1  *Type of the Paper (Article)*

# 2 An investigation on virtual information modeling
# 3 acceptance based on project management knowledge
# 4 areas

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14  **Abstract:** In the contemporary construction management, poor project performance, cost overrun,
15  and low-quality construction have become a central point of attention for improving project
16  performance including information, interaction and communication management. virtual design
17  and construction and building information modelling play indispensable role in improving the
18  project performance. The aim of this study is to propose a Virtual Information Modeling as a novel
19  information and communication technology method with potential to overcome problems in the
20  construction industry. Using one-sample t test with Kolmogorov-Smirnov approach, we analysed
21  data collected from structured questionnaire survey involving project managers working at
22  architecture, engineering and construction industries in Tehran, Iran. The results suggest that the
23  most important benefits and challenges of using Virtual Information Modeling are related to the
24  area of integration, and implementation of Virtual Information Modeling has the greatest impact on
25  this area of project management knowledge. Thus, integration should be considered a top priority
26  for construction companies implementing Virtual Information Modeling in their projects.
27  Policymakers should understand that careful management of virtual information is essential for
28  improving the performance of projects and enhancing the process efficiency.

29  **Keywords:** Virtual information modeling; project management knowledge areas; construction
30  projects; communication management.
31

## 1. Introduction

33      Construction companies have been struggling to improve their information management,
34  interactions and communications [1]. Information and communication technology has potential to
35  significantly reduce construction time and cost, defects, accidents, waste and operation and
36  maintenance costs while improving predictability and productivity in construction companies [2].
37  However, the majority of construction business processes are still heavily based on traditional means
38  of communication such as face-to-face meetings and the exchange of paper documents in the form of
39  technical drawings, specifications and site instructions. This is due to historical, industrial and market
40  forces that perpetuate the industry's culture, affecting the adoption of IT in day-to-day business
41  processes [1].
42      The research to date has tended to focus on improving project management methods and
43  practices [3]. Current trends in information and communication technology (ICT) are yielding a wide
44  range of new computer-based tools to support the architecture, engineering, construction and
45  facilities management (AEC) industries. These tools, particularly those associated with building

46   information models (BIMs) for project modeling and integration promise great improvement in the
47   effectiveness and efficiency of designing and managing construction projects. However, these
48   improvements require more than just technical solutions; their full potential cannot be realized
49   without corresponding changes in the work tasks and skill sets of the project participants [4].
50   Information and communication have always been important to AEC projects; however, approaches
51   for managing information have generally been informal and ad hoc [5].

52        Virtual design and construction was pioneered by research over the last two decades at the
53   Center for Integrated Facility Engineering (CIFE) at Stanford University [6]. The objective of virtual
54   design construction is to use virtual models to simulate the complexities of construction project
55   delivery, to understand the pitfalls project teams are likely to encounter, to analyze these pitfalls and
56   to address them in a virtual world before any construction work takes place in the real world [7].

57        The adoption and implementation of virtual design and construction in the architecture,
58   engineering and construction (AEC) industry has been growing in developed countries and has
59   become an important strategy in the construction industry to improve productivity and profitability.
60   Despite the many improvements and capabilities of virtual design and construction, it is still
61   unfamiliar to the construction industry in Iran, and project managers still rely on traditional
62   approaches. Over the past few years, some companies have been moving toward the use of new
63   methods, but only use some of the capabilities. Construction companies in Iran are hesitant to accept
64   and implement virtual design and construction approaches, since they are not familiar with this
65   method, and project managers are still unaware of the benefits of implementing virtual design and
66   construction. Therefore, the aim of this paper is to propose a novel Virtual Information Modeling
67   (VIM) framework for AEC industry particularly for developing countries.

68        The paper is structured as follows. First, the VIM method is introduced briefly through a
69   literature review. Then the benefits and challenges identified from the literature are categorized
70   according to project management knowledge areas. Then, using a questionnaire distributed to
71   employees in the AEC industry in Tehran province in Iran, the benefits and challenges of proposed
72   VIM are investigated and prioritized based on their applicability's in AEC industry.

73   **2. Virtual Information Modeling from Design to Construction**

74   *2.1. Terms and concepts*

75        Technology is generally defined as a technological solution in the context of construction
76   industry. For example, it refers to tools, machines, and modifications to these tools that are used to
77   achieve a project goal and perform a specific function or may resolve a problem in the context of the
78   construction industry [8, 9]. Technology in construction generally embraces digital devices, spatial
79   analysis systems, hand tools and excavation equipment and any combination of resources used in
80   the process of construction operation from design to construction and demolition [10-12]. In this
81   paper, Virtual Information Modelling (VIM) refers to two widely used concepts in the construction
82   literature: virtual design and construction and building information modelling.

83        The Center for Integrated Facility Engineering (CIFE) defines virtual design and construction as
84   the use of multi-disciplinary performance models covering design to construction, including the
85   facilities, work processes and organization of the design and construction teams in order to support
86   the construction project objectives. This concept allows a construction practitioner to build symbolic
87   models of the building, design organization and the design or construction processes early before a
88   large commitment to the client is made. Thus this supports mainly design and construction mangers
89   in terms of the description, evaluation, prediction and decisions about a project's scope, organization
90   and schedule with virtual methods [7].

91        A three-stage maturity model of development has been suggested for VIM by Khanzode, Fischer
92   et al. [7]: (i) The first stage is visualization, which traditionally, design was conducted by using two-
93   dimensional (2D) approaches, and a construction process was guided by methods such as CPM
94   (Critical Path Method) and bar charts. The aim of visualization is to represent design and rehearse
95   construction processes through visual simulation, three-dimensional (3D) technologies and virtual

96   reality. (ii) The second stage of VIM is integration which aims to integrate various processes and
97   different disciplines involved in a project. (iii) The third stage of VIM is automation, to automate
98   some of the tasks in the design and construction processes. Currently, design and construction
99   planning are creative work undertaken exclusively by humans; VIM provides a good platform for
100  this work [7].
101       As defined in National building information modeling standard, the digital representation of
102  physical objectives and functional characteristics of a facility such as a building or a bridge refers to
103  as Building Information Modeling (NIBS 2007). Building Information Modeling was utilized by
104  practitioners as a significant opportunity in the architecture, engineering and construction industry.
105  It is an emerging concept which is known as a solution to facilitate the integration and management
106  of information throughout the building life cycle.   Previous studies presented several case studies
107  and applications of this technology [13-15].
108       The scope of the definition of virtual design and construction is broader than that of building
109  information modelling, but both concepts give us a comprehensive view of utilizing a new
110  technology for both design and construction at different levels of office and project. The building
111  information modelling concept tends to cluster around a 3D model and visualize the technical aspects
112  of a project, virtual design and construction encompasses multi-disciplinary use of the models and
113  social methods for achieving the project goals. The virtual design and construction also stresses the
114  loop between defining objectives and rendering solutions with optimization and automation. Hence
115  while building information modelling and virtual design and construction share similar
116  characteristics, there are subtle additions to virtual design and construction in regard to the scope of
117  modeling, the drivers of modeling, and social methods for leveraging those models, making it more
118  comprehensive and holistic than building information modelling. However, since many entities and
119  individual projects across the industry set forth their own definition of building information
120  modelling, some may argue that building information modelling also includes these additional
121  characteristics. With this understanding in mind, i.e., with a broader definition of building
122  information modelling that matches virtual design and construction, both concepts the virtual design
123  and construction and building information modelling, namely VIM can be represent all relevant
124  technologies in construction [16].
125       While previous concepts pointed out to the technology itself, and the applications, they did not
126  give an insight into the process of the technology acceptance in a specific context. According to Rogers
127  [17], technology acceptance is defined as a series of steps taken in the technology utilization process.
128  In this process, a technology user passes through the process results in accepting or rejecting the
129  utilization of the VIM technology. Sepasgozar et al [18] classifies the technology adoption into three
130  major clusters from different perspectives: (i) socio-economic perspective [19]; (ii) managerial
131  perspective [8]; and (iii) psychological perspective [20, 21]. Studies that take a socio-economic
132  perspective such as Rogers [17] focused on profiling the users of particular technologies in different
133  disciplines. Rogers [19]   suggested that technology acceptance occurs within a social system, where
134  potential adopters communicate with each other based on a variety of attitudes towards technology
135  utilization. Roger's formative model includes five groups of technology adopters: innovators; early
136  adopters; early majority adopters; late majority adopters; and laggards. The key concept of this theory
137  relies on the concept of innovation relative to individual behavior, their relationships in a social
138  context, and communication. Research in construction adopted the concepts and applied them in a
139  way similar to other industries.
140       While there is some attempt to identify the barriers of technology adoption, the construction
141  industry continues to lag in utilizing new technologies, and is generally adverse to change as
142  discussed by Nicolini [22]; Bowden et al. [2]; Nikas et al. [23]; Harty [24]; Sepasgozar et al. [25], Milliou
143  and Petrakis [26]. The Melbourne Institute of Applied Economics and Social Research [27] indicates
144  that the construction technology index is significantly lower than any other industries. This index
145  had a large fell by 18.2% between 2005 and 2006. For example, Hinsch et al. [28] studied on
146  photovoltaic modules in Fraunhofer Institute for Solar Energy Systems (ISE) and reported that the
147  Dye Solar Cells (DSC) is investigated as a new technology since 15 years. Hinsch [29] wondered why

148    only a small portion of the photovoltaic modules was adopted by builders in construction market so
149    far, when the photovoltaic application has a strong market in overall. Cleveland [30] identified a
150    group of emerging technologies that may enable construction projects and support construction
151    operation in the field. However, he concluded that there are significant barriers to be investigated
152    and challenges to be addressed and several hurdles to overcome for adoption. The adverseness to
153    risk   and the technology acceptance lag is due to many reasons such as the stakeholders expectations
154    and communication, variability of a project's expertise, the uniqueness of the technology [31] and the
155    nature of industry itself [32] e.g. in developing country. These reasons make the construction industry
156    very different compared to other industries. This is extradited since the technology acceptance and
157    utilization processes in construction is not clearly understood, while they are mature streams in other
158    disciplines such as Information System (see: Vessey et al. [33]; Venkatesh et al. [34]).
159    The main concept of technology acceptance goes back to decades ago when Howard and Moore
160    [35, p. 34] found that the technology users' path to a utilization decision consists of a series of mental
161    or behavioral steps that potential adopters pass through. This might be coupled with organizational
162    factors when we analyze the adoption process including benefits and challenges at the project level.
163    Here, Adoption description reveals the necessary steps to introduce a product into the daily
164    operations of an organization [36]. A well-known phycological model of Theory of Reasoned Action
165    (TRA) developed by Ajzen and Fishbein [37] is concerned with the indicators of conscious intention
166    and users attitude towards a behavior.
167    Davis et al. [20] developed their model based on the Theory of Reasoned Action, namely
168    technology acceptance model including two main contracts presented in Figure 1. These
169    constructions are useful to predict individual behavior applied to the field of VIM technology.
170    Sepasgozar et al. [18] analyzed technology acceptance model, as a predictor of the an information
171    technology acceptance. The main construction are usefulness and ease of use.

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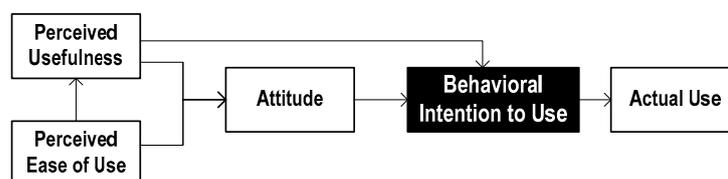


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174    **Figure 1.** Technology Acceptance Model (Source: Sepasgozar et al. [18] adopted Davis [20])
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*2.2. The Gap of Understanding Construction Technology Adopters at Organizational Level*

177    The literature ignored to continuedly investigate the barriers and drivers of technology
178    acceptance mainly VIM in developing countries. Since we understate the subjectivity of the barriers
179    as perceived by their participants, it is no surprise that they overlooked some fundamental factors
180    relevant to the context including developing countries in the literature of innovation adoption. The
181    innovation diffusion literature [17] emphasize that (a) technology acceptance is based the perception
182    that the VIM meets (or fails to meet) a desired level of utilization, and then (b) the process of reducing
183    the uncertainty of the perceived acceptance of VIM is largely depends on individuals interactions in
184    a project or organization, which is a peer to peer process. This concept poorly understood in the
185    literature. For example, Rahman's [38] deduction that a policy intervention may give a better
186    information dissemination about the benefits of modern methods in construction is valuable.
187    However, as mentioned above, they omitted the fact that some companies may be the wrong target
188    market for such a policy, and also overlooked the fact that many of the relevant stakeholders already
189    communicate with each other via site visits and social media, and exhibitions.
190    In order to extend the body of knowledge, it is essential to consider previous scientific
191    investigations in the field of technology adoption. The paper by Rahman [38] demonstrates how
192    neglecting established work in the innovation literature may lead to significant confusion. According
193    to Rahman [38], the technology acceptance model can be seen as a series of stages in the utilizing
194    process through which the technology user passes.
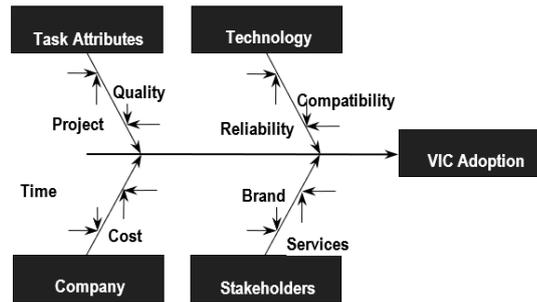
**Figure 1.** Fishbone Framework of the Influential Factors in VIC Adoption Decision.

The OECD reports [39] indicate that the construction industry is one of the highest of almost 30 industries in terms of its sourcing modules from intermediaries. Sepasgozar et al [40] carefully examined the literature and points to the poor understanding of the technology adoption process in the construction literature. For example, Rahman [38] contextualizes a claim of low modern methods in construction uptake by identifying that 7% of low rise multifamily homes are built by using modern methods in construction, the author also identifies that modern methods in construction are inappropriate for small scale projects, because of (a) the high overhead costs of utilizing a modern method and (b) the high cost per unit when quantities of technology applications is low. If adoption of modern methods in construction is not beneficial for small companies. Therefore, promoting a new technology and its application and benefits to them may actually be counterproductive and contribute to technology failure or the company failure. Figure 2 categorizes factors derived from the literature which will be used for developing the criteria for identifying VIM benefits and challenges.

Existing research in construction has considered the financial aspects of technology selection using conventional investment justification, and the implementation and evaluation of particular technologies [41, 42]. Whereas many typologies of adoption have been ignored such as process innovation, and barriers of technological administrative innovations. In addition, stakeholders and individuals, specifically technological gatekeepers, who attempts to find and get aware from a new technology, have important roles and may significantly influence the adoption. Scholars such as Slaughter [43]; Stewart and Tatum [44] investigated several innovations, and they pointed that innovators such as idea generator who face to a challenge in a construction project also may significantly influence the technology adoption, and can be a gatekeeper, e.g. an innovative designer in a contractor organization. A summary of benefits of implementing the virtual design and construction approach are classified according to ten areas of project management knowledge [45] are shown if Table 1.

**Table 1.** Benefits of VDC Application.

| Item | Benefits | Researcher and Year |
|---|---|---|
| VIM Integration | • Increase integrity among product, working process and organization in design-construction-operation team<br>• Achieve integrity and interactivity in business structures<br>• Optimize efficiency during all phases of the project<br>• Provide useful and useable information during the whole project life cycle<br>• Ensure conjunction among fragmented construction processes<br>• Ensure effective information and knowledge management<br>• Avoid same mistakes in different projects<br>• Improve productivity | [6]<br>[7]<br>[46]<br>[47]<br>[3]<br>[7] |

| Item | Benefits | Researcher and Year |
|---|---|---|
| Time efficiency of VIM usage | • Decrease the time of the decision-making process by using interactive behaviors<br>• Decrease the time of request for information (RFI) and receiving them<br>• Increase the speed of updating changes in all dependent models<br>• Decrease reworks<br>• Achieve short timetables and improve effect on project time | [48] |
| Cost reduction | • Reduce total costs<br>• Consider the value of project as a whole<br>• Improve cost estimation and estimation accuracy | [3, 46, 49] [50] |
| Quality | • Improve the quality of design and construction<br>• Improve the quality of provided construction documentation | [6, 49] |
| Stakeholder | • Improve the sense of ownership among stakeholders<br>• Improve understanding of design models by stakeholders during evolution of models<br>• Use for a wide range of companies and levels of ability and experience<br>• Help group decision-making<br>• Increase the efficiency of each partner | [6, 51] |
| Human Resource | • Increase staff safety | [52] |
| Procurement | • Facilitate resource management | [48] |
| Risk | • Facilitate scenario simulation and prediction of project activities by project team | [3, 53-55] |
| Scope | • Increase flexibility<br>• Develop constructability and implementation strategies | [6, 51] [52] |

224    Note: Items refer to the Project Management Knowledge Areas [45].
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229    A summary of challenges of implementing the VIM are classified according to several areas of
230    project management knowledge [45] are shown in Table 2.

231    **Table 2.** Challenges of VDC Application.

| Items | Challenges | Researcher and Year |
|---|---|---|
| Integration | Need for multi-party collaboration contracts<br>Need to change processes of project organization | [6, 51] |
| | Lack of software compatibility from one project to another | [3] |
| Time | Creating all models at the optimum level of detail and accuracy and reducing design speed | [3] |
| Cost | Excessive cost of software and hardware tools<br>Controversy over who should pay for VDC | [6, 51] [3] |
| | Creating training and learning costs | |
| Stakeholder | The need for all stakeholders to agree on standards for exchange between different models | [6, 51] |

| Items | Challenges | Researcher and Year |
|---|---|---|
| Human Resource | Need for a high level of expertise | [52] |
| Risk | The existence of innovative processes and the risk of change | [3, 53-55] |

232    Note: Items refer to the Project Management Knowledge Areas [45].

## 3. Materials and Methods

234    The construction industry of Tehran Province is divided into two main sectors. The first is
235    government infrastructure projects and the second is the housing industry. In recent years, the
236    construction industry has been thriving due to an increase in national and international investment
237    to the extent that it is now the largest in the Middle East region. The purpose of this research is to
238    study the benefits and challenges of applying virtual information modeling in construction projects
239    in Tehran, Iran. This research recognizes the benefits and challenges of applying VIM in projects, and
240    classifies them according to areas of project management knowledge, in order to specify the
241    significance of the benefits and challenges in project success.

242    The variables of the study are the variables which are identified for investigating the benefits
243    and challenges of applying VIM in projects which contain specified indicators in each of ten areas of
244    project management knowledge: integration, time, cost, communications, quality, stakeholder,
245    human resource, procurement, risk and scope (Snyder 2014). The research hypothesis is "the
246    identified benefits and challenges in each of the ten areas of project management knowledge
247    influence the successful completion of a project".

248    This study used a survey research design because it provides a relatively quick and better
249    method of collecting information from targeted samples and addressing research objectives.
250    Collecting VIM data is a time-consuming process, and all data has not been recorded; thus, a
251    questionnaire is a quick way of collecting data and it is an appropriate tool for empirical research and
252    can generalize findings by testing the hypotheses. The sample population for the research was
253    employees in the AEC industry in Tehran province in Iran who are familiar with VIM and are likely
254    to apply it in their organization's projects. Regarding the small number of individuals who are
255    familiar with VIM and likely to use VIM in their projects and no available database of these people.
256    A survey was comprised of tailored measurement scales with 30 questions pertinent to VIM benefits
257    and 10 questions related to challenges of VIM application in projects, based on the literature review
258    results were classified into ten areas of project management knowledge. The survey response rate
259    was 64%. Table 3 presents the summary of respondents' profile.

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268                              **Table 3.** Summary of respondents' profile.

| Item | | Number | Percent |
|---|---|---|---|
| Gender | Male | 24 | 75% |
| | Female | 8 | 25% |
| Age | ≤35 | 9 | 28% |
| | 36≤  ≤45 | 14 | 44% |
| | 46≤  ≤55 | 6 | 19% |
| | 56≤ | 3 | 9% |
| Educational Level | Bachelor | 6 | 19% |

| | | | |
|---|---|---|---|
| | Master | 22 | 69% |
| | PhD or above | 4 | 12% |
| Education | Architecture | 7 | 22% |
| | Civil Engineering | 13 | 41% |
| | Construction Management | 8 | 25% |
| | Industrial Engineering | 3 | 9% |
| | Mechanical Engineering | 1 | 3% |
| Experience in Construction Industry (Years) | ≤5 | 4 | 13% |
| | 6≤ ≤10 | 9 | 28% |
| | 11≤ ≤20 | 11 | 34% |
| | 21≤ ≤30 | 5 | 16% |
| | 31≤ | 3 | 9% |
| Understanding the VDC Concept | Yes | 26 | 81% |
| | To a certain Extent | 6 | 19% |
| | No | 0 | 0% |

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## 4. Results of the Structured Survey

Content validity was used to evaluate the survey validity. The draft survey was discussed by professors and specialists in this field and after the recommended changes were made, the final survey was prepared. To evaluate the reliability of the survey, Cronbach's Alpha Test was used in SPSS software. The acceptable coefficient in this test is 0.7 and as the Cronbach's Alpha is closer to one, the questionnaire will have a better reliability. Table 4 shows the results. To specify the way data has been distributed, the inferential statistics method was used through the Kolmogorov-Smirnov Test in SPSS software. A One-Sample T Test was used for confirmation or rejection of the benefits and challenges of applying VIM which were identified in the literature review. The Friedman Test was used to study the equality or inequality of the significance of benefits and challenges of VIM application through the One-Sample T Test.

**Table 4.** Reliability of Survey: Cronbach's Alpha Coefficient.

| | N of Items | N | Cronbach's Alpha |
|---|---|---|---|
| Benefits of VDC | 30 | 32 | 0.848 |
| Challenges of VCD | 10 | 32 | 0.739 |

*4.1. Kolmogorov-Smirnov Test*

Table 5 shows the results of the Kolmogorov-Smirnov Test for all of the research variables. The distribution of all research data variables (benefits and challenges) was normal, so parametric tests were used for variable tests and inferential analysis.

**Table 5.** Results of the Kolmogorov-Smirnov Test

| Variables | | Kolmogorov-Smirnov Z | Asymp. Sig. (2-tailed) | Result |
|---|---|---|---|---|
| | integration | 1.25 | 0.088 | Normal data |

| Variables | | Kolmogorov-Smirnov Z | Asymp. Sig. (2-tailed) | Result |
|---|---|---|---|---|
| Benefits of VDC application | time | 1.176 | 0.145 | Normal data |
| | cost | 1.038 | 0.195 | Normal data |
| | communications | 1.288 | 0.067 | Normal data |
| | quality | 1.296 | 0.061 | Normal data |
| | stakeholder | 1.151 | 0.142 | Normal data |
| | human resource | 1.135 | 0.152 | Normal data |
| | procurement | 1.268 | 0.08 | Normal data |
| | risk | 0.974 | 0.299 | Normal data |
| | scope | 1.355 | 0.051 | Normal data |
| Challenges of VDC application | integration | 0.896 | 0.398 | Normal data |
| | time | 1.303 | 0.067 | Normal data |
| | cost | 1.255 | 0.086 | Normal data |
| | stakeholders | 1.295 | 0.069 | Normal data |
| | human resources | 0.985 | 0.305 | Normal data |
| | risk | 1.166 | 0.148 | Normal data |

292   *4.2. One-Sample T Test for Analysis of the Benefits of VIM Application*

293   The benefits of applying VIM are classified according to the ten project management knowledge
294 areas. The results of the statistical analysis of each of the 30 benefits are presented in Table 6.
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296      **Table 6.** Results of One-Sample T Test for the Evaluation of Benefits

| Variables | Test Value = 3 | | | | 95% Confidence Interval of the Difference | | Result |
|---|---|---|---|---|---|---|---|
| | T | df | Mean | Sig. (2-tailed) | Lower | Upper | |
| Achieve integrity and interactivity in business structures | 12.571 | 31 | 4.6562 | 0 | 1.3875 | 1.925 | confirmed |
| Optimize efficiency during all phases of the project | 15.092 | 31 | 4.625 | 0 | 1.4054 | 1.8446 | confirmed |
| Provide useful and useable information during the whole project life cycle | 12.661 | 31 | 4.5938 | 0 | 1.337 | 1.8505 | confirmed |
| Ensure conjunction among fragmented construction processes | 7.628 | 31 | 4.4062 | 0 | 1.0302 | 1.7823 | confirmed |
| Improve productivity | 11.787 | 31 | 4.375 | 0 | 1.1371 | 1.6129 | confirmed |
| Increase integrity among product, working process and organization in design-construction-operation team | 12.771 | 31 | 4.375 | 0 | 1.1554 | 1.5946 | confirmed |
| Ensure effective information and knowledge management | 7.915 | 31 | 4.0625 | 0 | 0.7887 | 1.3363 | confirmed |

| Variables | Test Value = 3 | | | | 95% Confidence Interval of the Difference | | Result |
|---|---|---|---|---|---|---|---|
| | T | df | Mean | Sig. (2-tailed) | Lower | Upper | |
| Avoid same mistakes in different projects | 7.309 | 31 | 4.125 | 0 | 0.8111 | 1.4389 | confirmed |
| Integration | 16.07 | 31 | 4.4023 | 0 | 1.2244 | 1.5803 | confirmed |
| Achieve short timetables and improve effect on project time | 13.552 | 31 | 4.5938 | 0 | 1.3539 | 1.8336 | confirmed |
| Decrease the time of the decision-making process by using interactive behaviors | 7.155 | 31 | 4.0625 | 0 | 0.7596 | 1.3654 | confirmed |
| Decrease the time of request for information (RFI) and receiving them | 4.706 | 31 | 3.625 | 0 | 0.3541 | 0.8959 | confirmed |
| Increase the speed of updating changes in all dependent models | 6.664 | 31 | 4.0938 | 0 | 0.759 | 1.4285 | confirmed |
| Time | 13.416 | 31 | 4.0938 | 0 | 0.9275 | 1.26 | confirmed |
| Decrease reworks | 12.636 | 31 | 4.3438 | 0 | 1.1269 | 1.5606 | confirmed |
| Reduce total costs | 9.843 | 31 | 4.25 | 0 | 0.991 | 1.509 | confirmed |
| Consider the value of project as a whole | 11 | 31 | 4.375 | 0 | 1.1201 | 1.6299 | confirmed |
| Improve cost estimation and estimation accuracy | 5.036 | 31 | 3.75 | 0 | 0.4463 | 1.0537 | confirmed |
| Cost | 14.404 | 31 | 4.1797 | 0 | 1.0126 | 1.3467 | confirmed |
| Facilitate communications and interactions among stakeholders | 7.4 | 31 | 4.1562 | 0 | 0.8376 | 1.4749 | confirmed |
| Reduce complicated bureaucracies and solve problems more easily | 2.247 | 31 | 3.3438 | 0 | 0.0317 | 0.6558 | confirmed |
| Communications | 6.099 | 31 | 3.75 | 0 | 0.4992 | 1.0008 | confirmed |
| Improve the quality of design and construction | 7.506 | 31 | 4.0625 | 0 | 0.7738 | 1.3512 | confirmed |
| Improve the quality of provided construction documentation | 8.92 | 31 | 4.2812 | 0 | 0.9883 | 1.5742 | confirmed |
| Quality | 9.284 | 31 | 4.1719 | 0 | 0.9144 | 1.4293 | confirmed |
| Improve understanding of design models by stakeholders during evolution of models | 7.642 | 31 | 4.125 | 0 | 0.8247 | 1.4253 | confirmed |
| Improve the sense of ownership among stakeholders | 0 | 31 | 3 | 1 | -0.3172 | 0.3172 | rejected |
| Increase the efficiency of each partner | 0.338 | 31 | 3.0625 | 0.737 | -0.3144 | 0.4394 | rejected |

| Variables | Test Value = 3 | | | | 95% Confidence Interval of the Difference | | Result |
|---|---|---|---|---|---|---|---|
| | T | df | Mean | Sig. (2-tailed) | Lower | Upper | |
| Use for a wide range of companies and levels of ability and experience | 7.721 | 31 | 4.25 | 0 | 0.9198 | 1.5802 | confirmed |
| Help group decision-making | 7.726 | 31 | 4.1562 | 0 | 0.851 | 1.4615 | confirmed |
| Stakeholders | 7.93 | 31 | 3.7188 | 0 | 0.5339 | 0.9036 | confirmed |
| Increase staff safety | 0.892 | 32 | 3.125 | 0.379 | -0.1609 | 0.4109 | rejected |
| Human resources | 0.892 | 32 | 3.125 | 0.379 | -0.1609 | 0.4109 | rejected |
| Facilitate resource management | 3.985 | 31 | 3.422 | 0 | 0.2086 | 0.5711 | confirmed |
| Procurement | 3.985 | 31 | 3.422 | 0 | 0.2086 | 0.5711 | confirmed |
| Facilitate scenario simulation and prediction of project activities by project team | 3.544 | 31 | 3.352 | 0 | 0.1988 | 0.5105 | confirmed |
| Risk | 3.544 | 31 | 3.352 | 0 | 0.1988 | 0.5105 | confirmed |
| Increase flexibility | 3.999 | 31 | 3.437 | 0 | 0.2144 | 0.6606 | confirmed |
| Develop constructability and implementation strategies | 3.579 | 31 | 4.062 | 0 | 0.7331 | 1.3919 | confirmed |
| Scope | 3.681 | 31 | 3.75 | 0 | 0.5211 | 0.9789 | confirmed |

297

298  *4.3. Friedman Test for Prioritizing the Benefits of VIM Application*

299      The Friedman Test was used to prioritize the benefits of VIM which were confirmed in the One-
300  Sample T Test. The results for this test are shown in Table 7 and Table 8.

301              **Table 7.** Test Statistics of Friedman Test for Prioritization of Benefits of VDC

| N | 32 |
|---|---|
| Chi-Square | 210.606 |
| df | 26 |
| Asymp. Sig. | 0.000 |

302

303              **Table 8.** Average Rating of Benefits of VDC among the Confirmed Benefits

| Benefit | Average rating | Benefit Priority |
|---|---|---|
| Achieve integrity and interactivity in business structures | 19.58 | 1 |
| Optimize efficiency during all phases of the project | 18.78 | 2 |
| Achieve short timetables and improve effect on project time | 18.55 | 3 |
| Provide useful and useable information during the whole project life cycle | 18.39 | 4 |
| Provide conjunction among fragmented construction processes | 17.66 | 5 |
| Consider the value of project as a whole | 16.38 | 6 |
| Improve productivity | 16.2 | 7 |
| Increase integrity among product, working process and organization in design-construction-operation team | 16.16 | 8 |

| Benefit | Average rating | Benefit Priority |
|---|---|---|
| Decrease reworks | 15.95 | 9 |
| Use for a wide range of companies and levels of ability and experience | 15.62 | 10 |
| Improve the quality of provided construction documentation | 15.39 | 11 |
| Reduce total costs | 14.94 | 12 |
| Facilitate communications and interactions among stakeholders | 14.58 | 13 |
| Increase the speed of updating changes in all dependent models | 14.2 | 14 |
| Avoid same mistakes in different projects | 14.11 | 15 |
| Help group decision-making | 14.08 | 16 |
| Decrease the time of decision-making process by using interactive behaviors | 13.92 | 17 |
| Develop constructability and implementation strategies | 13.88 | 18 |
| Improve understanding of design models by stakeholders during evolution of models | 13.86 | 19 |
| Improve the quality of design and construction | 13 | 20 |
| Ensure effective information and knowledge management | 12.89 | 21 |
| Improve cost estimation and estimation accuracy | 10.47 | 22 |
| Decrease the time of request for information (RFI) and receiving them | 9.92 | 23 |
| Facilitate scenario simulation and prediction of project activities by project team | 7.84 | 24 |
| Reduce complicated bureaucracies and solve problems more easily | 7.52 | 25 |
| Increase flexibility | 7.5 | 26 |
| Facilitate resource management | 6.62 | 27 |

304
305      Table 7 indicates that the significance level is zero and it is less than the level of alpha error 0.05,
306  so the null hypothesis of "having equal importance among the benefits of applying VIM in successful
307  completion of the project" is rejected and the alternative hypothesis of "differing importance of the
308  benefits of applying VIM in successful completion of the project" is confirmed. Table 8 indicates that
309  the average rating and the priority of 27 benefits in applying VIM influence the successful completion
310  of projects. The most important benefits of applying VIM are "Achieve integrity and interactivity in
311  business structures" with average rank of 19.58, "Optimise efficiency during all phases of the project"
312  with average rank of 18.78 and "Achieve short timetables and improve effect on project time" with
313  average rank of 18.55. The least important benefits are "Reduce complicated bureaucracies and solve
314  problems more easily" with rank of 7.52, "Increase flexibility" with rank of 7.50 and "Facilitate
315  resource management" with rank of 6.62.
316

317  *4.4. One-Sample T Test for Analysis of the Challenges of VIM Application*

318      The results of statistical analysis for each challenge of VIM application are presented in Table 9
319  according to the areas of project management knowledge.
320

321              **Table 9.** One-Sample T Test Results for Evaluation of Challenges of VDC Application

| Variables | Test amount = 3 | | | | | | Result |
|---|---|---|---|---|---|---|---|
| | T | df | mean | Sig. (2-tailed) | 95% Confidence Interval of the Difference | | |
| | | | | | Lower | upper | |
| Need for multi-party collaboration contracts | 2.273 | 31 | 3.5 | 0.03 | 0.0514 | 0.9486 | confirmed |
| Need to change processes of project organization | 3.973 | 31 | 3.9688 | 0 | 0.4715 | 1.466 | confirmed |
| Lack of software compatibility from one project to another | 3.498 | 31 | 3.7812 | 0.001 | 0.3258 | 1.2367 | confirmed |
| Integration | 3.821 | 31 | 3.75 | 0.001 | 0.3497 | 1.1503 | confirmed |
| Creating all models at the optimum level of detail and accuracy and reducing design speed | 6.984 | 31 | 3.937 | 0 | 0.6637 | 1.2113 | confirmed |
| Time | 6.984 | 31 | 3.937 | 0 | 0.6637 | 1.2113 | confirmed |
| Excessive cost of software and hardware tools | -4.104 | 31 | 2.1875 | 0 | -1.2162 | -0.4088 | rejected |
| Creating training and learning costs | -4.176 | 31 | 2.0938 | 0 | -1.3489 | -0.4636 | rejected |
| Controversy over who should pay for VDC | 4.984 | 31 | 3.537 | 0 | 0.5227 | 1.1024 | confirmed |
| Cost | -2.748 | 31 | 2.6051 | 0 | -0.6586 | -0.2813 | rejected |
| The need for all stakeholders to agree on standards for exchange between different models | 1.561 | 31 | 3.218 | 0.129 | -0.067 | 0.5045 | rejected |
| Stakeholder | 1.561 | 31 | 3.218 | 0.129 | -0.067 | 0.5045 | rejected |
| Need for a high level of expertise | 9 | 31 | 4.125 | 0 | 0.0187 | 1.3799 | confirmed |
| Human resource | 9 | 31 | 4.125 | 0 | 0.0187 | 1.3799 | confirmed |
| The existence of innovative processes and the risk of change | 3.215 | 31 | 3.5 | 0.003 | 0.1828 | 0.8172 | confirmed |
| Risk | 3.215 | 31 | 3.5 | 0.003 | 0.1828 | 0.8172 | confirmed |

322

### 4.5. Friedman Test for Prioritizing the Challenges of VIM Application

The Friedman Test was used to prioritize the challenges of applying VIM which were confirmed in the One-Sample T Test. The results are shown in Table 10 and Table 11.

**Table 10.** Test statistics of Friedman test for prioritization of challenges of VIM application

| N | 32 |
|---|---|
| Chi-Square | 48.008 |
| df | 6 |
| Asymp. Sig. | 0.000 |

**Table 11.** Average Rating of Challenges of VDC Application among Confirmed Challenges

| Challenge | Average Rating | Challenge Priority |
|---|---|---|
| Need to change processes of project organization | 4.81 | 1 |
| Need for a high level of expertise | 4.77 | 2 |
| Creating all models at the optimum level of detail and accuracy and reducing design speed | 4.52 | 3 |
| Lack of software compatibility from one project to another | 4.42 | 4 |
| Need for multi-party collaboration contracts | 3.86 | 5 |
| The existence of innovative processes and the risk of change | 3.66 | 6 |
| Controversy over who should pay for VDC | 1.97 | 7 |

335
336     Table 10 indicates that the significance level is zero and it is less than the level of alpha error
337     0.05, so the null hypothesis is rejected and the alternative hypothesis of "differing importance of the
338     challenges of applying VIM in successful completion of the project" is confirmed.
339
340     Table 11 shows the priority of seven challenges in applying VIM which affect successful
341     completion of a project. The three greatest challenges are "Need to change processes of project
342     organization" with average rate of 4.81, "Need for a high level of expertise" with average rate of 4.77
343     and "Creating all models at the optimum level of detail and accuracy and reducing design speed"
344     with average rate of 4.52. The least important challenge is "Controversy over who should pay for
345     VIM" with average rank of 1.97.
346

347     **5. Discussions**

348     The objective of the research was to investigate the benefits and challenges of applying virtual
349     design and construction in projects and prioritize them. Through a literature review, the benefits and
350     challenges were identified and a survey of 32 construction industry employees in Iran was used to
351     confirm these benefits and challenges through statistical analysis. The 27 confirmed benefits of using
352     VIM are presented in Table 12, by area of relevant project management knowledge and their priority.
353

354
**Table 12.** Ranks of Benefits of VIM Application

| Priority | Project Management Knowledge Area | Benefit |
|---|---|---|
| 1 | Integration | Achieve integrity and interactivity in business structures |
| 2 | Integration | Optimize efficiency during all phases of the project |
| 3 | Time | Achieve short timetables and improve effect on project time |
| 4 | Integration | Provide useful and useable information during the whole project life cycle |
| 5 | Integration | Ensure conjunction among fragmented construction processes |
| 6 | Cost | Consider the value of project as a whole |
| 7 | Integration | Improve productivity |
| 8 | Integration | Increase integrity among product, working process and organization in design-construction-operation team |
| 9 | Time | Decrease reworks |
| 10 | Stakeholder | Use for a wide range of companies and levels of ability and experience |
| 11 | Quality | Improve the quality of provided construction documentation |
| 12 | Cost | Reduce total costs |
| 13 | Communications | Facilitate communications and interactions among stakeholders |

| Priority | Project Management Knowledge Area | Benefit |
|---|---|---|
| 14 | Time | Increase the speed of updating changes in all dependent models |
| 15 | Integration | Avoid same mistakes in different projects |
| 16 | Stakeholder | Help group decision-making |
| 17 | Time | Decrease the time of decision-making process by using interactive behaviors |
| 18 | Scope | Develop constructability and implementation strategies |
| 19 | Stakeholder | Improve understanding of design models by stakeholders during evolution of models |
| 20 | Quality | Improve the quality of design and construction |
| 21 | Integration | Provide effective information and knowledge management |
| 22 | Cost | Improve cost estimation and estimation accuracy |
| 23 | Time | Decrease the time of request for information (RFI) and receiving them |
| 24 | Risk | Facilitate scenario simulation and prediction of project activities by project team |
| 25 | Communications | Reduce complicated bureaucracies and solve problems more easily |
| 26 | Scope | Increase flexibility |
| 27 | Procurement | Facilitate resource management |

355
356    Table 12 shows the benefits associated with the area of project integration management have
357 higher priorities than other areas. The three main benefits of VIM are:
358 • Achieve integrity and interactivity in business structures;
359 • Optimize efficiency during all phases of the project;
360 • Achieve fast tacking approach and improve project schedule management plan.
361    Table 13 shows the seven challenges of adopting the virtual design and construction method by
362 the area of project management knowledge and their priorities.
363
364                    Table 13. Ranks of Challenges of VIM Application

| Priority | Project Management Knowledge Area | Challenge |
|---|---|---|
| 1 | Integration | Need to change processes of project organization |
| 2 | Human Resource | Need for a high level of expertise |
| 3 | Time | Creating all models at the optimum level of detail and accuracy and reducing design speed |
| 4 | Integration | Lack of software compatibility from one project to another |
| 5 | Integration | Need for multi-party collaboration contracts |
| 6 | Risk | The existence of innovative processes and the risk of change |
| 7 | Cost | Controversy over who should pay for VDC |

365
366    Just as the most important benefits of VIM are associated with the area of integration
367 management, the greatest challenges posed by VIM are also related to this area. This indicates the
368 importance of VIM in creating greater integration and also creating challenges, which highlights the
369 need for efficient management in this area. The three main challenges of VIM are:
370 • Need to change processes of project organization as the project team are will not be ready for
371    changes.

372 • Need for a high level of expertise in VIM; This is not a new finding.   All other papers about BIM
373   saying the same thing.
374 • Detailed design must be accurate and optimal, and it needs to be complete in a shorter time.

## 6. Conclusions and recommendations

376     The results show that while VIM creates the greatest benefit in the area of project integration
377 management, the greatest challenges are also in this area. VIM can support in a collection of processes
378 required to ensure that the various elements of the projects are properly coordinated. VIM involves
379 making trade-offs among competing objectives and alternatives to meet or exceed stakeholder needs
380 and expectations. This highlights the importance of attention to all aspects of the use of VIM,
381 specifically integration, and shows that even after the implementation of VIM the result is not always
382 positive. In this research, the benefits and challenges of using virtual information modeling in
383 construction projects were identified, based on the area of project management knowledge areas were
384 categorized and then prioritized according to a survey among the people working in construction
385 industry of Iran and being familiar with the concept of VIM. While the benefits and challenges of
386 using VIM for all areas of project management knowledge areas were considered simultaneously in
387 the research, future research could investigate the benefits and challenges using a larger sample and
388 from other countries and separately for each of the ten areas of project management knowledge.
389 Additionally, as the society of people using basic functions of VIM in their projects is gradually
390 expanding, this survey can be conducted in a larger society.
391

392 **Author Contributions:** "Nasim Didehvar conceived, designed and performed the experiments; Mohammadnabi
393 Teymourifard contributed materials and analysis tools; Mohammad Mojtahedi and Samad Sepasgozar. analyzed
394 the data and wrote the paper.

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