Status of 4D BIM Implementation in Indian Construction

V.P.C. Charlesraj and T. Dinesh

RICS School of Built Environment, Delhi NCR 201313 India
E-mail: vpcharlesraj@ricssbe.edu.in, dinesh.mc18n@ricssbe.edu.in

Abstract –

Enhanced visualisation is one of the low hanging fruits of BIM implementation. It helps in improving clarity in communications and fosters collaboration & coordination of construction projects for efficient delivery. 4D BIM combines the proposed sequence of work in a project with the 3D parametric digital model of the facility to be built. 4D BIM is highly beneficial both for managing people and materials. It can revolutionise the way facilities are designed, managed and developed. Significant benefits of 4D BIM have been reported in project planning & programming/scheduling, progress monitoring, conflict prevention & resolution, data security and construction safety. 4D BIM also adds value to business by facilitating marketing and sales.

BIM has been primarily used by design & management consultants and some large contractors in India for design optimisation and construction project management. While 4D BIM has the potential to contribute for the efficient project delivery, there is limited literature on the extent of 4D BIM implementation in India. An attempt has been made to investigate the status of 4D BIM implementation in India and study the perceived benefits, barriers and drivers by key stakeholders in the construction sector using a questionnaire survey among clients and contractors.

The results revealed high levels of awareness of 4D BIM, but the usage is low. Plan for usage in the short term is also found to be low. There is no significant difference in perception between the clients and contractors on benefits, barriers & drivers of 4D BIM. *Visualizing the construction flow, Validating the time schedules by simulations* and *Communicating the construction plan* are found to be the most perceived benefits. *Lack of 4D BIM knowledge within internal workforce, Traditional project delivery methods/contract* and *Lack of 4D BIM expertise in the market* have been reported as the critical barriers. The key drivers of 4D BIM are *Government Mandate for 4D BIM* and *Awareness of 4D BIM benefits and ROI*.

Keywords –

4D BIM; Application & benefits; Barriers & challenges; Indian construction

1 Introduction

Construction is the second largest employer next only to agriculture in India and contributes significantly to its GDP. As part of its goal to become a USD 5 trillion economy by 2024, India plans to spend USD 1.4 trillion on its infrastructure in the next five years. The level of complexity of such projects is very high due to international nature in procurement as well as sophisticated client requirements. Efficient project delivery is key in successful completion of these infrastructure projects. Traditional project delivery systems focussed on the iron triangle of project performance, time, cost and scope [1]. Emerging measures such as quality, occupational health & safety and stakeholder satisfaction demand new ways of doing business. Unfortunately, despite the fact that architects, builders and manufacturers fail every day to deliver on schedule, within budget and effectively meet the needs of their customers, not many of them achieve the desired outcomes [2].

Building Information Modelling (BIM) provides a platform for the stakeholders to work collaboratively under a common data environment for better efficiency and results [1]. Global construction projects are evolving day by day, demand for resources is growing, so there is a rising need for a sustainable process for construction scheduling to complete the projects on time within stipulated budget [2]. Design information 3D model can be used for construction planning, where time is added to the model, which is known as 4D BIM. 4D BIM improves the efficiency by reducing wastes and helps in timely completion of projects within budget by controlling the construction schedule and adds value to customers [3]. Despite the potential, it is reported that 4D BIM is not quite widely used by the construction project stakeholders. Hence, it is proposed to assess the extent of usage and understand the perspectives of key stakeholders on benefits, barriers and drivers of 4D BIM [4].

2 Literature Review

Due to increase in the complexity in projects over time, construction planners are being asked to deal with more responsibility and they play a more critical role in built environment. Gantt chart was developed by Henry Laurence Gantt in 1910 to schedule, coordinate and track the construction sequence over time. It has become the most used scheduling strategy in conjunction with improved techniques [5]. Later, schedulers understood the importance of critical activities and relations among activities, adopted critical path method (CPM), Program Evaluation and Review Technique (PERT) and many more concepts with the help of scheduling software like Microsoft project, Primavera, AstaProject, etc. to create and update schedules by allocating required resources. Traditional methods and today's scheduling software are not directly linked to design or building model [5].

Complex and large projects have different levels of planning like quarterly, monthly and weekly. Effective communication plays a major role in construction planning and guides the projects by facilitating planning & scheduling of the construction works to complete the projects and meet project objectives that include emerging performance measures [1]. Lack of communication will have immediate consequences like rework, non-uniformity, and misapplication of resources which increases the construction time and cost [6].

2.1 4D BIM

4D BIM allows planners to communicate visually and to schedule activities in time and space by linking of construction plan to the 3D model [7]. 4D BIM provides time-related information that is combined with various components of an information model for a specific item or work area that could include specifics of its design and deployment lead time [5]. The information contained in this model also contains the production rate that can be used to help assess the schedule and configure the activities by considering their position and production rate [8].

2.1.1 Project Planning using 4D BIM

Construction planning involves scheduling and sequencing activities in time and space by taking to account available resources, constraints, and other concerns in the process [5]. Traditional methods such as bar charts and the CPM do not consider the spatial configuration associated with these activities. Scheduling is therefore a complex manual job and often does not fully synchronise with the design and makes it difficult for the project stakeholders to easily understand the plan and its impact on the management of site logistics [9]. 4D planning is an extended and deeper version of conventional planning that develops the construction planning to a higher level of detail to provide greater accuracy and less risk. 4D models are also helpful in speeding up the construction process, thereby reducing mistakes and easily eliminating them [7].

To build 4D BIM model, 4D tools requires 3D model from BIM authoring tool and the construction schedule data from scheduling tool. Both the 3D model and construction schedule data are imported into the 4D tool. Then, the scheduler links the "components from the 3D model to the construction activities from the schedule and forms a time-based 4D BIM model [8].

Simulation provides significant guidance and early detection of mistakes in preparation. Instead of making layout mistakes later in the construction phase and trying to fix on-site issues that can be very costly, errors can already be avoided in the design phase [10]. The information that is obtained from the process will be quite large in the early stages by involving all stakeholders and should be collected in depth as the project progresses. It is important to note that 4D BIM refers to a specific way to link data to a knowledge model. The 4D model can be simulated with 'n' sequence number and can make as many changes as possible, and finally created with appropriate 4D sequence simulation [2].

The expertise of contractors is very critical when designing a 4D model for planning processes. If the model is built during the building's design phase, then the contractor can provide valuable feedback on buildability, estimated cost of construction, and sequencing. Also, 4D process planning simulations serve as a communication tool to identify potential bottlenecks and methods to improve coordination between project teams [11].

2.2 Benefits of 4D BIM

4D BIM offers an enhanced vision for planning, constructing and designing, sustaining or developing uniform information model that includes all the relevant information on the life cycle of the project. 4D modelling plays a major role in coordination between planners and customers during the planning phase. This helps project stakeholders spot issues in the construction phase and keep track of progress [5,6]. 4D BIM application helps to build virtual project and stimulate with different scenarios, which give all the stakeholders a better picture to identify the risks in the project at early stage and mitigate those risks by taking corrective measures.

The following key benefits and applicability of 4D BIM have been reported. Visualizing the construction progress at any time with clear look-ahead presentation [6]; Logistics planning (resources flow with in the construction site) [6,14]; Site layout planning (Reduces field interferences which may occur during the execution process, thereby improving the buildability) [6,15]; Location based planning; Clear understanding of the construction process and Construction methodology studies [6]; Validating the time schedules by simulations; Work progress meeting discussions through video for better understanding [16]; Safety planning (Visual representation of the hazards and the safety plan.) [6,18]; Documentation and claim analysis (Pretty easy to prove who is responsible for the delay and what potential results are anticipated) [19]; Reduction of risk in the project [6]; Enhanced customer satisfaction [6]; Design investigation with schedule simulations which aid to reduce the amount of rework required [6].

2.3 Barriers to 4D BIM Implementation

Despite of benefits that 4D BIM provides to construction industry, still there are few technical and non-technical barriers which are hindering the widespread diffusion of 4D BIM [5]. The extensive adoption of 4D BIM and BIM has more influence on non-technical barriers than on technical barriers. Construction industry realized the value of BIM to an extent and started using it in design phase but BIM usage in production phase for construction planning is growing at slow rate.

Elghaish & Abrishami [20] and Zou et al. [21] reported *challenges related to developing 4D model (model scope, level of detail, temporary components, decomposition and aggregation)* and *lack of proper execution plans, guidelines and standards to follow* as barriers to 4D BIM implementation. Zou et al. [21] also reported *not worth time investment to learn* and *lack of time for employees to learn* as barriers. *Lack of 4D BIM expertise in the market, lack of standards for 4D BIM, difficulty in understanding 4D BIM methods* and *lengthier process of 4D BIM creation* have been reported by Kassem et al. [22]. Kassem et al. [22] and Ahmed et al. [23] identified the following barriers: *lack of demand from the client side to use 4D BIM, high costs to invest in software, high costs for training, lack of 4D BIM knowledge within internal workforce, employee resistance to change from traditional construction planning practices to 4D BIM, traditional project delivery methods/contract,* and *problems with exchanging data between software/Interoperability*.

2.4 Summary

There is a disconnect between the traditional design & planning methods and contemporary planning & scheduling tools. Construction industry realized the value of BIM to an extent and started using it in design phase but BIM usage in planning & production phases is growing at slow rate. Gledson and Greenwood [6] investigated the benefits and applications of 4D BIM in the context of the United Kingdom. Kassem et al. [22] and Ahmed et al. [23] reported the barriers to 4D BIM implementation in the United Kingdom and Qatar respectively. Although 4D BIM has the potential to contribute for the efficient project delivery, it has been observed that country-specific studies have been reported only for UK [6,22] & Qatar [23] and no study has been reported on the extent of 4D BIM implementation in the Indian context. Hence, there is a need to investigate the status of 4D BIM implementation in India and study the perceived benefits & barriers by various stakeholders in the construction sector. An attempt has been made to investigate the extent of 4D BIM usage, perspectives of key stakeholders on 4D BIM in terms of benefits, barriers and drivers in Indian construction.

3 Research Methodology

Identification of various indicators for benefits, barriers and drivers of 4D BIM is done through literature review. BIM functions are used to assess the applicability and benefits. Indicators used in the study are presented in Table 1.

Questionnaire survey-based quantitative approach is used to study the perspectives of the construction professionals on the applicability, benefits, barriers and drivers of 4D BIM.

3.1 Design of Experiment

Target population for this study are clients and contractors in Indian construction industry. Convenient sampling method is used for the selection of respondents.

A questionnaire survey instrument has been developed and deployed online for the survey. This questionnaire is divided into 6 sections, Section 1 contains cover note and a small video on 4D BIM, Section 2 is used to collect the demographic information of the participant and next four sections have questions on applicability of 4D BIM; 4D BIM's perceived benefits over conventional construction planning approaches; Barriers and challenges of 4D BIM adoption; and drivers/solutions for 4D BIM adoption.

Descriptive statistics is used for data analysis. Relative Importance Index (RII) is used to rank the indicators to understand the relative importance as perceived by the respondents [6,23]. *T-test* is used to check the statistical significance of the perceived differences between clients and contractors, if any. Cronbach Alpha is used for internal consistency and data reliability for analysis [6,23].

4 Data Collection and Analysis

The questionnaire instrument is deployed on Google Forms and the enquiries are sent to over 100 prospective respondents (clients & contractors) through Email, LinkedIn, and over phone. There are 38 valid responses received, which includes 17 contractors and 21 clients after continuous follow-up in a span of 4 weeks. Cronbach Alpha is used to evaluate the internal consistency of the instrument and reliability of the data collected for further analysis. The calculated Cronbach Alpha values are presented in Table 2. It is observed that all the values are greater than 0.7, the threshold for social studies, and the data collected is reliable for further analysis [6,23].

Table 1. BIM functions, Barriers and Drivers

BIM Functions	
F01	Logistics planning
F02	Site layout planning
F03	Communicating the construction plan
F04	Planning the construction sequence
F05	Visualizing the construction flow
F06	Location based planning
F07	Validating the time schedules by simulations
F08	Work progress meeting discussions
F09	Safety planning
F10	Documentation and claim analysis
F11	Risk Management
F12	Design investigation with schedule simulations

Barriers to 4D BIM Implementation	
B01	Lack of demand from the client side to use 4D BIM
B02	High costs to invest in software
B03	High costs for training
B04	Lack of 4D BIM knowledge within internal workforce
B05	Lack of 4D BIM expertise in the market
B06	Not worth time investment to learn
B07	Lack of time for employees to learn
B08	Employee resistance to change
B09	Lack of standards for 4D BIM
B10	Challenges related to developing 4D model
B11	Difficulty in understanding 4D BIM methods
B12	Traditional project delivery methods/contract
B13	The lengthier process of 4D BIM creation
B14	Problems with exchanging data between software

Drivers of 4D BIM	
D01	Developing local standards for 4D BIM
D02	Government Mandate for 4D BIM
D03	Improving software functionality
D04	Good support from software vendors
D05	Awareness of 4D BIM benefits and ROI
D06	Availability of 4D BIM expertise in the market

Table 2. Reliability Statistics

Dimensions	Cronbach's Alpha	N of items
Applicability	0.912	12
Relative benefits	0.934	12
Barriers	0.852	14
Drivers	0.856	6
Overall	**0.888**	**44**

5 Results & Discussion

There were 38 valid responses, which include 17 (45%) from contractors and 21 (55%) from clients. Majority of them are from large organisations (76.3%) and others from medium (7.9%) & small (15.8%) organisations. Respondents belong to top management (34.2%), middle management (50%) and operations (15.8%) level in their respective organisations. Construction work experience of the respondents is presented in Figure 1. It can be observed that 40% of the them have more than 10 years and 26% of the respondents have 5-10 years of work experience.

5.1 Awareness & Use of 4D-BIM

It has been observed that majority (68%) of the respondents are aware of 4D BIM and have not used it and 24% are aware and used. Only a little fraction (8%) have responded that they are unaware of 4D BIM (Figure 2). This shows higher level of 4D BIM awareness and lower levels of usage. It has been attempted to understand the plan of the respondents who are aware but have not used 4D BIM. While some of the respondents indicated that they have plans to use 4D BIM in near future (11% within a year & 31% in 1-3 years), a significant 58% of respondents have plans to use 4D BIM after three years only (Figure 3). This implies anticipated lower adoption of 4D BIM in the short run.

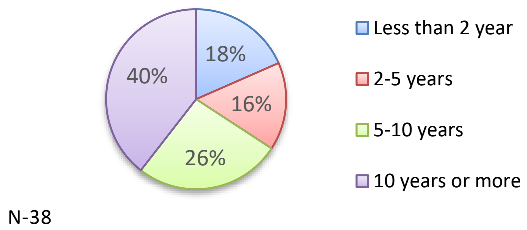

Figure1. Work experience of respondents

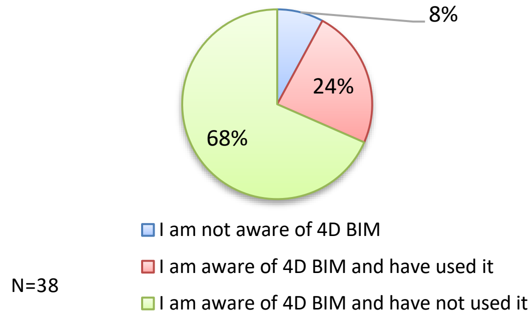

Figure 2. 4D BIM awareness and usage

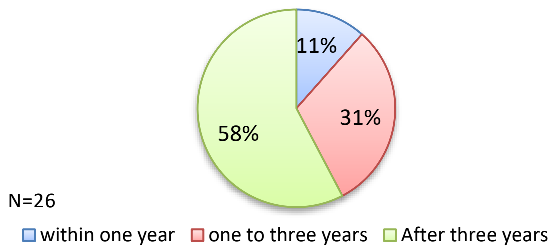

Figure 3. Plan to use 4D BIM

5.2 Applicability of 4D BIM

The participants were asked to provide their opinion on the applicability of 4D BIM by on a five-point Likert scale (Not at all Applicable to Highly Applicable) against various BIM functions as found in Table 1. The frequency distribution of responses as well as RII are presented in Figure 4. It can be noticed from the pattern of responses that the respondents have rated 4D BIM as highly applicable. Among the BIM functions *Visualizing the construction flow (F05)*, *Communicating the construction plan (F03)* and *Validating the time schedules by simulations (F07)* have been found to be the most preferred application of 4D BIM. Even though *Site layout planning (F02)* and *logistic planning (F01)* have been ranked low, they are still very much applicable. In addition, clients have rated *Design investigation with schedule simulations (F12)* very much applicable.

5.3 Relative Benefits of 4D BIM

In response to the question on benefits & usefulness of 4D BIM, the participants rated various BIM functions as found in Table 1 on a five-point Likert scale (Not at all Beneficial to Highly Beneficial). The frequency distribution of responses as well as RII are presented in Figure 5. It can be noticed that the response pattern is similar to the applicability above. *Visualizing the construction flow (F05)*, *Communicating the construction plan (F03)* and *Validating the time schedules by simulations (F07)* have been rated as top benefits of 4D BIM. However, clients perceive that *Design investigation with schedule simulations (F12)* is more beneficial compared to *Communicating the construction plan (F03)*. Again, high scores of RII for other indicators reveal the highly beneficial in nature of 4D BIM.

5.4 Barriers to 4D BIM Implementation

The respondents perceive that *Lack of 4D BIM knowledge within internal workforce (B04)*, *Traditional project delivery methods/contract (B12)* and *Lack of 4D BIM expertise in the market (B05)* as the top barriers for the adoption and use of 4D BIM in Indian construction (Figure 6.). This is in response to a question on barriers on a five-point Likert scale of Agreement. *Not worth time investment to learn (B06)* and *Lack of time for employees to learn (B07)* have been rated low as barriers.

5.5 Drivers of 4D BIM

Drivers are key for improved adoption. In response to a question on drivers of 4D BIM on a five-point Likert scale (Very Low to Very High), the respondents rated

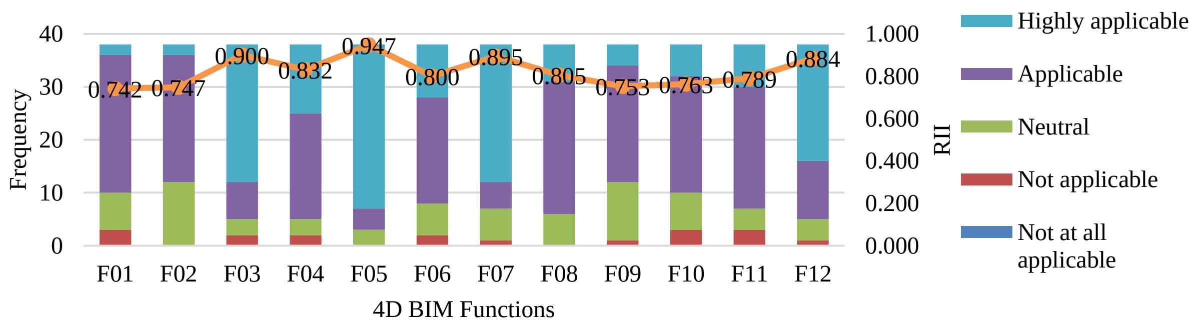

Figure 4. Applicability of 4D BIM

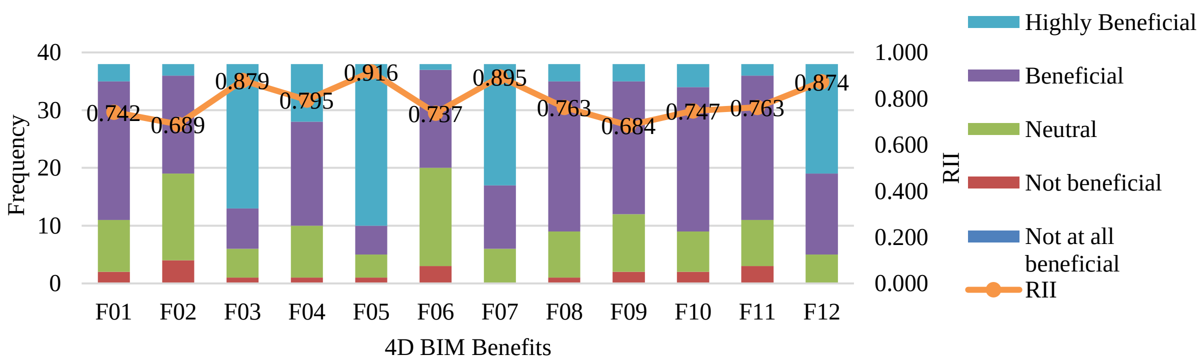

Figure 5. Benefits of 4D BIM

Government Mandate for 4D BIM (D02) as the top driver (Figure 7). Along with D02, *Awareness of 4D BIM benefits and ROI (D05)* and *Availability of 4D BIM expertise in the market* (D06) are also perceived as top drivers for 4D BIM. It can be noticed that *Good support from software vendors (D04)* has been rated lowest.

5.6 Hypothesis Testing

While there has been general agreement among the clients and contractors on their responses with few exceptions, it has been attempted to test this statistically to ensure that this is not by chance. The independent t-test is a statistical test that is used for difference in means [14]. Also, t-test is applicable when there are only two groups to be compared and sample size is very low.

The following hypotheses are tested using t-test for two independent sample assuming equal variance at 5% significance level.

Null hypothesis H0: *There is no significant difference in perceptions of clients and contractors on applicability, benefits, barriers and drivers of 4D BIM in Indian construction.*

Alternate hypothesis H1: *To test the null hypothesis, there is significant difference in the means of Clients and Contractors on applicability, benefits and barriers of 4D BIM functions in construction industry.*

The test results are presented in Table 3. As p-value for all the four variables are greater than 0.05, there is no sufficient evidence to reject H0 and hence H0 is accepted. It implies that the there is no significant difference in perceptions of clients and contractors on applicability, benefits, barriers and drivers of 4D BIM in Indian construction.

Table 3. Results of t-test for null hypothesis

Variables	p-value
Applicability	0.134
Benefits	0.707
Barriers	0.367
Drivers	0.132

However, at indicator level, a statistically significant difference in perception is observed for the barrier, *Lack of time for employees to learn (B07)* between the clients and contractors.

5.7 Discussion

It is indeed an encouraging revelation that there is high level of awareness of 4D BIM in Indian construction. But the challenge is to convert this into adoption and

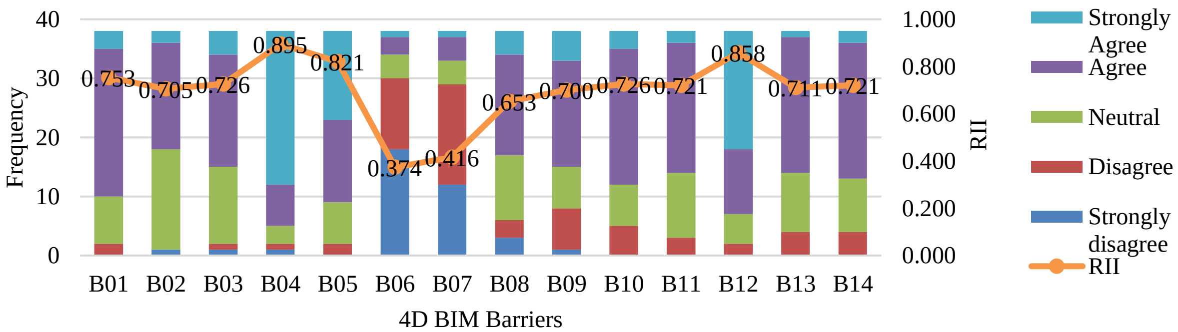

Figure 6. Barriers to 4D BIM implementation

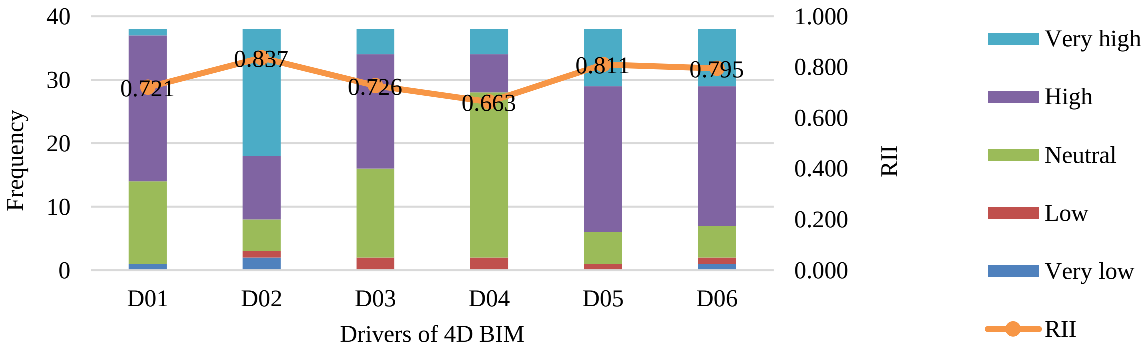

Figure 7. Drivers of 4D BIM

implementation [6]. Despite increased awareness, willingness to use 4D BIM, preferably after three years is not so encouraging. In order to keep up with the global competition as well as to meet the growing demand for infrastructure in India, there is a significant need to embrace 4D BIM sooner than later in Indian construction.

Responses to the application and benefits of 4D BIM *(F05, F03, F07 & F12)* emphasise the need for enhanced visualisation for communication and improved schedule performance. Capacity and capability building through education and training is key to realise these expectations/benefits. This also point towards the digital transformation of construction business in India [2]. Clients focus on *Design investigation with schedule simulations (F12)* over *Communicating the construction plan (F03)* showcases the change in priority of clients to quality designs & timely delivery [24].

It is also important to look at the barriers to 4D BIM adoption. *Lack of 4D BIM knowledge within internal workforce (B04)* calls our attention to training and continuous professional development within the organisations. To overcome the barrier, *Traditional project delivery methods/contract (B12),* innovative procurement methods such as Integrated Project Delivery (IPD) and Smart Contracts with the help of Block Chain can be explored. *Lack of 4D BIM expertise in the market (B05)* demand for educational institutions to relook at the curriculums to ensure that the students graduate with digital skills that are necessary [25]. As *Not worth time investment to learn (B06)* and *Lack of time for employees to learn (B07)* have been rated low as barriers, it seems that the organisations and its employees have mentally prepared to embrace this change.

A closer look at the drivers for the 4D BIM in India reveals that *Government Mandate for 4D BIM (D02)* requires immediate attention. At present, there is no official mandate from the government(s) in India for the use of BIM in construction projects. Other top drivers, *Awareness of 4D BIM benefits and ROI (D05)* demands need for more use cases from India and *Availability of 4D BIM expertise in the market* (D06) points towards education & training for upskilling that shall ensure the supply of talent [24].

It has been observed that the top benefits of 4D BIM identified in India are in line with the UK study [6] except for *logistics planning* (F01) that was rated high in UK. Non-technical barriers such as inefficiency to quantify the tangible benefits and lack of awareness by stakeholders were reported as the critical barriers in UK. In the context of Qatar, in addition to the barriers identified in UK, non-availability of skilled professionals was also found to be critical. In India, use of traditional project delivery methods and lack of demand by clients have been identified as top barriers for 4D BIM adoption in addition to lack of awareness and expertise in 4D BIM.

6 Summary and Conclusions

An attempt has been made to investigate the adoption and implementation of 4D BIM in Indian construction through survey research. The study aimed at assessing the extent of 4D BIM adoption and capture the perceived benefits, barriers and drivers for 4D BIM. The target population for this study was the clients and contractors in Indian construction. One third of the participants responded to the survey and the general pattern in the response revealed that there is high level of awareness on 4D BIM among the clients and contractors in India. Also, most of them plan to use 4D BIM later (after three years) than sooner. It has been found that there is no statistically significant difference between the clients & contractors on their responses.

Visualizing the construction flow (F05), Communicating the construction plan (F03) and *Validating the time schedules by simulations (F07)* have been found to be the top benefits of using 4D BIM. The perceived top barriers for 4D BIM are: *Lack of 4D BIM knowledge within internal workforce (B04)*, *Traditional project delivery methods/contract (B12)* and *Lack of 4D BIM expertise in the market (B05)*. The study also revealed that *Government Mandate for 4D BIM (D02), Awareness of 4D BIM benefits and ROI (D05)* and *Availability of 4D BIM expertise in the market (D06)* are the key drivers for 4D BIM in India. Innovative procurement systems, smart contracts, reinvention of construction education and capacity building & capability development through training can address the changing needs of the clients and contractors for enhanced value creation.

Considering the relatively smaller sample size, the confidence on the conclusions drawn is limited. A wider study among the clients and contractors with increased sample size may reveal greater insight. It is also worth investigating the role of enhanced visualisation for communication in improved schedule performance. Studies on capacity building & capability development would facilitate strategies for supply of necessary talent. Also, the present curriculum in built and natural environment courses may be relooked at to keep up with the demand for digital skills. Policy studies to support government decisions on mandating 4D BIM would be desirable for a roadmap.

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