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Determination of Significance of 4D-BIM Features

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Abstract: Planning is one of the advancements in Building Information Modeling (BIM) domain which enables the practitioner to visualize the relation of time with 3D objects. Notwithstanding the fruitful existing studies, the awareness of the practitioners concerning 4D-BIM features is not sufficient. Moreover, the construction industry suffers from the lack of features of the existing 4D-BIM software. Furthermore, the existing features vary from software to software due to a lack of awareness with respect to the importance of the features of 4D-BIM. These drawbacks result in unsuccessful 4D-BIM applications in the construction industry. Therefore, this study aims to define 4D-BIM features and detect their importance in the construction industry. Hence, 4D-BIM features were detected via an in-depth literature review and a Focus Group Discussion (FGD) conducted with 10 experts. Consequently, 16 4D-BIM features were detected. Later, the features were evaluated by 35 experts who have experience in the 4D-BIM domain, and the obtained data were analyzed via Relative Importance Index (RII) method to detect the significance levels of 4D-BIM features. As a result, the significance level of each feature was found to be greater than 0.5 according to RII method, which indicates that each of the features in 4D-BIM has critical importance in the planning of the project. It is highly believed that this study will pave the way for future 4D-BIM-related studies as well as increase the awareness of the practitioners, software developers and researchers in terms of the current needs of the construction industry.

4D-BIM Özelliklerinin Öneminin Belirlenmesi

Anahtar Kelimeler
BIM,
İnşaat,
Planlama,
Göreceli Önem Endeksi

Öz: Planlama, uygulayıcıların 3D nesnelerle zaman ilişkisini görselleştirmesini sağlayan Yapı Bilgi Modellemesi (YBM) alanındaki gelişmelerden biridir. Mevcut çalışmalara rağmen, uygulayıcıların 4D-YBM özellikleri ile ilgili farkındalığı yeterli değildir. Ayrıca inşaat sektörü, mevcut 4D-BIM yazılımlarının yetersiz özelliklerinden muzdariptir. Ayrıca, 4D-BIM'in özelliklerinin önemi konusunda farkındalık eksikliği nedeniyle mevcut özellikler yazılımdan yazılıma değişmektedir. Bu dezavantajlar, inşaat sektöründe 4D-BIM uygulamalarının başarısız olmasına neden olmaktadır. Bu nedenle, bu çalışma 4D-YBM özelliklerini tanımlamayı ve inşaat sektöründeki önemini tespit etmeyi amaçlamaktadır. Bu nedenle, derinlemesine bir literatür taraması ve 10 uzmanla gerçekleştirilen Odak Grup Tartışması (OGG) ile 4D-YBM özellikleri tespit edildi. Sonuç olarak çalışmamızda 16 adet 4D-YBM özelliği tespit edilmiştir. Daha sonra öznitelikler 4D-YBM alanında deneyim sahibi 35 uzman tarafından değerlendirilmiş ve elde edilen veriler Göreceli Önem İndeksi (RII) yöntemi ile analiz edilerek 4D-YBM özniteliklerinin anlamlılık düzeyleri tespit edilmiştir. Sonuç olarak, 4D-YBM 'deki her bir özelliğin projenin planlanmasında kritik öneme sahip olduğunu gösteren RII yöntemine göre her bir özelliğin önem düzeyi 0,5'ten büyük bulunmuştur. Bu çalışmanın gelecekte 4D-YBM ile ilgili çalışmaların önünü açacağı ve inşaat sektörünün mevcut ihtiyaçları konusunda uygulamacıların, yazılımcıların ve araştırmacıların farkındalığını artıracağına inanılmaktadır.

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1. Introduction

BIM domain is far beyond the conventional 3D modelling by including some significant features. Bisedes 3D modeling, BIM allows the user to manage a lot of information such as material, cost and time. It is therefore important to refer to the dimensions of BIM. In fact, each time a certain type of information is entered into the model, a different dimension is specified, and therefore various dimensions are produced in the BIM process. There are seven accepted "dimensions" in BIM domain. While software having conventional 3D modeling – which is not called BIM - includes geometric and graphical information, software based on 4D BIM modeling includes time-related information through Gantt charts and timelines. 5D modeling includes cost management features. While 6D modeling covers environmental, economic and social sustainability features, 7D modeling includes building life cycle, facility management, maintenance and repair features. Improving the process of construction projects, technology has been developed rapidly in recent years, which has led to major changes in Architecture, Engineering and Construction (AEC) industry [1]; therefore, conventional methods have become outdated. Construction firms need to adapt to the innovations brought by technology over time in order to survive in the competitive environment [2]. Building Information Modeling (BIM) - which is one of the most significant and remarkable technological developments in the AEC industry - is an approach where the information is availed and managed for the design, construction and operation processes of a facility [3]. As part of broader digital technologies, BIM provides an opportunity to the construction industry to raise the performance of construction projects via better data integration and project collaboration platform [4]. Being a digital model, BIM enables practitioners to access and share information needed in the life cycle of the building [5]. By the same token, the main essential BIM implementation is the collaboration of numerous stakeholders at different phases of the facility life cycle to add, omit, update or modify the concerning information in the BIM to support and reflect the role of those stakeholders [6]. BIM focuses on the collaborative project lifecycle process, and in this context, the idea of integrating time information into a 3D model revealed the 4D-BIM [7]. Time management is one of the most important mediums in construction projects, and 4D-BIM is a powerful tool for managing time effectively by planning the construction process in a 3D model [8]. For this reason, with the abandonment of conventional methods and the acceleration of the BIM adaptation process, the number of research and studies on the application of BIM has increased over time [9]. Notwithstanding the advancement in 4D-BIM domain, today, many construction projects have still faced many bottlenecks such as delays in deadlines, financial losses and disputes due to inadequacy in tracking and managing construction projects. In addition to this, embracing the current BIM technology also requires many changes in the projects and organizations which hinders the adoption of BIM in the construction industry [10]. Because of the aforementioned bottlenecks affecting the BIM integrations negatively, numerous fruitful studies have been conducted with respect to 4D-BIM domain. When an in-depth literature review is conducted, it is observed that the existing studies mostly have focused on the topics such as the factors hindering the implementation of 4D-BIM, the opportunities provided by 4D-BIM, improving the construction performance with 4D-BIM, safety issues and other studies improving the 4D-BIM applications. The concerning literature is elaborated in Section 2 to provide deep insight into motivation of this study. Although raising the awareness of the construction industry concerning the features of 4D-BIM is very crucial for the 4D-BIM adoption [11], there is no holistic study that comprehensively elaborates on the features of 4D BIM in the literature concerning 4D-BIM domain.

Although there have been significant improvements in the 4D-BIM domain, the features of 4D-BIM software – which enables time management in the construction industry – vary from software to software and there is no study defining the significance of these features. Furthermore, in practice, the available features of 4D-BIM don't fully satisfy the practitioners and it is claimed that new features which can improve the practicability of 4D-BIM are essential. By the same token, the adaptation of 4D-BIM in today's construction projects is not very common [12] since some of the important attributes of planning software are not available in the 4D-BIM software [13] and the construction industry requires an effective planning medium to manage the construction processes proactively and complete the projects successfully. Therefore, improving the planning features in 4D-BIM is of paramount importance to enable practitioners to manage construction projects according to project objectives. Therefore, this study aims to reveal the existing and requiring features of 4D-BIM software and determine their significance. To achieve the objective of this study, at the outset, the existing features related to the 4D-BIM were identified by conducting an in-depth literature review. Then, an FGD was held with 10 experts who have experience in the domain of 4D-BIM to detect further 4D-BIM features. Afterwards, the information obtained as a result of an in-depth literature review and FGD session was listed, and 35 experts were asked with the help of questionnaires prepared with Likert 5-point scale. The data obtained were evaluated through the RII method and the importance levels of the features of 4D-BIM software were determined. Critical Evaluation of Literature

section is introduced after the Introductions section to demonstrate relevant studies with respect to 4D-BIM domain and, to improve the comprehension of 4D-BIM domain. Later, Methodology section is introduced by elaborating the development of the research framework and examining the main research methods, namely Focus Group Discussion and Relative Importance Index. Moreover, to improve the readability of the manuscript, Findings and Discussions section is detailed with the subsections such as Detecting the Features of 4D-BIM and Detecting the Significance Level of 4D-BIM Features via RII Method. Consequently, Conclusion and Recommendations section is presented to reveal the contribution of this study to the construction industry and future studies on this domain.

With the help of this study, the needs of the construction sector in terms of 4D-BIM were defined, and in this context, it is believed that this study will shed light on practitioners, software developers and academics working on the 4D-BIM domain. In addition to paving the way for future studies with respect to the improvement of the 4D-BIM, this study helps the software developer to take advantage of this study to improve the 4D-BIM software. Since 4D-BIM is adopted in many construction projects in the majority of countries including Turkish construction industry, it is believed that the outcomes of this study improve the construction industry globally. Therefore, it is believed that this study is novel and highly contributes to the improvement of the construction industry worldwide.

2. Material and Method

2.1. Determination of Existing Features of 4D-BIM

This study aims to identify the features of 4D-BIM software and determine the importance of these features in order to define the needs of the construction industry. Firstly, in this study, an in-depth literature review was conducted to gain a comprehensive insight into the fundamentals of 4D-BIM and its features. Consequently, 8 features of 4D-BIM were detected via literature.

2.2. Focus Group Discussion

In methodology section, secondly, an FGD session is conducted. FGD has long been adopted as one of the most respected research methods to gather and synthesize the seeking data through dynamic and interactive group discussions held by experts having experience in the concerning topic [35]. Experts are able to reveal their opinions while they gain insight into the other group members' opinions on the topic through constant interactions during the course of the FGD section [36]. By the same token, constant interactions enable the experts to refine their ideas among the participants in FGD session; therefore, this method is considered one of the most suitable methods when a topic requires to be broadly elaborated from different aspects [37].

Selecting an appropriate number of experts is of great importance to obtain reliable outcomes [38]. While selecting a large number of participants may result in drawbacks in terms of moderation of FGD, FGD sessions conducted with a small number of participants may end up with lack of creative ideas due to the undesired level of interaction [38]. Furthermore, the qualifications of experts are very crucial to discuss the topic comprehensively. Therefore, the expert selection method is illustrated in Figure 1 below. In the FGD session, the final decision is made when the group or majority of the group reaches a joint agreement.

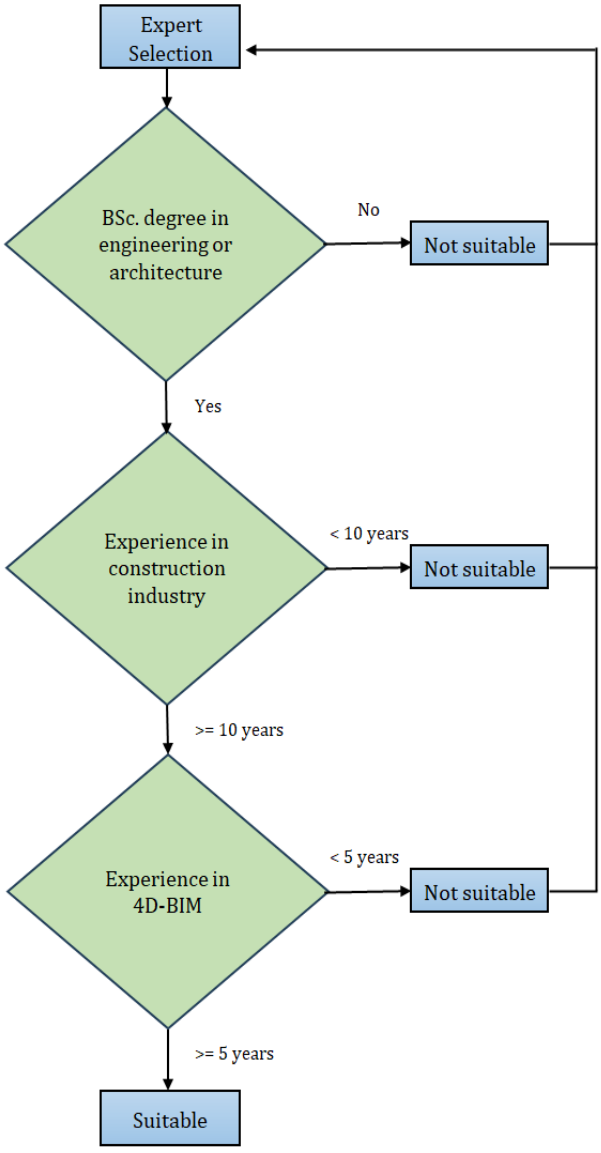

Figure 1. Expert selection criterion

In this study, 10 experts experienced in the 4D-BIM domain were selected according to the expert selection criterion defined in Figure 1 to detect further features of 4D-BIM. The FGD is a method adopted when expert knowledge and opinions in a particular field are required, and it is ensured that the best results and suggestions are obtained for the concerning subject by virtue of the discussions and evaluations of the experts in the panel [39]. Experts selected for this study are those who have experience in the construction industry minimum of 10 years and have gained 4D-BIM experience for a minimum of 5 years.

2.3. Relative Importance Index

The 4D-BIM features obtained from the literature review were introduced to the experts participating in the FGD session, and the new features of 4D-BIM were detected by the experts. Afterwards, the data obtained from the literature review and FGD session were listed, and then 35 experts – who were selected according to the expert selection criterion defined in Figure 1 - were asked to determine the significance level of each 4D-BIM feature of this list with the help of questionnaires using the Likert 5-point scale. In the Likert scale, there are five significance levels (1 to 5) evaluated by the experts to whom the questionnaire was directed [40], [41]. The obtained data were analyzed via RII method and the significance levels of the features of 4D-BIM software were determined.

Being a widely used tool for ranking factors, RII has long been recognized as a very fruitful and reliable statistical approach [42]. By the same token, RII, a method preferred by many researchers in their studies, is used to rank the factors according to their importance. The application of RII method is depicted in Equation 1 below.

$$\text{RII} = \frac{\sum_{i=1}^{i=n} W_i}{A*N} \quad (1)$$

The W_i expression represents the weight value between 1-5 given by the participants for each feature, the A expression represents the highest weight value (5), and the N expression represents the total number of participants (35). As a result of the given equation, the significance level of each feature was detected as a value between 0 and 1, and the higher the value, the more important the feature is.

3. Results

3.1. Detecting the Features of 4D-BIM

At the outset of the study, the features of BIM software were determined in light of an in-depth literature review. Then, an FGD session was held with 10 experts experienced in the field of 4D-BIM. In the FGD session, the 4D-BIM features obtained from the literature review were introduced to the experts and the new features of 4D-BIM were requested from the experts. The demographic characteristics of the experts who participated in the interviews are depicted in Table 1 below.

Table 1. Demographic characteristics of experts

Expert #	BSc. Degree	Experience in the construction industry (Year)	Experience in 4D-BIM (Year)
1	Civil Engineer	19	9
2	Civil Engineer	17	7
3	Mechanical Engineer	16	8
4	Architect	16	9
5	Civil Engineer	17	5
6	Civil Engineer	15	7
7	Civil Engineer	13	6
8	Civil Engineer	12	8
9	Architect	10	7
10	Civil Engineer	10	5

8 4D-BIM features were detected via an in-depth literature review. In addition to the literature review, experts suggested 8 further attributes of 4D-BIM which are "Resource Leveling", "Allocation of Resources to Activities and Preparation of Resource Charts", "Financial Period", "Resource Curves Entry for the Resources", "Earned Value Analysis", "Activity Code", "Assigning Calendar to the Lags and Resources" and "Allowing Different Calendar in a Project". As a result of the literature review and the FGD session, a total of 16 features were obtained as illustrated in Table 2 below. The studies revealing the features of the 4D-BIM Program are cited under Table 2.

Table 2. Features Included or should be included in the 4D-BIM Program

No	4D-BIM Features	1*	2*	3*	4*	5*	6*	7*	8*	9*
1	Adopting the Critical Path Method (CPM)	x			x					
2	Cost Control						x		x	
3	Delay Analysis	x								
4	Health, Safety and Environment (HSE) Management			x	x		x	x	x	
5	Resource Management & Leveling							x	x	x
6	Resource Assignment and Preparation of Graphical Resource Reports									x
7	Financial Period									x
8	Resource Curves Entry for the Resources									x
9	Construction Supply Chain Management (CSCM)		x						x	
10	Automated Generation of Evacuation Paths				x					
11	Risk Assessment					x				
12	Visualization of the time and space relationships			x	x		x		x	
13	Earned Value Analysis									x
14	Activity Code									x
15	Assigning Calendar to the Lags and Resources									x
16	Allowing Different Calendars in a Project									x

1*= [13], 2*= [43], 3*= [44], 4*= [21], 5*= [45], 6*= [46], 7*= [47], 8*= [22], 9*= Experts

3.2. Detecting the Significance Level of 4D-BIM Features via RII Method

The data obtained from an in-depth literature review and an FGD session was evaluated by the 35 experts who have 4D-BIM experience via surveying with 5 Point Likert Scale. The surveying were contacted via LinkedIn and e-mail. 100 experts who have 4D-BIM experience were invited to surveying, and 35 experts accepted to participate. The demographic information of experts is presented in Table 3 below.

Table 3. Demographic characteristics of the experts participating in the survey

Roles	Total	Experience in Construction (Year)				Experience in BIM (Year)		
		0-5	6-10	11-15	16-20	0-5	6-10	11-15
Project Manager	3	0	1	2	0	2	0	1
BIM Software Dealer	3	2	1	0	0	3	0	0
Senior BIM Engineer/ Architect	15	7	4	1	3	11	2	2
BIM Manager	10	2	4	0	4	5	3	2
BIM Consultant	4	0	3	0	1	1	2	1
Total	35	11	13	3	8	22	7	6

The experts participating in the study were examined in various categories in terms of occupational group, total experience and 4D-BIM experience. Based on the total experience of the participants, the value with the highest percentage was the 6–10-year category with 37.14%, while the value with the lowest percentage was the 11-15 year category with 8.57%. When BIM experiences are evaluated, it is detected that the highest value is between years of 0 to 5 with a rate of 62.86%, while the lowest value is

in the category of 16-20 years with a rate of 3.5%. Considering the distribution of respondents according to occupational groups, the Senior BIM Engineer/Architect occupational group constitutes 42.86% of the participants. This is followed by BIM

Manager with 28.57% and BIM Consultants with 11.43.2%. Occupational groups with the lowest percentage of survey participants were Project Managers and BIM Software Dealers with 8.57%.

Participants in the survey were asked to rate each feature of 4D-BIM on a scale of 1-5 according to its importance. The importance of each 4D-BIM feature was computed by using the RII method based on the survey data. The closer the RII value is to 1, the more important the feature of 4D BIM is. By examining the data obtained, the significance levels of 16 features are demonstrated in Table 4 depicted below.

Table 4. Significance levels of 4D-BIM features as per Relative Importance Index

Features of 4D-BIM	Very Low (1)	Low (2)	Medium (3)	High (4)	Very High (5)	RII	Rank
1*	0	1	1	4	29	1	1
2*	0	0	2	11	22	0.9	2
3*	1	1	6	7	20	0.9	3
4*	0	2	5	10	18	0.9	4
5*	1	3	6	10	15	0.8	5
6*	3	2	5	8	17	0.8	6
7*	3	1	7	7	17	0.8	7
8*	0	4	9	11	11	0.8	8
9*	2	4	5	15	9	0.7	9
10*	2	3	10	9	11	0.7	10
11*	1	7	7	8	12	0.7	11
12*	4	4	6	10	11	0.7	12
13*	2	4	8	14	7	0.7	13
14*	4	5	7	7	12	0.7	14
15*	4	5	8	11	7	0.7	15
16*	5	5	9	9	7	0.7	16

1* Visualization of the time and space relationships, **2*** Delay Analysis, **3*** Adopting the Critical Path Method (CPM), **4*** Activity Code, **5*** Assigning Calendar to the Lags and Resources, **6*** Resource Assignment and Preparation of Graphical Resource Reports, **7*** Earned Value Analysis, 8* Risk Assessment, **9*** Construction Supply Chain Management (CSCM), **10*** Resource Management & Leveling, **11*** Health, Safety and Environment (HSE) Management, **12*** Cost Control, **13*** Resource Curves Entry for the Resources, **14*** Allowing Different Calendar in a Project, **15*** Financial Period, **16*** Automated Generation of Evacuation Paths.

Considering the RII results of the features, there is no feature with a value lower than 0.5. This indicates that each of the features in 4D-BIM is of critical importance in the planning of the project.

4. Discussion

It is derived from Table 4 that the feature concerning "Visualization of the Time and Space Relationships", which has a very high RII value of 0.949, is the most significant feature of 4D-BIM. This feature, which received 5 points from 82.86% of the participants, has the highest importance on the list. Survey respondents have a joint agreement that the main use of 4D is visualization. Compared to traditional methods, 4D-BIM enables practitioners to obtain real-time viewing of all processes of projects in detail thanks to time integration into 3D smart objects. [46]. Classical methods of visualization, such as Gantt charts, lack the ability to illustrate the relationships between time and space [48]. With the help of this feature, more understandable and practical results are obtained, and it ensures that the problems that may be encountered can be foreseen, and the necessary precautions are taken in advance [48]. Therefore, visualization of the relationship between time and space is primarily preferred by experts.

As a result of the study, the feature of "Delay Analysis" emerges as the second important feature. The disputes that may arise due to delays in the construction projects among the project stakeholders can be significantly reduced with the help of the integration of the delay analysis feature into 4D-BIM [13].

"Adopting the Critical Path Method (CPM)" and "Activity Code" features were detected as the third significant features with a rate of 0.851. CPM enables the projects to be conducted according to the plan and diminishes the bottlenecks in terms of time. With the activity codes, data such as item numbers, location information and source codes can be accessed [13]. It enables the project to be grouped under certain headings by filtering in the software.

The next most important feature was "Assigning Calendar to the Lags and Resources" with an RII rate of 0.8. Resource management is one of the most important stages to consider during the development of a project management plan [49]. Identifying, procuring, effective use and management of the project resources for the successful completion of the project are necessary [49]. Therefore, considering the working days and non-working days of the resources is very vital to provide more reliable schedule outcomes.

The remaining features' significances are below the rate of 0.8 according to RII analysis. These are "Resource Assignment and Preparation of Graphical Resource Reports", "Earned Value Analysis", "Risk Assessment", "Construction Supply Chain Management (CSCM)", "Resource Management & Leveling", "Health, Safety and Environment (HSE) Management", "Cost Control", "Resource Curves Entry for the Resources", "Allowing Different Calendar in a Project", "Financial Period" and "Automated Generation of Evacuation Paths" respectively. Among the features offered by 4D technology, these features received the lowest scores from the experts. In the background of the low preference for these features of 4D-BIM, factors such as the low number of studies indicating the importance of these features in the literature play a crucial role.

Based on the comments of the practitioners, it can be deduced that the features of 4D-BIM – which is frequently used by the practitioners - are shaped especially in line with customer expectations; therefore, the benefit of 4D-BIM is limited within the framework of certain features. In addition, the importance of 4D-BIM features has not been emphasized enough; therefore, the perceived benefits of 4D-BIM are limited, which may be one of the main reasons for the low RII values of some features.

It is clear that the current potential of 4D-BIM is not fully benefited by the practitioners. Because the preferred features of 4D-BIM vary depending on factors such as the characteristic of projects, customer expectations and business strategy of the companies. Therefore, practitioners should be more aware the possible potential of 4D-BIM and its benefits.

With the emergence of innovations such as 4D-BIM, understanding the project designs has become easier for even project stakeholders who do not have deep knowledge concerning the construction industry, so that many more stakeholders can be involved in the planning stage of a construction project [50]. Those who apply 4D-BIM in construction projects improve project delivery and add value to the planning process; however, the successful implementation of the 4D feature is only possible if the practitioners and contractors gain enough knowledge and experience on BIM [22]. Therefore, as in the UK, 4D-BIM usage can become prevalent through encouragement made by institutions and the government.

5. Conclusion

It is of great importance to improve the planning features in 4D-BIM to enable practitioners to manage their construction projects according to the project objectives. Therefore, this study has an objective to figure out the existing and further needed features of 4D-BIM software and determine their significance level. In this study, first of all, an in-depth literature review was carried out and the features in 4D-BIM were determined. Then, an FGD session was held with 10 practitioners who have experience in the domain of 4D-BIM. At this stage, the 4D-BIM features were introduced to the experts, and further features that should be included in 4D-BIM were requested. In the wake of detecting the features of 4D-BIM, these features were directed to 35 experts working in the field of 4D-BIM, and each feature of 4D BIM was asked to be evaluated in the range of 1 to 5 points. The data obtained from the surveys conducted with 35 experts were analyzed by using the RII method and the importance levels of 4D-BIM features were determined. The features with the highest importance according to the RII analysis are listed below.

- Visualization of the time and space relationships (RII = 0.949)
- Delay Analysis (RII = 0.914)
- Adopting the Critical Path Method (CPM) (RII = 0.851)
- Activity Code (RII = 0.851)
- Resource Management (RII = 0.8)
- Assigning Calendar to the Lags and Resources (RII = 0.8)

The feature, namely visualization of the time and space relationships has the biggest importance for 4D-BIM application according to this study. Majority of the 4D-BIM software meets the expectations of the construction industry because they serve this feature. On the other hand, although delay is the inevitable part of the construction industry, and dealing with it is one of the most important needs of the construction projects according to experts participating in this study, none of the 4D-BIM software include this feature. Furthermore, the features such as Critical Path Method, Activity Code, Resource Management, Assigning Calendar to the Lags and Resources have the great importance for 4D-BIM application according to this study; however, majority of the existing software don't involve these features. Developing 4D-BIM software by taking these features into account will increase the adoption of the software by the construction industry and will also pave the way for the industry to carry out more successful projects.

As a result, the findings obtained from the study revealed the significance level of 4D-BIM features. It is highly believed that this article will enable the practitioners and researchers to understand the potential of 4D-BIM in the construction industry by defining the needs of the industry concerning 4D-BIM. Furthermore, revealing the existing and needed features of 4D-BIM software and determining their importance, this study may enable software developers to improve 4D-BIM software globally.

Declaration of Ethical Code

In this study, we undertake that all the rules required to be followed within the scope of the "Higher Education Institutions Scientific Research and Publication Ethics Directive" are complied with, and that none of the actions stated under the heading "Actions Against Scientific Research and Publication Ethics" are not carried out.

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