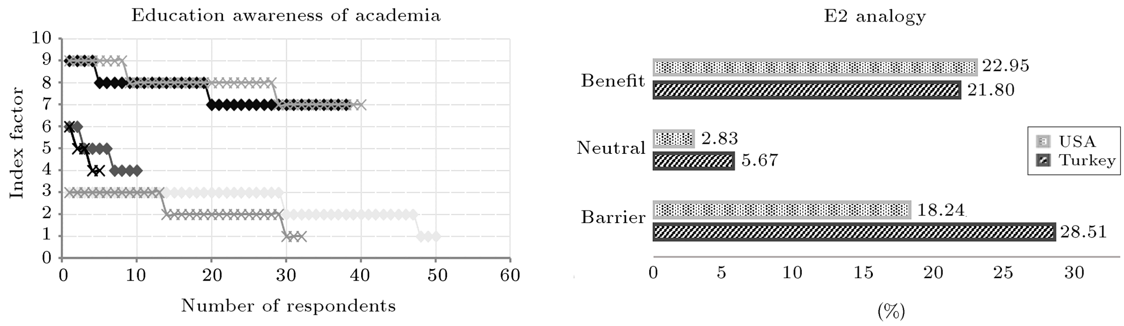
one of the biggest advantages of I-BIM according to a high ratio of the respondents for considering it as a positive influence on I-BIM. Nowadays, programs including BIM 360, Tekla, BIMsight, Autodesk Revit and Navisworks, BIMobject, and BIMx are helping most of the firms around the world to organize their construction activities in a proper way. Generally, information sharing is done by some of these programs through the cloud-base web service which provides team members access to data to improve decision-making and avoid expensive delays. Therefore, it is noticeable to consider E3 as the only pure benefit of education category of I-BIM by considering the mentioned supportive facts.

4.6. Financial (F)

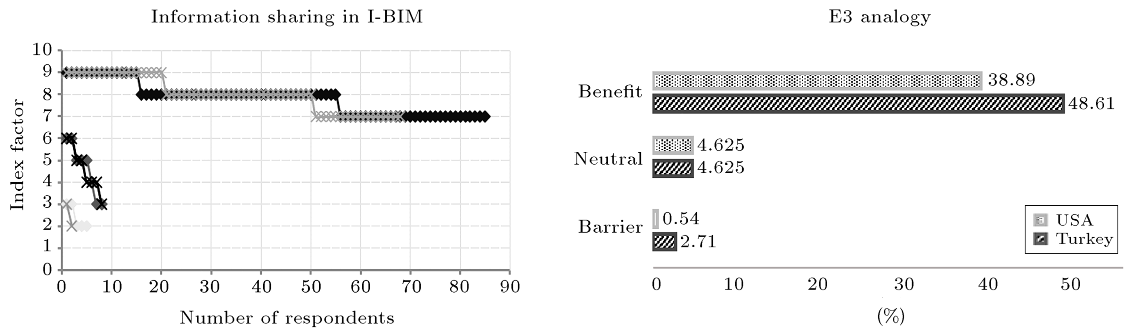
One of the most important investments in a successful I-BIM implementation is training and it has been the greatest barrier to I-BIM adoption, as in Figure 11(c). According to the study results, respondents recognized



(a)



(b)

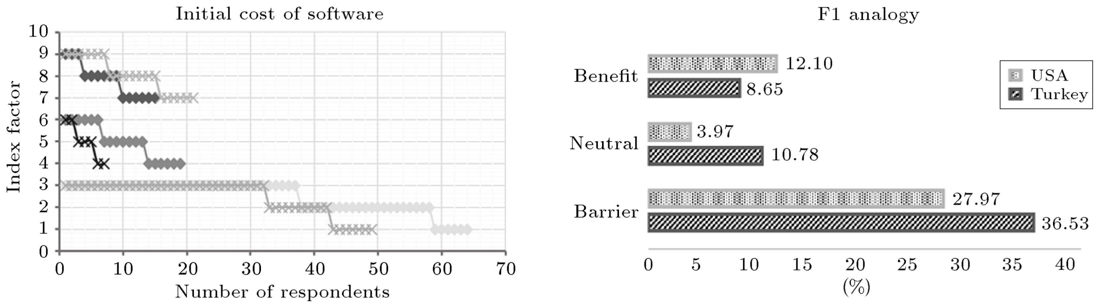


(c)

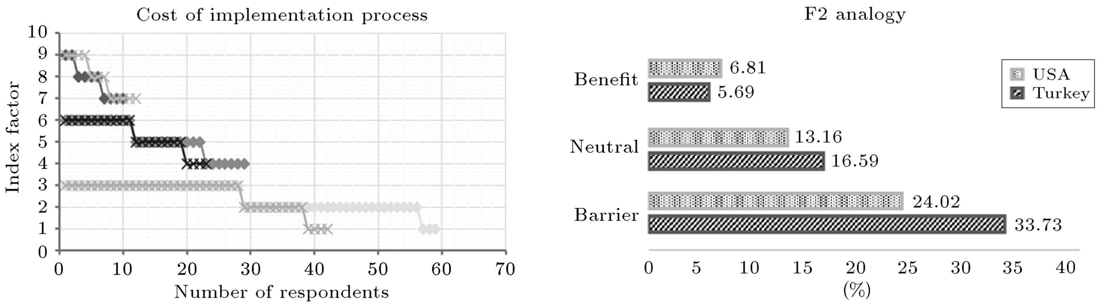
Figure 10. Education related variables for I-BIM utilization.

F3 as a critical problem and firms attempt to provide much training for their staff in order to resolve this concern. Also, initial cost of I-BIM software, Figure 11(a), has been ranked as the second financial barrier to I-BIM adoption. Indirectly, this parameter indicates the number of I-BIM users in the industry because one of the main reasons behind any expansive product can be the lack of customers, which led to the high costs of production to cover the expenses of product manufacturing and make a reasonable profit for the company. Besides these two barriers, it is noticeable to consider the cost of development, Figure 12(b), as another obstacle that has been categorized as a software upgrade and hardware maintenance. According to the literature review, American companies have spent less than 2% of their net revenues on hardware, hardware maintenance, software, software upgrades, or training. Relatively, hardware and software costs funded the most to overall expenses, whereas expenses associated with hardware maintenance and software upgrades are less than 0.5 of the overall net revenue of the firms.

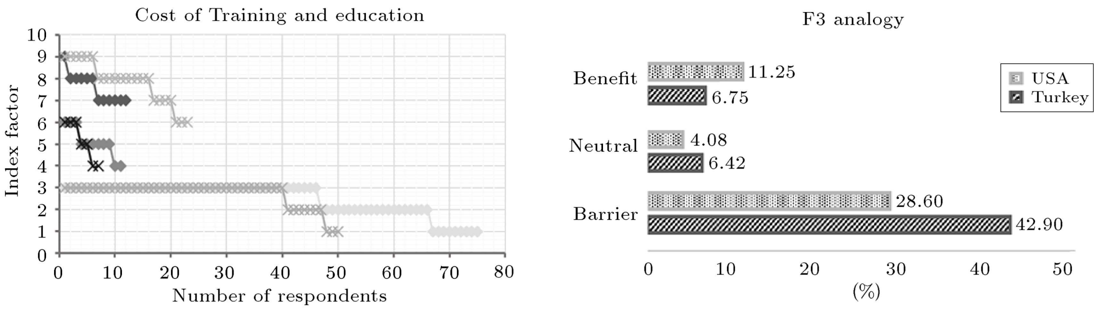
The survey was an attempt to investigate tangible costs associated with utilization of I-BIM, software and training, companies' turnover, and stakeholders' involvement. Somehow, these costs are the ones that are easier to quantify and compare to other factors. Despite the fact that these factors and costs are undeniable, still, lots of organizations and governments are uncertain about I-BIM utilization for their projects. Due to the respondents' opinions in this survey, any companies involved with large projects get benefits from I-BIM adoption and through changes, the turnover of companies will increase extensively, as stated earlier in Figure 12(a). For third-world countries, there are still doubts about F4 factors due to economic conditions of those countries. Furthermore, public and private sectors as major stakeholders, F6 variable, could play a key role in the success of I-BIM by



(a)



(b)



(c)

Figure 11. Financial related variables for I-BIM utilization (Part 1).

promoting and providing support for implementation, research, and development in the future. It is a matter of fact that in advanced countries, stakeholder involvements are more possible than third-world countries. This fact can be proved as in Figure 12(c) and most of the American consider F6 factor as a benefit; however, in Turkey, more than 50% of respondents were not sure how this variable could affect the progress and improvement of their companies.

4.7. Managerial (M)

From the managerial aspect of I-BIM utilization, ten variables have been selected. According to the respondents' opinions, BIM adoption for infrastructure projects has a positive impact on factors such as client requirements, coordination among project parties, project size and complexity, project quality management, project scheduling, time management, project life cycle cost, and leadership and management supports, as illustrated in Figures 13 and 14. It is notable to imply the relation between M1 and M2 with CR1, E3, and F6 variables discussed in more detail for all the related factors of each case study in the variable assembly section. Basically, it is shown that these two managerial factors have a strong link to collaboration between all related parties and information sharing in I-BIM platform. This relation can cause less conflicts, proper coordination, and finest environments in any project in order to fulfill all necessary requirements of a project asked by the client. Moreover, these relations will lead to most accurate financing of a project which has a direct relation with M4 and M6 factors, because it can avoid any possible cost and time overrun of a project which has effect on any potential conflicts among parties including financial aspects.

One of the factors that requires much attention in today's world is the social cost. Gilchrist and Allouche [45] proposed it as the project contractual cost comprising direct, indirect and social costs. However, in order to measure social cost for specific purposes, it

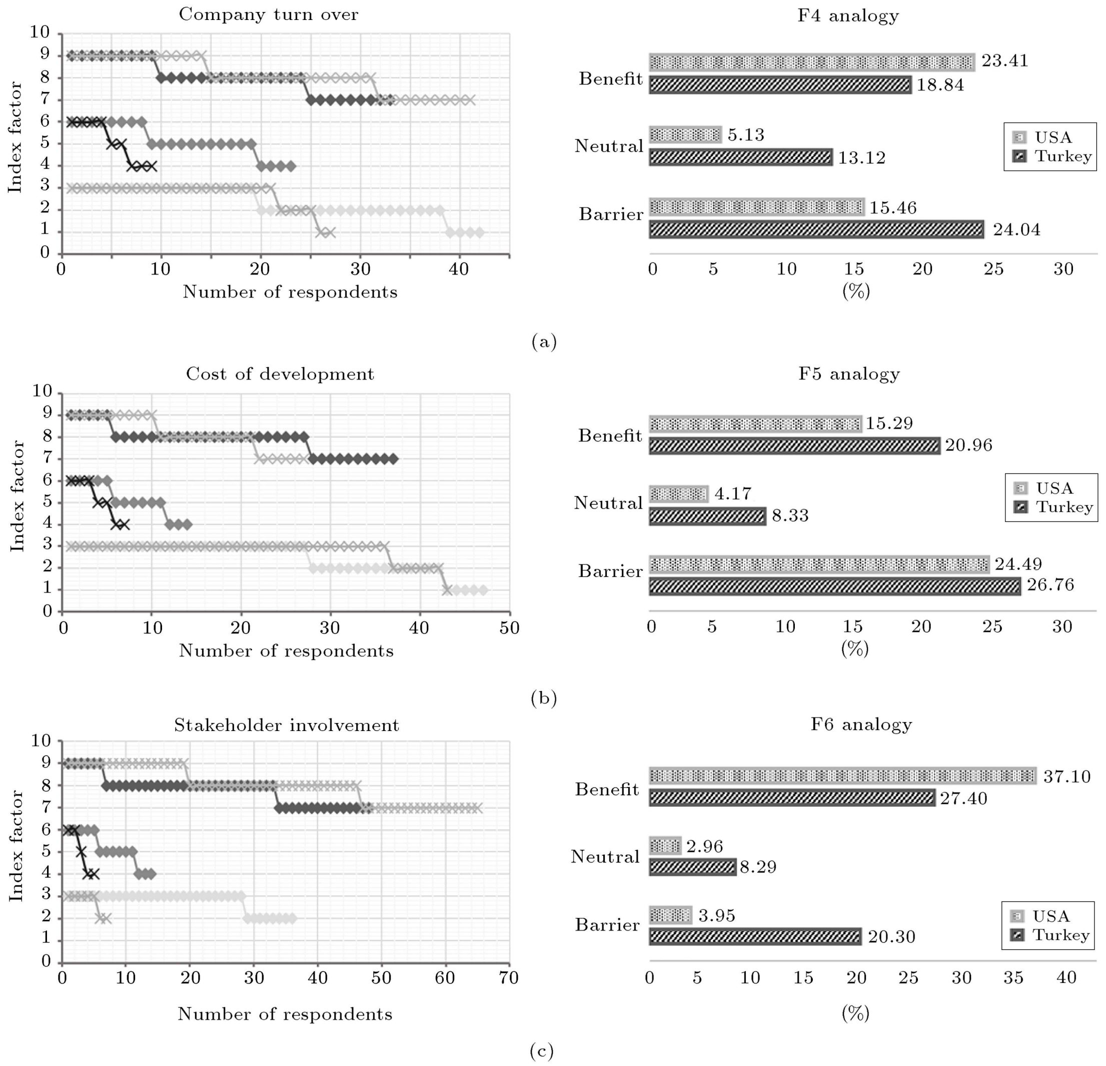


Figure 12. Financial related variables for I-BIM utilization (Part 2).

has been grouped based on the area of impacts such as economic activity, pollution, traffic, and ecological/social/health. Based on the survey results, there is a strong belief about the role of I-BIM in facilitating the quantification of social cost in a more accurate way, being justified enough for scholars to recognize the full potential of I-BIM in future research work, even though this subject requires greater attention from all researchers around the world. Also, given the variables M4 and M6 considered for BIM adoption, there is a similar opportunity for I-BIM utilization, since more than 90% of respondents made it clear that these two factors were the benefits, as indicated earlier in Figures 14(a) and (c).

One of the other important preliminarily aspects of any project is Environmental Impact Assessment (EIA) reports. The main purpose of using EIA is to safeguard the environment to make sure that when deciding whether or not to approve a project that may have critical impacts on the environment, the government would do so with full knowledge of the all possible significant effects. In this respect, I-BIM utilization can and will have a positive impact on EIA as identified to be a benefit by questionnaire responses in Figure 15(c).

4.8. Public Authority (PA)

PA, or governments to be specific, plays a key role in the success of any nation towards developments. In this research, three factors with critical impact on the success of I-BIM utilization exist. Every piece of information that a project owner may need about a facility throughout its life can be made available using I-BIM as an information warehouse so as to produce an electronic version of any piece of documents. The main drawback of this module lies in the construction industry because it does not yet have the open standards and infrastructure to mine that information and collect it in order to organize it in the most sufficient way and distribute it with all involved firms and companies. In

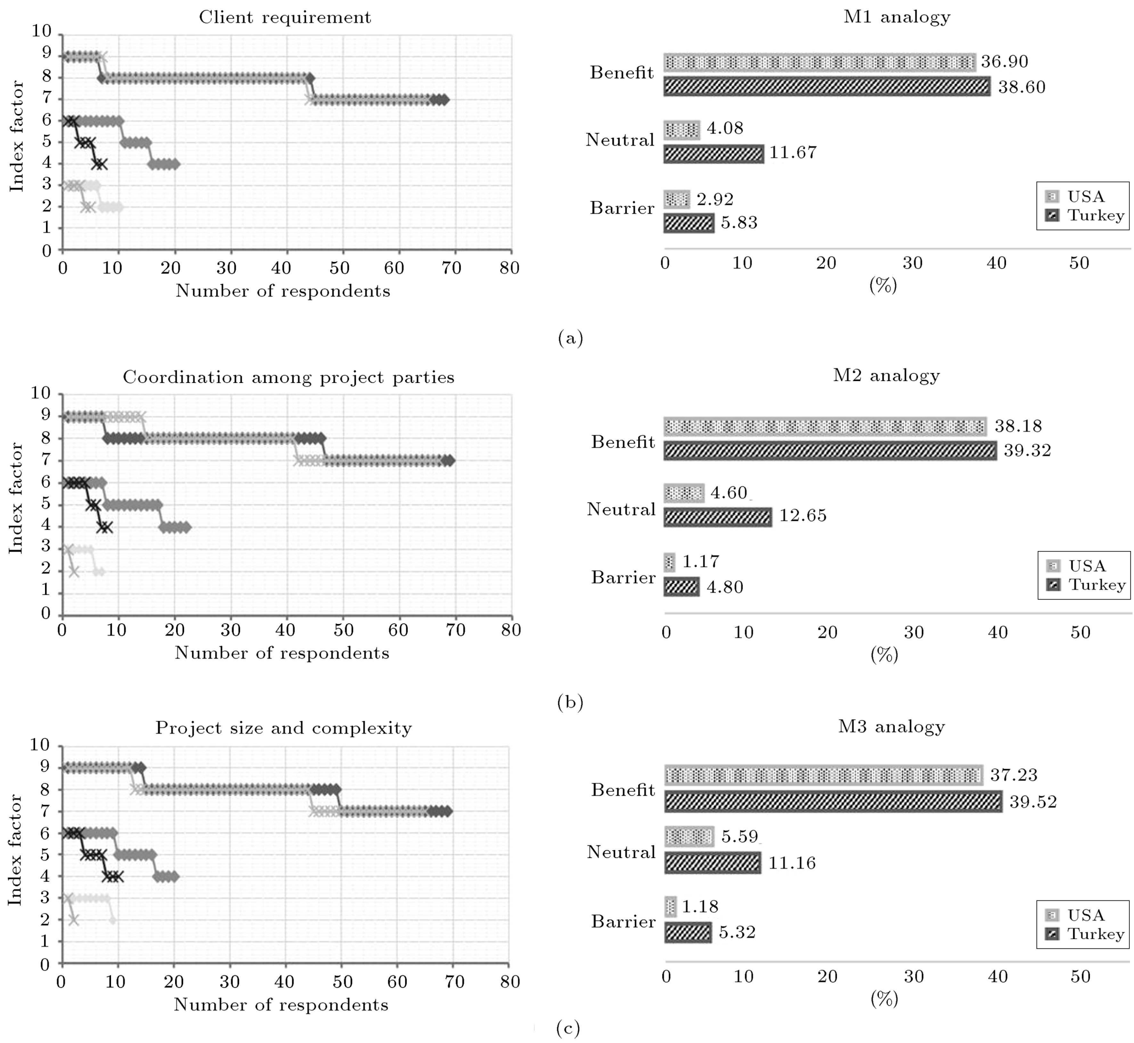


Figure 13. Managerial related variables for I-BIM utilization (Part 1).

May 2015, the latest edition of National BIM Standards of United States was published that contained nineteen reference standards, terms and definitions, nine information exchange standards, and eight practice guidelines to support users in their implementation of open BIM standard-based deliverables based on the national BIM standards approved by the U.S., which exhibits incomplete national standards as stated for PA1 variables in Figure 16(a).

In spite of the mentioned barriers, the awareness level of the construction industry is growing with some help from the academia and youth generation who are joining the course. This fact can be supported by the relation between PA2 and E2 variables since both industry and academia need to have a clear understanding of all the five categories of I-BIM utilization. Moreover, this critical parameter is certainly playing an important role in merging conventional construction methods with I-BIM. Through the completion of this merge, the construction industry will lead a new era whose owners, planners, realtors, appraisers, mortgage bankers, designers, engineers, estimators, specifiers, facility managers, safety engineers, occupational health providers, environmentalists, contractors, lawyers, contract officers, subcontractors, fabricators, code officials, operators, risk managers, renovators, first responders, and demolition contractors all can benefit by having access to I-BIM.

4.9. Variables assembly

The relation of all the discussed variables under each category is irrefutable. In order to prove these relations, the correlation matrix for each country is presented and Figures 17 and 18 show this correlation for Turkey and United States of America, respectively. As stated before, under the Contractual Relation category, CR1 and CR3 are considered as advantageous factors. Based on the presented matrix, these two factors have a relevant relation with each other, E3 and most of the managerial factors. Independency of CR1 variable from financial and public authorities variables should be considered. Education, as the second category, has

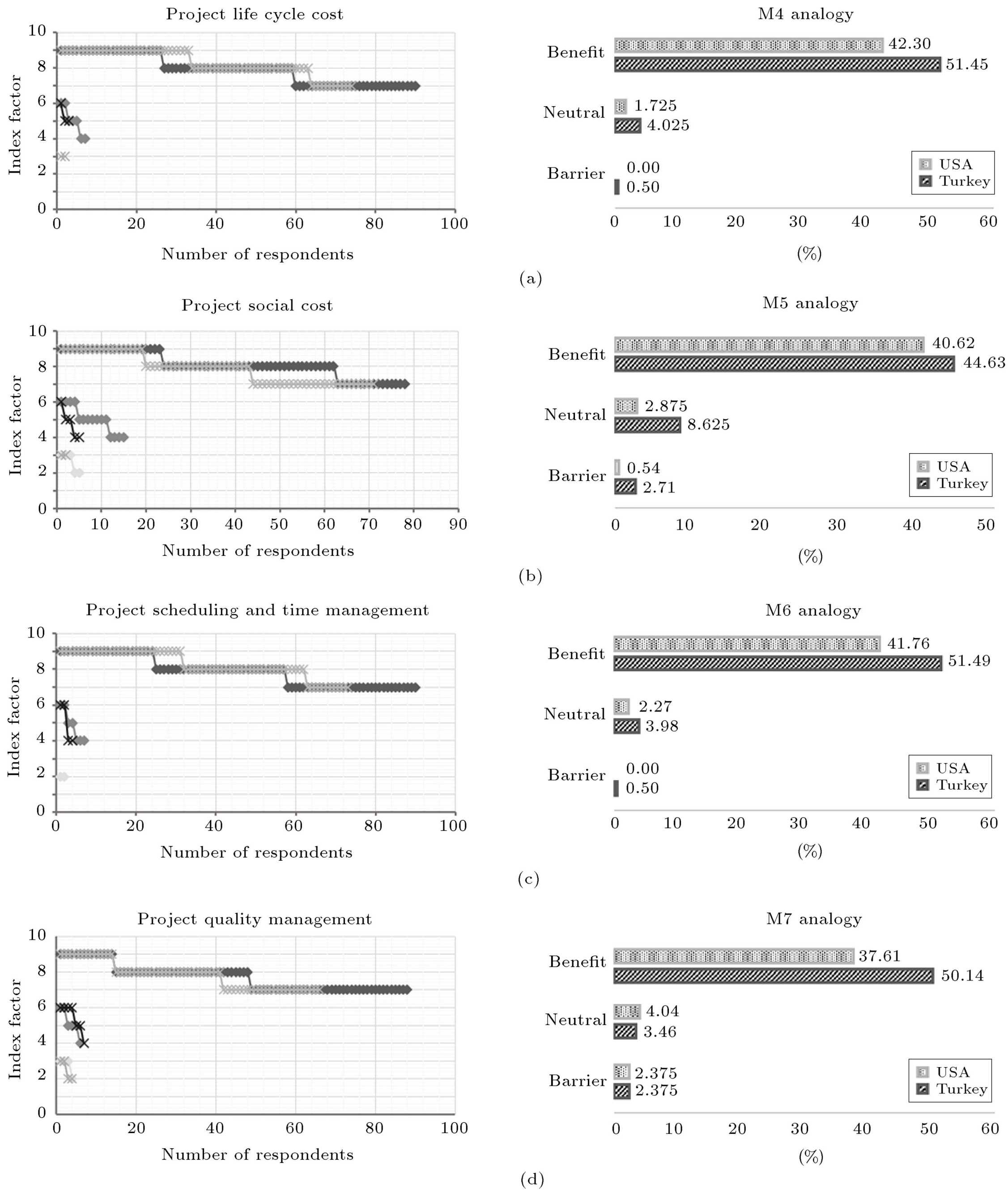


Figure 14. Managerial related variables for I-BIM utilization (Part 2).

three independent variables. The relation between E1 and E2 proves the bond between education of fresh engineers and lack of expert personnel. This fact can possibly help the construction industry compensate the deficiency of educated staff for any construction projects including infrastructure. On the other hand, E1 factor has a strong connection to the financial and public authorities variables. This relation proves the role of governments for both advanced and third-world countries in order to increase awareness of the entire industry and provide enough facilities to cover lack of regulation and standards. Therefore, this factor can lead any government to provide financial resources to support utilization of I-BIM on related projects to avoid any potential time and cost overrun for any type of infrastructure projects. It is significant to mention the independency of E3 from financial variables; conversely, it has a strong link to all managerial variables including M2, M3, and M7 for both case study countries.

According to our previous discussion, there is an interconnection among all financial variables, except E4 and E6. This contradiction is a key factor in proving the important role of stakeholders, especially

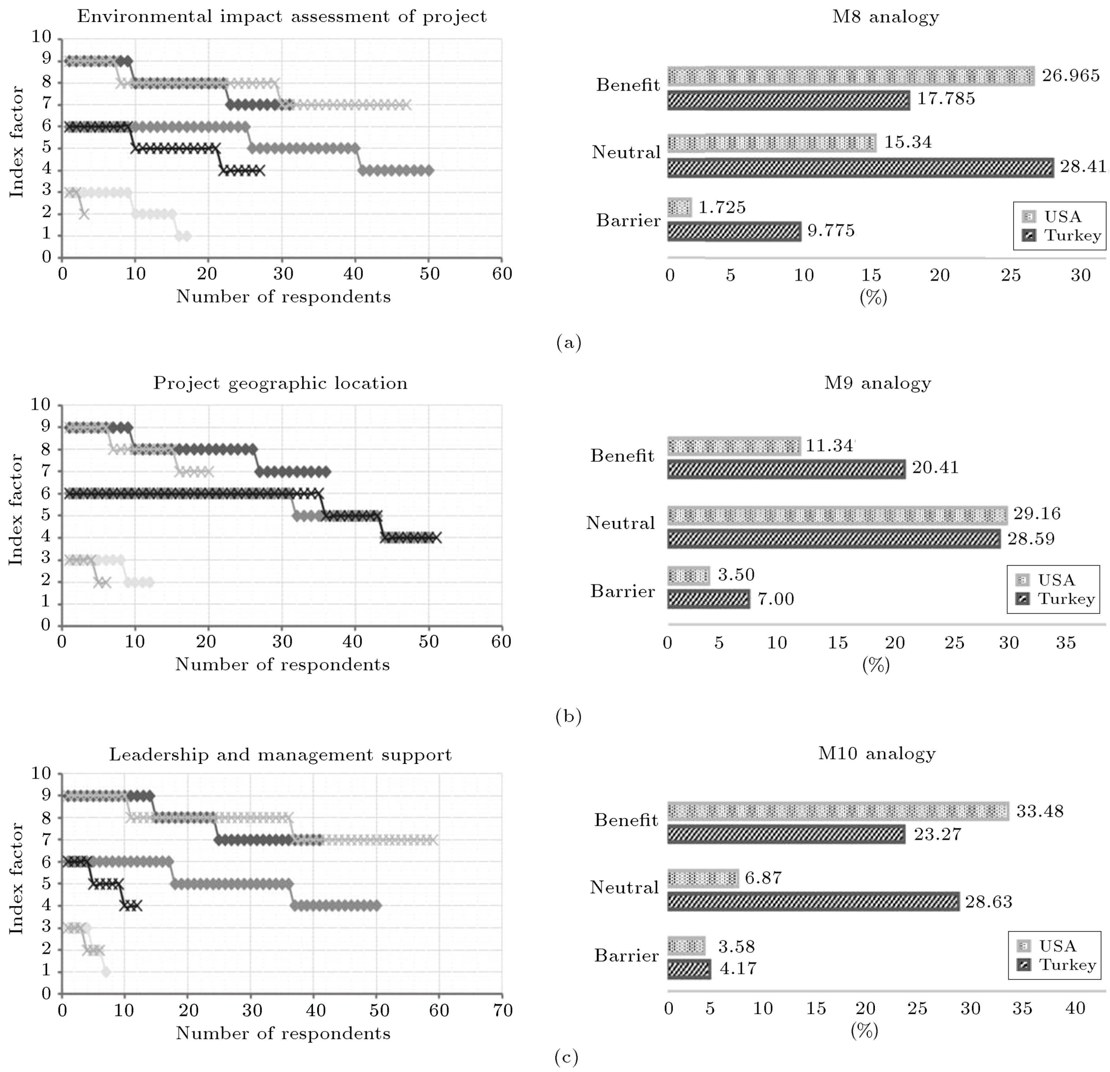


Figure 15. Managerial related variables for I-BIM utilization (Part 3).

in developing countries. Therefore, to gain an advantage of I-BIM to increase the potential turnover of the involved companies, stakeholders' involvement is unavoidable. The next category is managerial variables with 10 significant factors, all related to the nature of construction, time, cost, quality, and labor collaboration. EIA of any project with a proper leadership and management through all team parties including government can lead any project to success and it can be defined for I-BIM utilization based on the correlations among M8, M9, and M10 with all other 23 variables, especially with CR2, E3, F6, M3, and PA2. It is noteworthy that M1 to M7 variables are independent of financial and PA variables. This fact proves that through the utilization of I-BIM for the infrastructure, any project can be delivered in time with the most adequate budget and parties without interference of government or, more specifically, project clients. It is interesting to mention the solid link among all PA factors to financial variables. This irrefutable fact demonstrates the path on the way of I-BIM in order to untie knot of this issue, Therefore, all infrastructure project be able to gain enough benefit out of I-BIM.

5. Conclusions

Recently, inventive construction approaches received interests. Building Information Modeling (BIM) is among the commonly accepted ways of achieving integration at different stages of the construction projects and its benefits enhanced the schedule and planning stage alongside coordination and operation. In order to increase the quality of the project and save more time and cost, Infrastructure Building Information Modeling (I-BIM) is the best solution, but its implementation is subject to its own challenges and it is a risky path due to multiple factors including lack of expert personnel, insufficient budget, inadequate national standards, and regulation issues. The major objective of this study was

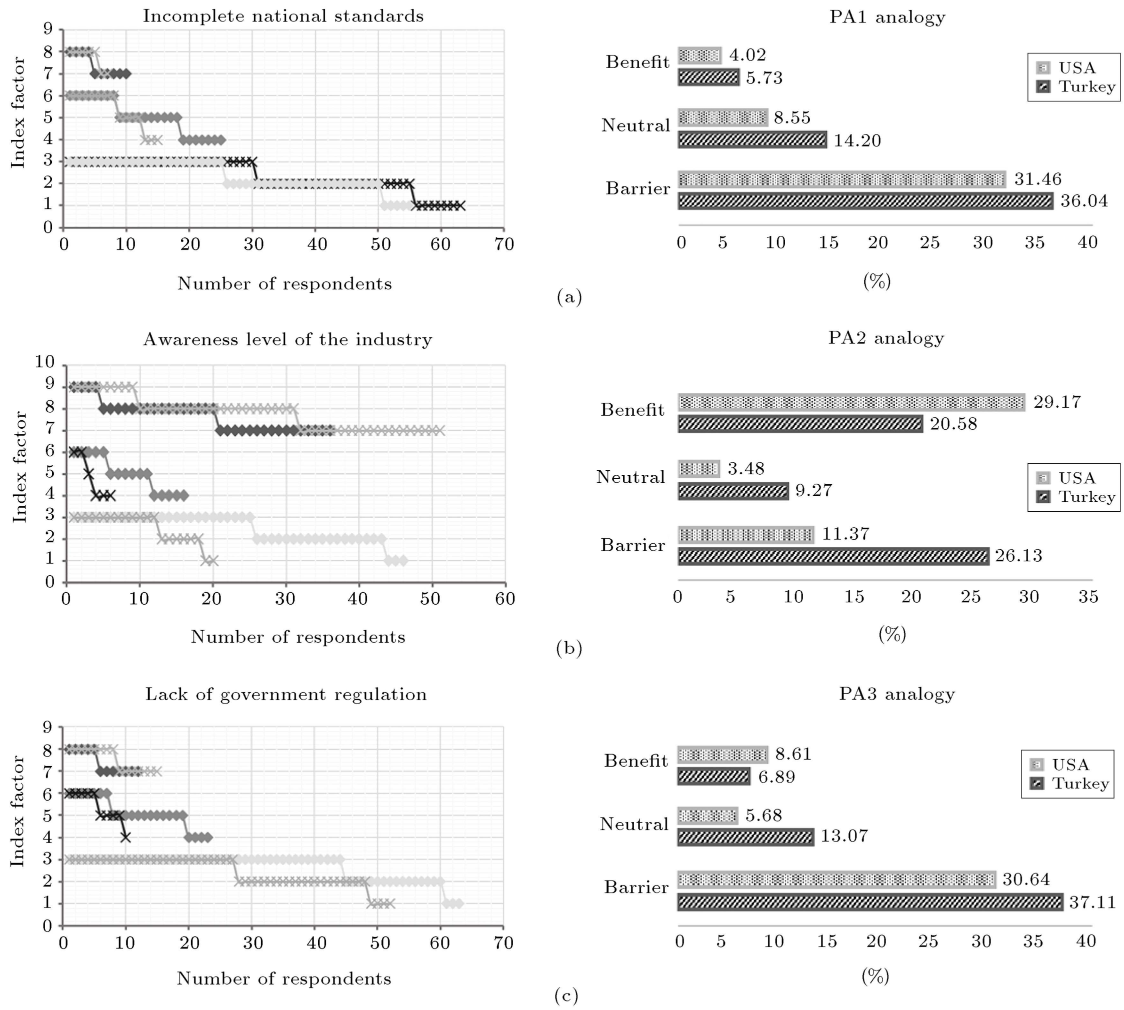


Figure 16. Public authority related variables for I-BIM utilization.

to identify and prove the existing lack of using BIM for infrastructure projects in the selected countries in order to mitigate the existing barriers to I-BIM adoption by identifying its obstacles and privilege. Based on the findings of data mining, factors including incomplete national standards, lack of government regulation, initial cost of software, availability of expert personnel, and cost of training and education are the most considerable barriers to I-BIM utilization. However, such factors as information sharing, staff collaboration, responsibility for inaccuracies, client requirement, cost and time control, quality management, and social costs were considered as the most important privileges of I-BIM, which could make clients, contractors, consultant teams, and governments an assembly and they could share benefits of collaboration, representation, process, and lifecycle to create an innovative and efficient project environment.

It can be concluded that there are numerous factors, as found in the literature, which contribute to BIM implementation for infrastructure projects in different categories. Authors attempted to categorize all the related factors in the most accurate way in order to prove the importance of using I-BIM. This study helped compare the relation among all the investigated factors because they were more likely to be interrelated to one another. For future research, a new model can be developed in order to demonstrate the effect of I-BIM on the socially related costs of infrastructure projects in order to mitigate or reduce it. Moreover, as another research topic, there is a potential to develop a program to finally quantify the social costs based on the BIM or I-BIM depending on the nature of projects. Also, the relation between I-BIM variables in these manuscripts can be investigated as a standalone topic to discover the true relation among all the related variables of I-BIM utilization.

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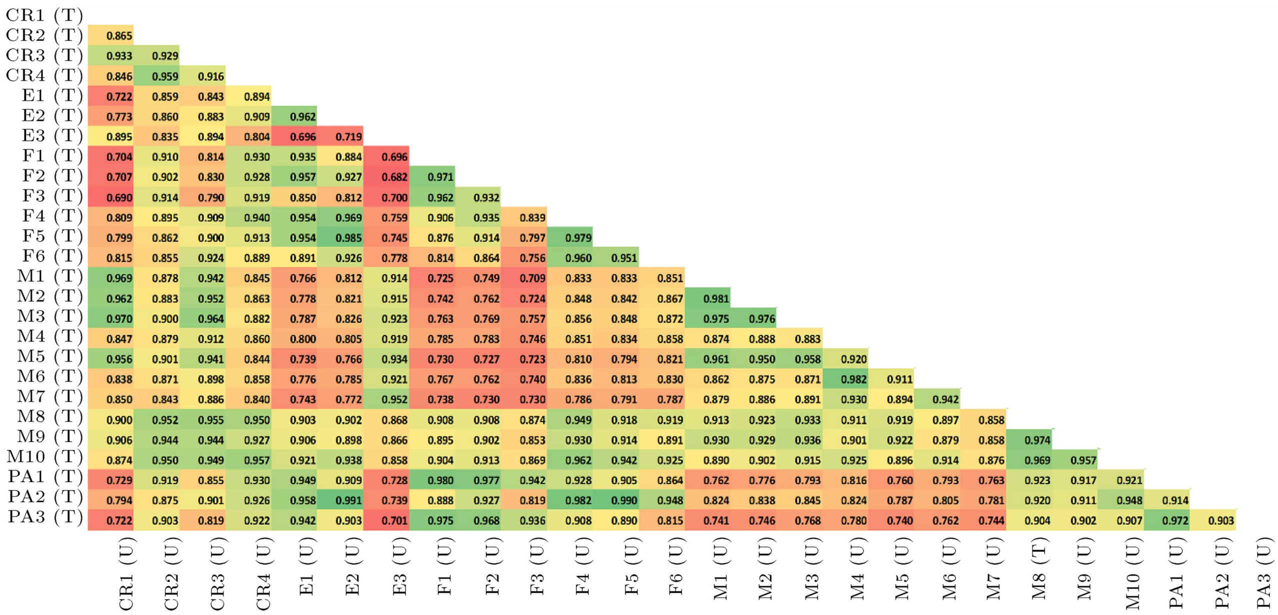

Figure 17. Correlation matrix of I-BIM variables for Turkey.

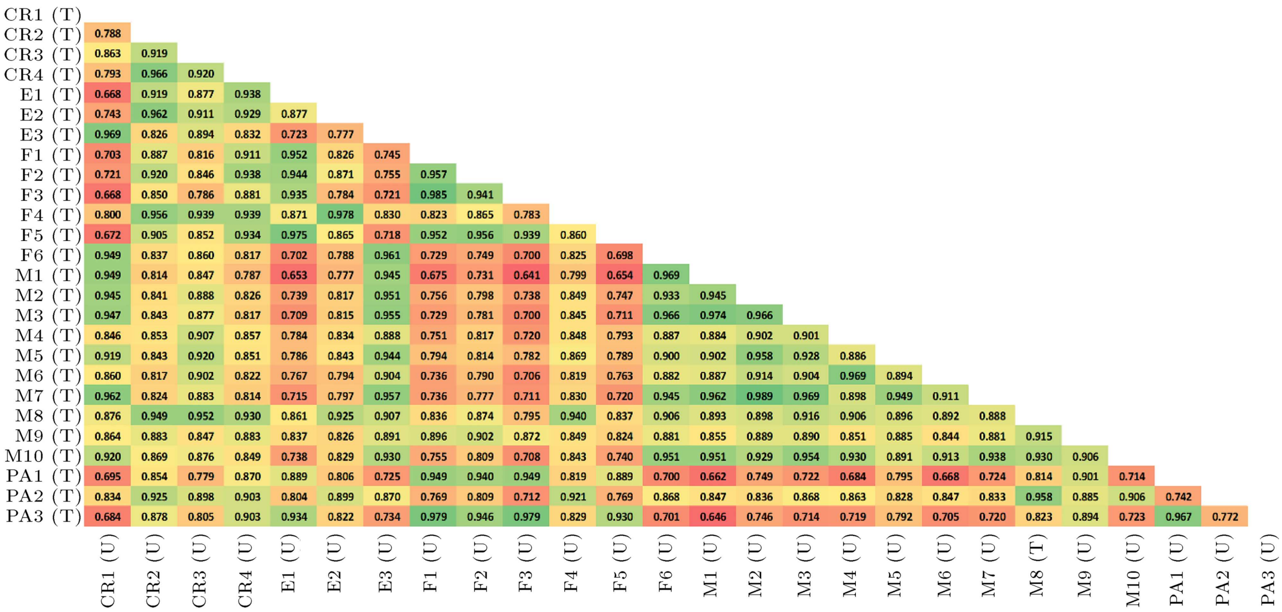

Figure 18. Correlation matrix of I-BIM variables for United States of America.

neers, Stantec, Jacobs/CH2M, Carollo, Garver, Kleinfelder, RJN, and CTBUH Future Leader Committee Global.

References

1. Wang, L., Huang, M., Zhang, X., et al. "Review of BIM adoption in the higher education of AEC disciplines", *Journal of Civil Engineering Education*, **146**(3) (2020).
2. Cheng, J.C.P., Lu, Q., and Deng Y. "Analytical review and evaluation of civil information modeling", *Automation in Construction*, **67**, pp. 31–47 (2016).
3. Lu, Y., Li, Y., Skibniewski, M., et al. "Information and communication technology applications in architecture, engineering, and construction organizations: A 15-year review", ASCE, *Journal of Management in Engineering*, **31**(1), A4014010/1-19 (2015).
4. Bjork, B. "A framework for discussing information technology applications in construction", In *CIB Working Commission W78 Workshop*, Cairns, Australia (1997).
5. El-Ghandour, W. and Al-Hussein, M. "Survey of information technology applications in construction", *Construction Innovation*, **4**(2), pp. 83–98 (2004).
6. Adwan, E. and Al-Soufi, A. "A review of ICT technology in construction", *International Journal of Manag-

ing Information Technology (IJMIT), **8**(3), pp. 1–21 (2016).

7. Bryde, D., Broquetas, M., and Volm, J.M. "The project benefits of building information modelling (BIM)", *Int. J. Project Manage*, **31**(7) pp. 971–980 (2013).

8. *Building Information Models-Information Delivery Manual*, International Standard, Second Version, ISO 29481-1 (2016).

9. Azhar, S. "Building information modeling (BIM): Trends, benefits, risks, and challenges for the AEC industry", *Leadersh. Manage. Eng.*, **11**(3), pp. 241–252 (2011).

10. Smith, P. "BIM & the 5D project cost manager", 27th IPMA World Congress, Darin Kameedan (2014).

11. Mustafa, S., Kim, K., Tam, V., et al. "Exploring the status, benefits, berries and opportunities of using BIM for advancing prefabrication practice", *International Journal of Construction Management*, **20**(2), pp. 146–156 (2018).

12. Jung, Y. and Joo, M. "Building information modelling (BIM) framework for practical implementation", *Automation in Construction*, **20**(2), pp. 126–133 (2011).

13. Biancardo, S., Viscione, N., Oreto, C., et al. "BIM approach for modeling airports terminal expansion", Special Issue, *Smart Cities and Infrastructures*, **5**(5), p. 41 (2020).

14. Uddin, M.M. and Khanzode, A.R. "Examples of how building information modeling can enhance career paths in construction", *Practice Periodical on Structural Design and Construction*, **19**(1), pp. 95–102 (2013).

15. Cheng, J., Lu, Q., and Deng, Y. "Analytical review and evaluation of civil information modeling", *Automation in Construction*, **67**, pp. 31–47 (2016).

16. Wong, A., Wong, F., and Nadeem, A., *Comparative Roles of Major Stakeholders for the Implementation of BIM in Various Countries*, Hong Kong Polytechnic University (2009).

17. McGraw Hill Construction "The Business Value of BIM in North America: Multi-Year Trend Analysis and User Ratings (2007-12)", Smart Market Report, McGraw Hill (2013).

18. Aladag, H., Demirdogen, G., and Isik, Z. "Building information modeling (BIM) use in Turkish construction industry", *Procedia Engineering*, **161**, pp. 174–179 (2016).

19. Kaewunruen, S., Sresakoolchai, J., and Zhou, Z. "Sustainability-based lifecycle management for bridge infrastructure using 6D BIM", Special Issue, *Future Cities: Urban Planning, Infrastructures and Sustainability*, **12**(6), 2436 (2020).

20. Eastman, C., Teicholz, P., Sacks, R., et al., *BIM Handbook: A Guide to Building Information Modelling for Owners, Managers, Designers, Engineers and Contractors*, Canada: John Wiley and Sons (2011).

21. Schade, J., Olofsson, T., and Schreyer, M. "Decision-making in a model-based design process", *Construction Management and Economics*, **29**(4), pp. 371–382 (2011).

22. Park, J. and Kim, J. "Building information modelling-based energy performance assessment system (an assessment of the energy performance index in Korea)", *Construction Innovation*, **12**(3), pp. 1471–1475 (2012).

23. Nepal, M., Staub-French, S., and Pottinger, R. "Providing query support to leverage BIM for construction", *The Construction Research Congress 2012, West Lafayette, Indiana, United States: American Society of Civil Engineers (ASCE)*, pp. 767–777 (2012).

24. Ahmad, A.M., Demian, P., and Price, A.D. "BIM implementation plans: a comparative analysis", *Proceedings of 28th Annual ARCOM. Edinburgh, UK: Association of Researchers in Construction*, pp. 33–42 (2012).

25. Farnsworth, C.B., Beveridgea, S., Miller, K.R., et al. "Application, advantages and methods associated with using BIM in commercial associated construction", *International Journal of Construction Education and Research*, **10**(1080), pp. 1557–1778 (2014).

26. Weygant, R.S., *BIM Content Development: Standards, Strategies and Best Practices*, New Jersey, USA: John Wiley and Sons (2011).

27. Aibinu, A. and Venkatesh, S. "Status of BIM adoption and BIM experience of cost consultants in Australia", *American Society of Civil Engineers (ASCE)*, **140**(3), pp. 1–10 (2014).

28. Raposo, C., Rodrigues, F., and Rodrigues, H. "BIM-based LCA assessment of seismic strengthening solutions for reinforced concrete precast industrial buildings", *Innovative Infrastructure Solution*, **4**, article number 51 (2019).

29. Becerik-Gerber, B. and Rice, S. "The perceived value of building information modeling in the U.S. building industry", *J. Inf. Technol. Constr.*, **15**, pp. 185–201 (2010).

30. Cheung, F.K.T., Rihan, J., Tah, J., et al. "Early stage multi-level cost estimation for schematic BIM models", *Automation in Construction*, **27**, pp. 67–77 (2012).

31. Both, P., Koch, V., and Kindsvater, A. "Potentials and barriers for implementing BIM in the German AEC market", *Proc., 30th eCAADe Conf.*, **2**, Czech Technical Univ., Prague, Czech Republic (2012).

32. Migilinskas, D., Popov, V., Juocevicius, V., et al. "The benefits, obstacles and problems of practical BIM implementation", *Procedia Eng.*, **57**, pp. 767–774 (2013).

33. Ahn, Y.H., Kwak, Y.H., and Suk, S.J. "Contractors' transformation strategies for adopting building information modeling", *J. Manage. Eng. (ASCE)*, **32**(1), 05015005/1-13 (2016).

34. Eadie, R., Browne, M., Odeyinka, H., et al. "BIM implementation throughout the UK construction project lifecycle: An analysis", *Automation in Construction*, **36**, pp. 145–151 (2013).

35. SZEDA (Shenzhen Exploration & Design Association), Guide for BIM application and development in the engineering and design industry of Shenzhen, Tianjin Science & Technology Press, Tianjin, China (2013).

36. Organization and digitization of information about building and civil engineering works, including building information modeling (BIM) - Inforamtion management using building information modeling. British Standard, ISO 19650-2 (2018).

37. Cao, D., Li, H., Wang, G., et al. "Identifying and contextualizing the motivations for BIM implementation in construction projects: An empirical study in China", *Int. J. Project Manage.*, **35**(4), pp. 658–669 (2016).

38. Costin, A., Adibfar, A., Hu, H., et al. "Building Information Modeling (BIM) for transportation infrastructure - literature review, application, challenges, and recommendations", *Automation in Construction*, **94**, pp. 257–281 (2018).

39. Gerbov, A., Singh, V., and Herva, M. "Challenges in applying design research studies to assess benefits of BIM in infrastructure projects: Reflections from Finnish case studies", *Engineering, Construction and Architectural Management*, **25**(1), pp. 2–20 (2018).

40. Alreshidi, E., Mourshed, M., and Rezgui, Y. "Exploring the need for a BIM governance model: UK construction practitioners' perceptions", *Computing in Civil and Building Engineering (ASCE)*, pp. 151–158 (2014).

41. Ganah, A.A. and John, G.A. "Achieving Level 2 BIM by 2016 in the UK", *Computing in Civil and Building Engineering (ASCE)*, pp. 143–150 (2014).

42. van Eldik, M.A., Vahdatikhaki, F., dos Santos, J.M.O., et al. "BIM-based environmental impact assessment for infrastructure design projects", *Automation in Construction*, **120**, 102186/1-12 (2020).

43. Won, J., Lee, G., Dossick, C., et al. "Where to focus for successful adoption of building information modeling within organization", *J. Constr. Engr. Manage (ASCE)*, **139**(11), 04013014/1-13 (2013).

44. Arayici, Y. and Coates, P., *A System Engineering Perspective to Knowledge Transfer: A Case Study Approach of BIM Adoption*, Virtual Reality-Human Computer Interaction, X.-X. Tan, Ed., InTech, Rijeka, Croatia, pp. 179–206 (2012).

45. Gilchrist, A. and Allouche, E.N. "Quantification of social costs associated with construction projects: state-of-the-art review", *Tunn. Undergr. Space Technol*, **20**(1), pp. 89–104 (2005).

46. Zhou, Y., Yang, Y., and Yang, J.B. "Barriers to BIM implementation strategies in China", Engineering, *Construction and Architectural Management*, **26**(3), pp. 554–574 (2019).

47. Ayinla, K.O. and Adamu, Z. "Bridging the digital divide gap in BIM technology adoption", *Engineering, Construction and Architectural Management*, **25**(10), pp. 1398–1416 (2018).

48. Zhao, X., Wu, P., and Wang, X. "Risk paths in BIM adoption: empirical study of China", **25**(9), pp. 1170–1187 (2018).

49. Ali Enshassi, A., Abu Hamra, L., and Alkilani, S. "Studying the benefit of building information modeling (BIM) in architecture, engineering, and construction (AEC) industry in the Gaza strip", *Jordan Journal of Civil Engineering*, **12**(1), pp. 401–412 (2018).

50. Koseoglu, O. and Nurtan-Gunes, E. "Mobile BIM implementation and lean interaction on construction site: A case study of a complex airport project", *Engineering, Construction and Architectural Management,* **25**(10), pp. 1298–1321 (2018).

51. Rodrigues, F., Isayeva, A., Rodrigues, H., et al. "Energy efficiency assessment of a public building resourcing a BIM model", *Innovative Infrastructure Solution*, **5**, Article number 41 (2020).

52. Celik. T., Kamali, S., and Arayici, Y. "Social cost in construction projects", *Environmental Impact Assessment Review*, **64**, pp. 77–86 (2017).

53. Bjork, B. and Laakso, M. "CAD standardization in the construction industry- a process view", *Automation in Construction*, **19**(4), pp. 398–406 (2010).

54. Alvanchi, A. and Seyrfar, A. "Improving facility management of public hospitals in Iran using building information modeling", *Scientia Iranica*, **27**(6), pp. 2817–2829 (2020).

55. Olowa, T., Witt, E., and Lill, I. "Conceptualizing building information modeling for construction education", *Journal of Civil Engineering and Management*, **26**(6), pp. 551–563 (2020).

56. Qin, X., Shi, Y., Lyu, K., et al. "Using a Tam-Toe model to explore factors of building information modelling (bim) adoption in the construction industry", *Journal of Civil Engineering and Management,* **26**(3), pp. 256–277 (2020).

57. Ma, G., Song, X., and Shang, Sh. "BIM-based space management system for operation and maintenance

phase in educational office buildings", *Journal of Civil Engineering and Management*, **26**(1), pp. 29–41 (2020).

58. Matos, R., Rodrigues, F., Rodrigues, H., et al. "Building condition assessment supported by building information modelling", *Journal of Building Engineering*, **38**, 102186/1-12 (2021).

59. Rodrigues, F., Antunes, F., and Matos, R. "Safety plugins for risks prevention through design resourcing BIM", *Construction Innovation*, **21**(2), pp. 1471–1475 (2020).

60. Xing, W., Gue, F., Jahren, C., et al. "Case studies of using BIM for infrastructure in utility tunnel projects in Jiangsu, China", *American Society of Civil Engineers, Construction Research Congress*, pp. 482–490 (2020).

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