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Investigating the Perceived Human Errors in 4D-BIM Construction Scheduling

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INVESTIGATING THE PERCEIVED HUMAN ERRORS IN 4D-BIM CONSTRUCTION SCHEDULING

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ABSTRACT

Four-dimensional building information modeling (4D-BIM or 4D Scheduling) is well known to benefit the construction industry in many ways. 4D-BIM is an effective scheduling technique which integrates traditional scheduling methods and advanced visualization of the construction sequences in a 3D environment. Despite the potential benefits of 4D-BIM to improve scheduling quality, errors still often occur in construction schedules. The objective of this research is to understand the association between human errors and computer-aided scheduling. This paper focuses on examining the current practices of 4D-scheduling to gain insights on potential errors during the process of scheduling. Furthermore, the paper discusses a set of root causes of scheduling errors based on different types of human errors in cognition error theories. The research determined human errors through an integrated approach of literature review and a survey. The results of this study are expected to provide new knowledge about what human errors that commonly occur during the scheduling processing using BIM and their root causes. This study also discusses a few error reduction/prevention methods that can help BIM practitioners, schedulers, organizations to avoid perceived human errors during 4D-BIM work process.

DEDICATION

This thesis is dedicated to my parents for their endless love, support and encouragement throughout my life.

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I would like to thank everyone that have contributed to this project. I would like to thank Travis Harrison, BIM Manager, Sherman Construction for his support and help in piloting the survey questionnaire.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONYMS

BIM – Building Information Modeling

4D-BIM – 4-dimensional building information modeling

HET – Human Error Taxonomy

IEEE – Institute of Electrical and Electronics Engineers

VDC – Virtual Design and Construction

MEP – Mechanical, Electrical and Plumbing

CHAPTER ONE

INTRODUCTION

4D-Building Information Modeling is an advanced scheduling technique which integrates 3D-BIM model with the project schedule using 4D sequence simulation software. This tool enables visualizing the sequence of tasks of a schedule in a 3D environment against time unlike the traditional Gantt charts. Additionally, this technique supplements one's understanding of the construction sequence and helps rectify errors in schedules and 3D-BIM models. Researchers have developed various tools to automatically generate construction schedules through BIM-based integrated approach under resource constraints [15], automatic data extraction using open BIM technology [14], knowledge-based systems approach [6] etc., further enhancing 4D-BIM usage. Many BIM software vendors and design consultants say " BIM enhances the quality of the construction documents by reducing human error as well as motivating architects to think through the building process for a more finalized project in the design phase" [17]. Despite these innovations in the industry, human errors still prevail in every activity of the 4D-BIM process due to failure of human cognition. Architects and engineers do not have predefined strategies for error management and do not see them recurring in several cases and hence error prevention should be viewed as a continuous process rather than a product of certain activities or behaviors [16]. Also, construction and civil engineering industry professionals have found it very difficult to grasp their mistakes and learn from them, especially when concerned with identification and prevention of design errors [16]. Several studies explain cognition error theories, reasons behind the human errors and error prevention methods, most of them are domain specific. Hence, there is a necessity of more research on human error prevention in the crucial phases of pre-construction such as design, planning, scheduling, visualization, etc. The research outcome will help reduce human errors in construction planning which can minimize costly fixes during the construction or operational phases.

There can be various sources of scheduling errors due to different types of human errors. For instance, communication plays a vital role in the construction. Miscommunication can cause serious job accidents, project rework, and employee problems [19]. If a scheduler is miscommunicated with the wrong dates, resources, milestones etc., of the project, it can result in a completely faulty schedule. Similarly, any loss of information or incorrect data from the 3D model can potentially lead to mismatch of elements in the model with the tasks in the schedule exacerbating it. Furthermore, the lack of knowledge or using wrong settings of the tool for the project may yield erroneous end products inducing financial and time loss in remodeling, hiring experienced personnel and purchasing appropriate tools. The best way to fix these errors may be by analyzing and improving the current processes and suggesting appropriate control measures to avoid such errors in the long term. There have been various studies on generating automatic schedules, new tools for modeling, light and energy analysis etc., in different aspects of BIM, but very little effort is undertaken on human errors in 4D-BIM. This study aims to fill that gap by investigating the types of human errors and their root causes in 4D scheduling by adopting a human error taxonomy coupled with survey, interviews approach to understand the effect of human errors in various phases of 4D-BIM.

To guide this research, this paper focuses on three research questions:

RQ1: Which activities and phases of the 4D-BIM process are prone to human errors?

RQ2: What are the root causes of those human errors and their types?

RQ3: What are the possible solutions for error reduction/prevention?

This study adopted a literature review approach to identify the 4D-BIM workflow and Human Error Taxonomy (HET) to classify the root causes into the types of human errors based on the type of error each root cause causes. The primary contributions of this work are:

- A new perspective of human errors in 4D-BIM Construction Scheduling domain specific work process adopting survey and interview approach
- Identified the activities that are prone to errors from among the planning, scheduling, 3D model creation and schedule update phases of 4D-BIM
- Identified the root causes behind those errors and classified them into types of root causes defined in Human Error Taxonomy
- Proposed possible solutions for error reduction/prevention

CHAPTER TWO

BACKGROUND

Construction Planning and Scheduling

Construction Planning is a vital and challenging phase of construction projects both in the management and execution which involves defining of work packages/tasks, estimating resources and duration required for each task, defining dependencies among different tasks of the project. Sometimes this may also include choosing a suitable technology or software [8]. In addition, construction planning also includes making organizational decisions about the extent of involvement of each project participant and relationships between them. A reliable budget and the schedule for work can be developed only if the plan is good. A construction plan is developed by adopting a primary significance on either cost or on schedule. For projects with schedule prominence, it is critical to schedule activities overtime, maintain proper dependencies between them and check for resources availability. Some important aspects of construction planning and scheduling include identifying the scope of work, identifying the activities of the project, estimating the resources and durations required for each activity and defining resource constraints during schedule development, defining relationships or dependencies between activities, determining lead and lag time between activities etc., [9]

Defining Activities of the Project

The terms "Activities" or "Tasks" simply mean items of work and are often used interchangeably in construction. But traditionally, an activity is a subdivision of project tasks i.e., a project task comprises of a set of activities which in turn are comprised of work packages. A Project Task is a structure that helps us in scheduling of activities of the project, estimating the durations and resources required for each activity and defining the dependencies between them [8]. A hierarchical approach to breakdown higher level summary activities to smaller components as work activities is usually adopted in any project and is formally known as Work Breakdown Structure.

Defining dependencies between activities

Dependencies are defined once the activities are identified. This enables us to know the sequence in which the activities must take place. A single construction project may contain a few to many sequences depending upon the requirements and regulations [8]. These are represented as a network using arrows called as branches or links and circles called nodes. Sometimes the project managers design the dependencies manually in unexpected ways to facilitate flexibility and cost factors as many of the scheduling softwares do not have the capability of doing so.

Estimating durations of the activities

In every construction project, every activity has a certain time frame in which the activity is supposed to be finished, this time frame is known as duration of the activity [9]. Generally, most of the duration estimates are only approximations to the actual duration due to varying crew habits and productivity. Durations are estimated by either maintaining a historical data of activities or considering the probability distribution of an activity's duration and expected or most likely duration for scheduling purposes [8].

Defining resource constraints of the activities

Resource requirements are estimated along with the duration and dependencies of the activities. This usually includes number of workers, type of workers, amount of material and equipment etc. There are always or more constraints to be considered such as availability of equipment or crew. Location can also be a constraint for some activities that are scheduled at same location but cannot be done at the same time.

Building Information Modeling (BIM)

BIM is the process of creating and managing the physical and functional aspects of a building in the form of digital models and is one of the most important developments happened recently in the architecture, engineering, and construction (AEC) world. It involves different types of tools and technologies based on the purpose of the client. These help in understanding the design of the project and how every element of building behave throughout the project. Being mostly used for planning, design, construction, and operation phases of a facility, these can also be used to identify any potential issues in all the phases. Autodesk defines BIM as "a process that begins with the creation of an intelligent 3D model and enables document management, coordination and simulation during the entire lifecycle of a project (plan, design, build, operation and maintenance)" [11]. The U.S National Building Information Modeling Standard (NBIMS) defines BIM as "a digital representation of physical and functional characteristics of a facility [12]. As such it serves as a shared knowledge resource for information about a facility forming a reliable basis for decisions during its lifecycle from inception onwards". These models are used to analyze and create design options to help the stakeholders understand what the building looks like.

BIM Dimensions

A BIM Model can be used for specific purposes as defined for the project requirements and complexity. Based on the level of the model and type of use, specific items are incorporated into the existing 3D model. These incorporations are that are use specific known as BIM Dimensions. As of now, BIM technology has 3D, 4D, 5D, 6D and 7D dimensions that contribute a good deal to the AEC industry.

4D BIM (3D + Construction Schedule)

4-dimensional building information modeling (4D BIM/4D Scheduling) refers to the linking of different 3D elements of a 3D model with similar items in a construction schedule (time), hence the name 4D i.e., due the fourth dimension “time” [9]. This enables us to visualize the sequence of tasks of a schedule in a 3D environment against time in the form a simulation unlike the traditional Gantt charts. This helps the project stakeholders to plan, sequence the activities in the schedule. Visualizing the schedule in a 3D environment helps mitigate risks, report and monitor the construction activities.

5D BIM (3D + Schedule(time) + Cost)

5-dimensional building information modeling (5D BIM) refers to linking the time schedule to the 3D model along with the cost information in the form of material schedules and quantity take offs. This allows various participants (architects, designers, contractors, owners etc.,) of the project to understand the ballpark cost projections and visualize the progress of construction activities and their related costs over time [9]. Other benefit is that, updating a model automatically updates the cost data in the takeoff reducing the extra paperwork and time.

6D BIM

6-dimensional building information modeling (6D BIM) is the process of adopting sustainable type of design which helps us analyze the building's energy consumption and generate energy estimates during initial stages of the design. This dimension can be treated as a step beyond 5D BIM which only considers the project's upfront costs. 6D BIM helps us in projecting the entire cost of a facility thereby achieving sustainability and cost-efficiency.

7D BIM

7-dimensional building information modeling (7D BIM) refers to linking of project life cycle management information with the 3D elements in a model. This dimension is sometimes also referred as facility management phase. These are usually the "as-built" BIM models with all the information associated with the facility such as specifications, pictures, product links and sources, product data, warranties, operation manuals, manufacturer information etc., [9]. These 6D models are handed over to the owner once the project is finished for facility management.

CHAPTER THREE

LITERATURE REVIEW

4D BIM Scheduling

The adoption of Building Information Modeling (BIM) in design and planning proved to be an advantage in processing existing problems in construction. BIM, in general is used for various purposes such as visualization, generating shop drawings, communication, estimating, scheduling, sequencing the activities, clash detection etc. 4D BIM Scheduling enables users to not only visualize the sequence of the construction activities in a 3D environment. Usage of BIM significantly increases the efficiency and can play a vital role in sharing information and knowledge between stakeholders with a potential to reduce errors and rework. However, the role of these computer applications in helping to reduce or prevent errors were not well defined and use of computer applications such as BIM may not ensure a perfect schedule due to human factors. While some studies claim that these modeling applications help in reducing errors and reworks, some claim that these applications include increased risk of errors and reworks due to addition of number of possible assumptions and interventions to be made [17]. To better understand the human errors associated with 4D scheduling, it is critical to review the 4D scheduling process. 4D scheduling can be broken down into the following five phases: planning, computer-aid scheduling, 3D-model development, 4-D visualization, and schedule update during the execution phase. Each of these phases includes several activities where errors may occur. Table 1 below illustrate a typical process of developing a 4D schedule broken down into five phases and further divided into different activities.

Phases of 4D-BIM	Activities
Planning and Scheduling	i) identifying the scope of work ii) identifying the activities of the project iii) defining dependencies between activities iv) estimating durations of the activities v) determining lag and lead time vi) define resource constraints during schedule development/update
Computer-Aided Scheduling	i) entering start and end dates, ii) setting working days (as per project calendar) iii) creating summary activities [18] iv) setting logics/dependencies between activities [18] v) creating resource pool and assigning resources
3D-Modeling	i) designing a 3D-Model (Architectural, Structural, MEP)
4D-Visualization	i) linking schedule tasks with respective elements in 3D model using visualization or the sequence simulation software
Schedule Update	i) recording progress/status ii) updating changes in activities and sequence iii) updating resource availability/usage

Table 1. 4D BIM Scheduling procedure

Human Error Taxonomy (HET)

IEEE Standard 24,765 (ISO/IEC/IEEE 24,765:2017) [13], defines *error* as “a human action that produces an incorrect result”. Anu et al. (2018) [2] defined error as “the failing of human cognition in the process of problem solving, planning, or execution”. According to a study on human errors (Reason 1990) [20], three types of plan-based errors can occur which are as follows:

- **Slips** and **Lapses** are errors due to *failure of execution* of a planned action sequence irrespective of whether the plan is sufficient to achieve the goal. Slips are caused because of inattention and lapses are caused because of memory failure.
- **Mistakes** are *knowledge-based errors* that occur when a plan itself is insufficient to achieve the goal even though the action sequence is according to plan.

Table 2 shows the potential root causes of these errors from the review of cognition theories. For slips, common causes of errors are misusing of tools, mis communication and accidentally overlooking of the inspection processes. Lapses errors occur typically because of forgetting information or loss of information from the working memory. Finally, mistakes are mainly due to the complexity of the problem which highly challenges the development of a proper plan of actions. For this, individual errors were identified and then categorized into each error class as either a Slip, a Lapse or a Mistake based upon whether the error class is a *planning error* or an *execution error.* Then the execution errors are grouped into Slips and Lapses based upon whether the error is due to inattention (Slips) or due to memory failure (Lapses).

Type of Error	Root causes of errors
Slips	i) mis-using tools [2] [16]
Lapses	i) knowledge shortage [18] ii) unfamiliar with the work [16] iii) loss of information from stakeholders [2] iv) forgetting information [2] [19] v) accidentally overlooking required verification process [2]
Mistakes	i) complex project scope [2] ii) miscommunication [2] [16] [19] iii) wrong information from stakeholders [2]

Table 2. Classification of root causes of human errors

Study in Human Errors in construction can be beneficial since it is completely human-centric. Construction involves a high level of planning, collaboration, interaction and understanding between multiple stakeholders. Involvement of multiple opinions, interventions and assumption can result in number of problems further leading to errors [17]. Categorizing these causes of human errors in 4D BIM construction scheduling into a taxonomy will provide the stakeholders in understanding the types of errors and their causes that can occur during the process and also help reviewers ensure that the mitigation procedures and their results are of sufficient quality for development to proceed. This awareness leads the stakeholders to be more careful in further stages of construction.

Human Errors in Construction

Human errors causing design changes or rework are deemed to be the major contributor to delays in schedule and cost overruns in design and construction projects. Inaccurate decisions made during design can happen due to weak human cognition [23]. These decisions from designers' cognition can propagate throughout the project and may increase the chances for errors to occur. Busby 2001 [24] mentioned that these decision-making errors occurring during the design process are due to biases. Designers tend to use knowledge-based solutions or decisions such as re-use of designs or specifications that satisfy the clients' immediate needs in case of stress due to schedule and fee pressures [17]. Designers may omit to: involve others in design decisions, inform others of assumptions made, elicit other's needs and schedules, or understand the history of problem solving in a replicated design [24]. Love et. al. 2011 [17] noted a design consultants experience which explains how overlapping feelings may effect design process- *"Sometimes I forget what project I'm involved with and what I've done. When I am dealing with a query on one project, I get an urgent request from another I am involved with. The interruptions are frustrating as we are under constant pressure to get things done. I've found myself often forgetting my chain of thought when I'm interrupted".* However, designers' liability for errors is "determined by whether they have performed their services with the standard of care consistent with other professional designers within their community" [16]. As errors are common in construction projects, designers should therefore accept the likelihood of errors every time they design or prepare any relevant documentation. Lopez et. al. 2010 [16] also noted a few root contributors of human errors in design, which include but not limited to i) loss of Biorhythm, where an individual's biorhythm which involves emotional and intellectual mental states are influenced by job experiences, which in turn influences their ability to meet the work requirements. ii) inadequate training of design consultants/competitive fees, iii) inefficient utilization of computer-aided automation, iv) inadequate quality assurance, v) ineffective coordination and integration of the design team.

Atkinson 2010 [3] constructed a model of the error process based on a three-level hierarchy consisting of primary causes, secondary or managerial causes and tertiary or global causes. Primary causes consist of factors relevant to the individual. Secondary or managerial causes relate to factors, under the control of the organizations or managers of the project. Tertiary or global causes consist of factors that are completely outside the control of the organizational unit. Primary causes are those which arise from internal psychological processes that result from ignorance, negligence or fraud. Managerial causes include failings in checking, supervision and control, failures in communication, errors caused by concurrency i.e., executing several projects simultaneously leading to errors. Finally, global causes are financial pressures, time pressures, cultural and social pressures as a cause of errors. Error recovery process includes three steps: *detection, indication and correction [22]*. It is suggested that the first step in the process of recovering errors is to detect the occurrence. Indication is where the error and its occurrence are brought the person or organization that is responsible for its correction. Final step, correction includes the actual correction of errors. Love 2004 [22] suggested that errors often go undetected until a problem arises due to poor planning, lack of knowledge and experience.

CHAPTER FOUR

METHODOLOGY

To achieve the goal of this study, potential human errors were identified and categorized into different classes based on the predefined categories of the cognition error theory as discussed in the Literature Review section. A survey with industry professional was conducted to examine which stages and activities of 4D-BIM scheduling that are prone to errors and their root causes. The details of the survey design are provided below.

Preliminary survey questionnaire

The survey questionnaire consists of seven sections. Section I collects general information of the respondent such as type of organization/company, role of respondent in the organization/company, years of experience working on BIM, experience in using 4D-BIM for the projects. Section II to Section VI comprises of each phase of 4D scheduling process in which the respondents rate the likelihood of errors in every activity in each phase using a 5-point Likert scale (1 = not likely at all, 2 = somewhat likely, 3 = moderately likely, 4 = very likely, 5 = extremely likely). Also, respondents were requested to mention the software used for scheduling, 3D and 4D modeling in respective sections. Section VII comprises of nine root causes of errors, in which respondents are supposed to select the most probable cause of errors occurring in each activity. The nine root causes are as follows: *i) mis-using tools, ii) knowledge shortage, iii) complex project scope, iv) unfamiliar with project type, v) wrong information from stakeholders, vi) loss of information from stakeholders vii) forgetting information, viii) miscommunication, ix) accidentally overlooking required verification processes.*

Piloting and final survey questionnaire

Prior to delivering the questionnaire to prospective participants, a pilot study was conducted with a BIM/VDC Manager. After the review of questionnaire and receiving the feedback, necessary changes have been made accordingly based on suggestions received. For example, he noted that the start and end dates, estimating durations of activities may be seriously affected by the miscommunication between the contractor and the subcontractor and subsequently miscommunication was added into the root causes of errors. His comments were consistent with the potential root causes of preliminary survey form. Thus, the preliminary survey design was used as the final and then forwarded to respondents through an online survey for data collection. Later, the responses from the survey were tested by employing various statistical methods mentioned below:

Chi-Square Test for Normality

The Chi-Square Test for Normality/Goodness of Fit has been used to test the hypothesis of the survey data. The Goodness of Fit theorem is used to test the null hypothesis, H_o*: data are sampled from a normal distribution.*

Goodness of Fit

The Goodness of Fit theorem is used to check and see if the observed (*obs)* data is sufficiently well compared to that of the expected *(exp)* values [10]. The following required assumptions are made to be met:

i. Data is randomly sampled,

ii. The observations are independent of each other,

iii. Cell size *(n)* is less than or equal to 5.

For enough values k, the Pearson's chi-square test statistic has approximately a chi-square distribution with n-1 degree of freedom, i.e. χ^2(n-1), where the Pearson's chi-square test statistic is defined as:

$$\chi^2(\text{n-1}) = \sum_{i=1}^{n} \frac{(obs - \exp)^2}{\exp}$$

If p-value for a given chi-square distribution is less than the level of significance *($\propto$)* or the chi-square critical values is less than the chi-square test statistic, then the null hypothesis is rejected and vice versa.

One Sample Sign Test

The Sign Test is a non-parametric test which is applied when the conditions for single sample t-test are not met. This test has been used to test and find out the activities that are prone to human errors. The benefit of this test is that it does not have any conditions to be met and assumptions to be made but only that the data should be non-parametric. It is performed by assigning signs to each observation of the sample, hence the name [10]. Once the data is found to be non-parametric, the sign test is used with the null hypothesis, H_o*: population median* $\geq k$.

To perform this test, the number of observations that are greater than k and less than k are given a sign '+' and '-' respectively. Then number of observations with each sign are counted. Now, if the null hypothesis is true then the probability that each observation of the data is greater than k is 0.5. Let the number of observations with sign '+' be p and with sign '-' be q. Hence, we test the probability that the p number of observations out of $p+q$ are less than the median given that the probability on any trail is 0.5.

Therefore, if p-value is greater than the level of significance *($\propto$)*, we can reject the null hypothesis and vice versa.

Note: '+' and '-' signs can also be replaced with '1' and '0' as per the convenience.

Kendall's coefficient of concordance/Kendall's W

Kendall's W is a non-parametric statistic used to assess agreement among raters of a survey. It ranges between '0' (no agreement) and '1' (complete agreement). This test is used to find out the root causes for the human errors occurring in the activities identified to be prone to human errors. If the test statistic W is equal to 1, then all the survey respondents have fully agreed to the same list of objects. If W is equal to 0, then their responses are considered to be random and there is no overall agreement among the survey respondents. Any value between 0 and 1 indicate greater or lesser degree of agreement among the survey respondents [10].

For example,

If there are *n* objects and *m* respondents, where an object *I* is given a rank $r_{i,j}$ by respondent *j*, then the total rank of the object *I* is R_i, where

$$R_i = \sum_{j=1}^{m} r_{i,j}$$

and the mean of the total ranks is $\bar{R}$, where

$$\bar{R} = \frac{1}{n}\sum_{i=1}^{n} R_i = \frac{1}{n}\sum_{i=1}^{n}\left[\sum_{j=1}^{m} r_{i,j}\right]$$

The sum of variances, S is

$$S = \sum_{i=1}^{n} (R_i - \bar{R})^2$$

Kendall's W is defined as

$$W = \frac{12 * S}{m^2(n^3 - n)}$$

Correction for Ties

If there are tied values in the data set, then those tied values are ranked as average of the ranks that would be given if there had been no ties [9]. For example, the set {21,34,21,45,66,21,78,45,92,13} has values of 21 tied in 7th, 8th, 9th ranks, whereas values of 45 tied in 4th and 5th ranks. Since the mean for the values of 21 i.e., {7,8,9} is 8 and mean for the values of 45 i.e., {4,5} is 4.5, the ranks can be assigned to the data set as {8,6,8,4.5,3,8,2,4.5,1,10}.

Kendall's W Property

$$\text{If } n \geq 5 \text{ or } m>15,\ m(n-1)\,W \sim \chi^2\,(n-1)$$

This property can be used to test the agreement among the respondents i.e.,

H_o: There is no agreement among the survey respondents.

Though we have a certain level of agreement among the respondents due to low value of W, H_o can be rejected if the p-value is less than level of significance (0.1) and vice versa.

CHAPTER FIVE

RESULTS AND DATA ANALYSIS

Out of 300 survey requests, 59 participants responded. From this set of responses, 17 invalid responses (e.g., incomplete or consistent selection of same rating) were filtered out. Therefore, 42 responses were used to study the likelihood of errors and 40 responses were used to study the root causes of those errors removing the incomplete responses. Participants of the survey reported to have multiple roles in the organization (see Figure 1). Overall representation of those participants is 7 (15.22%) Project Engineers, 2 (4.35%) Schedulers, 33 (71.74%) BIM/VDC professionals, 1 (2.17%) Planning Lead, 1 (2.17%) President, 1 (2.17%) Director of Technologies and 1 (2.17%) Executive with organization/company from Construction, Architecture, Engineering, Facility Management and BIM Service Provider fields.

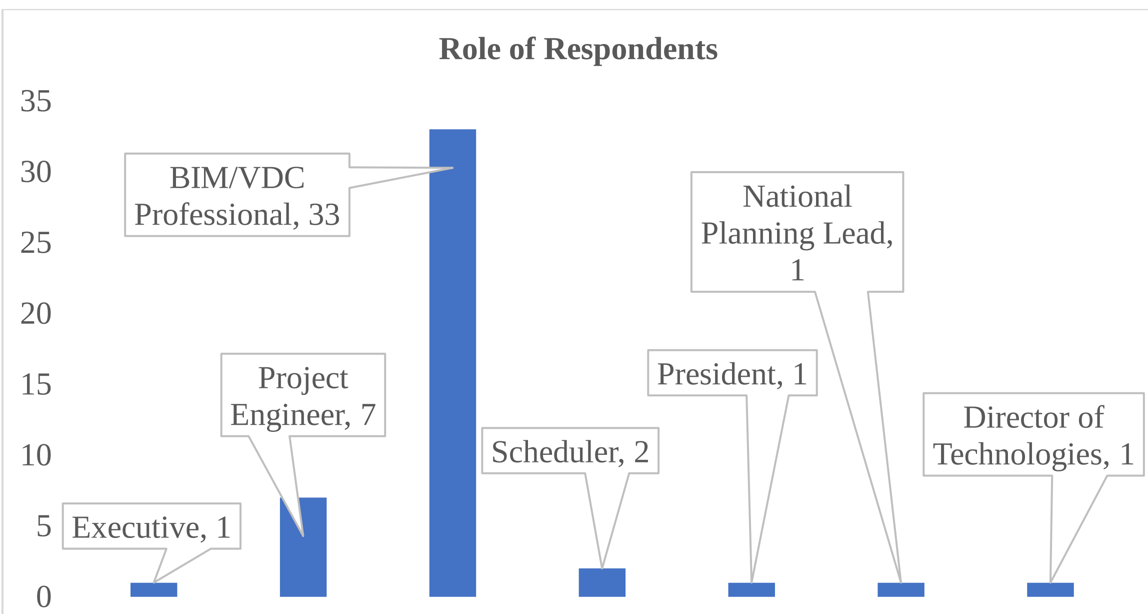

Figure 1. Role of the respondents who took part in the survey

Results

Activities prone to errors

After analyzing the ratings of likelihood of errors in every activity, the activities prone to human errors with mean ≥ 3 (moderate) on Likert scale are found to be: (Table 3)

"*identifying the scope of work", (Planning and Scheduling Phase)*

"defining dependencies between activities", (Planning and Scheduling Phase)

"estimating durations of the activities", (Planning and Scheduling Phase)

"determining lag and lead time", (Planning and Scheduling Phase)

"define resource constraints during schedule development/update", (Planning and Scheduling Phase)

"designing a 3D-model", (3D-modeling Phase)

Root causes of human errors

Though there can be more than one mentioned root cause for each activity, the respondents were asked to select the one which is more applicable/most affecting. The top five root causes of human errors are found to be: (Table 4)

i) knowledge shortage,

ii) complex project,

iii) wrong/loss of information from the stakeholders,

iv) miscommunication,

v) mis-using tools,

Data Analysis

Table 3 shows the survey responses for the likelihood of human errors occurring in each activity of different phases in 4D-BIM workflow.

Phases of 4D-BIM	Activities of each phase prone to errors	Ratings on 5-point Likert Scale					Mean
		(1)	(2)	(3)	(4)	(5)	
Planning and Scheduling	identifying the scope of work*	2	16	9	10	5	3.000
	identifying the activities of the project*	2	19	11	7	3	2.762
	defining dependencies between activities*	2	13	15	8	4	2.976
	estimating durations of the activities*	0	12	14	12	4	3.190
	determining lag and lead time*	0	19	11	7	5	2.952
	define resource constraints during schedule development/update*	1	8	20	10	3	3.143
Computer-Aided Scheduling	entering start and end dates	13	19	7	2	1	2.024
	setting working days (as per project calendar)	14	17	9	1	1	2.000
	creating summary activities	10	26	3	2	1	2.000
	setting logics/dependencies between activities*	3	17	12	9	1	2.714
	creating resource pool and assigning resources*	1	19	13	7	2	2.762
3D-Modeling	designing a 3D-Model (Architectural, Structural, MEP) *	3	14	9	13	3	2.976
4D-Visualization	linking schedule tasks with respective elements in 3D model using visualization or the sequence simulation software	5	14	17	5	1	2.595
Schedule Update	recording progress/status	2	27	8	3	2	2.429
	updating changes in activities and sequence*	2	21	10	7	2	2.667
	updating resource availability/usage	1	24	10	5	2	2.595

Table 3 Ratings and mean of each activity of different phases of construction

*Notes: Ratings: 1 = not likely at all, 2 = somewhat likely, 3 = moderately likely, 4 = very likely, 5 = extremely likely, * indicates top 10 activities prone to human errors*

Activities prone to human errors	mis-using tools	knowledge shortage	complex project scope	unfamiliar with project type	wrong/loss information from stakeholders	forgetting information	miscommunication	accidentally overlooking required verification processes
identifying the scope of work	0	6	(15)	0	9	1	6	3
identifying the activities of the project	0	9	(19)	2	6	1	2	1
defining dependencies between activities,	1	(16)	8	2	4	1	5	3
estimating durations of the activities	0	(12)	6	5	9	2	3	3
determining lag and lead time	1	(13)	6	2	10	1	3	4
define resource constraints during schedule development/update	4	8	8	3	(9)	0	7	1
entering start and end dates	7	6	7	0	(10)	2	6	2
setting working days (as per project calendar),	10	(12)	2	2	2	4	6	2
creating summary activities	6	(16)	8	1	4	0	3	2
setting logics/dependencies between activities	5	(15)	10	2	4	1	3	0
creating resource pool and assigning resources	6	(11)	5	4	7	2	3	2
designing a 3D-Model (Architectural, Structural, MEP)	6	7	9	3	(10)	1	2	2
linking schedule tasks with respective elements in 3D model using visualization or the sequence simulation software	9	(12)	7	2	2	1	4	3
recording progress/status	(9)	3	1	0	(9)	6	8	4
updating changes in activities and sequence	6	2	7	0	7	6	(11)	1
updating resource availability/usage	5	6	4	1	(9)	5	(9)	1

Table 4. Number of votes representing the possible root causes of Human Errors in each activity of the 4D-BIM workflow

Discussion

Table 3 shows the number of responses and likelihood of errors in each activity according to the respondents of the survey. Mean for each activity has been calculated by weighing the responses from 1 to 5. It can be clearly seen that most of the activities in Planning and Scheduling phase and the only activity in 3D-modeling phase are nearly equal to 3 representing the nature of errors in those activities to be more than moderately likely. Top 10 activities are indicated with "*" in table 3 considering their means. Table 4 shows the number of responses for each root cause specific to each activity of the 4D-BIM workflow. Root causes with highest number of responses for each activity are denoted by "()" in table 4.

To study the reliability of the survey responses various statistical methods have been employed. Firstly, Chi-Square test for normality is used on every activity of the 4D-BIM process to check if the data follow a normal distribution. After identifying that the data is not normal/non-parametric, one sample sign test, a non-parametric test is employed to determine the activities that are prone to human errors based on the likelihood responses of the survey respondents. In this study, any activity that has been voted greater than or equal to 3 (moderately likely) on the 5- point Likert scale has been identified as an activity that is prone to human errors. Finally, Kendall's coefficient of concordance/ Kendall's W has been used to check the overall agreement of respondents in rating the possible root causes of those errors. Kendall's W used to test the agreement of respondents in both overall root causes and root causes specific to each activity. All analyses were conducted using Microsoft Excel after extracting the survey data from Survey Data collecting website.

Activity	Chi-Square	p-value	Result
identifying the scope of work	13.476	0.00917	Not normal
identifying the activities of the project	22.762	0.00014	Not normal
defining dependencies between activities	14.905	0.00490	Not normal
estimating durations of the activities	17.524	0.00153	Not normal
determining lag and lead time	24.190	0.00007	Not normal
define resource constraints during schedule development/update	26.333	0.00003	Not normal
entering start and end dates	27.524	0.00002	Not normal
setting working days (as per project calendar)	25.619	0.00004	Not normal
creating summary activities	52.048	0.00000	Not normal
setting logics/dependencies between activities	20.381	0.00042	Not normal
creating resource pool and assigning resources	27.524	0.00002	Not normal
designing a 3D-Model (Architectural, Structural, MEP)	13.238	0.01017	Not normal
linking schedule tasks with respective elements in 3D model using visualization or the sequence simulation software	21.810	0.00022	Not normal
recording progress/status	54.429	0.00000	Not normal
updating changes in activities and sequence	29.190	0.00001	Not normal
updating resource availability/usage	42.048	0.00000	Not normal

Table 5. Chi-Square test indicating that the survey responses are Non-parametric

Table 5 below shows the results of chi-square test for normality indicating the responses of the survey are Non-parametric.

Given H_o: *The data is sampled from a normal distribution.*

With the chi-square values greater than the critical value of 9.49 and p-value less than 0.05 level of significance, we can reject the null hypothesis and conclude that the data is not normal/non-parametric. Hence, non-parametric tests have been employed to validate the responses further. To validate the likelihood of errors and find out the activities that prone to errors, one sample sign test has been used. Table 6 below shows the results from one sample sign test. Activities with responses supporting the population median ≥ likelihood of errors rating of 3 are considered as the activities prone to errors.

Hence, H_o: *population median ≥ 3* and 0.05 significance level

From Table 6 we can see that, for activities "*identifying the scope of work", "defining dependencies between activities", "estimating durations of the activities", "determining lag and lead time", "define resource constraints during schedule development/update", "designing a 3D-model",* p-value is greater than 0.05 significance level and can be identified as the activities that are prone to human errors. Now, to identify the potential root causes for those errors, Kendall's W has been used to test the agreement among the respondents in voting the root causes. Table 7 below shows the results for Kendall's W.

Hence, H_o: *There is no agreement among the survey respondents* and Level of Significance: 0.05

Activity	**p-value**	**Result**
identifying the scope of work	0.36	fail to reject
identifying the activities of the project	0.04	reject
defining dependencies between activities	0.35	fail to reject
estimating durations of the activities	0.83	fail to reject
determining lag and lead time	0.14	fail to reject
define resource constraints during schedule development/update	0.86	fail to reject
entering start and end dates	0.00	reject
setting working days (as per project calendar)	0.00	reject
creating summary activities	0.00	reject
setting logics/dependencies between activities	0.05	reject
creating resource pool and assigning resources	0.03	reject
designing a 3D-Model (Architectural, Structural, MEP)	0.50	fail to reject
linking schedule tasks with respective elements in 3D model using visualization or the sequence simulation software	0.01	reject
recording progress/status	0.00	reject
updating changes in activities and sequence	0.01	reject
updating resource availability/usage	0.00	reject

Table 6. Results from One Sample Sign Test

Root Causes	mis-using tools	knowledge shortage	complex project scope	unfamiliar with project type	wrong/loss information from stakeholders	forgetting information	miscommunication	accidentally overlooking required verification processes
Sum of the individual rankings	188	108.5	133.5	226.5	159	229.5	166.5	223.5
Overall Ranking	5	1	2	7	3	8	4	6

Activity	No. of respondents	No. of Root Causes	Kendall's W	Chi-Square	p-value	Result
All activities combined	40	8	0.215	60.264	0.00000000013	Reject

Table 7. Kendall's W of concordance for all the activities combined

From the Table 7, we can notice that there is a significant amount of agreement among the survey respondents as p-value is very less than the level of significance 0.5 and the null hypothesis can be rejected. It has been noticed that *"knowledge shortage", "complex project scope", "wrong/loss of information from stakeholders", "miscommunication", "mis-using tools"* are ranked as the topmost potential root causes of errors in the 4D-BIM process. Later, the Kendall's W has been conducted on each activity individually to check if we could find out the root causes of errors specific to each activity. Tables 8a, 8b, 9a, 9b below show the results of Kendall's W for individual activities. Hence, H_o: *There is no agreement among the survey respondents* and Level of Significance: 0.1

	mis-using tools	knowledge shortage	complex project scope	unfamiliar with project type	wrong/loss information from stakeholders	forgetting information	miscommunication	accidentally overlooking required verification processes
identifying the scope of work	200	176	140	200	164	196	176	188
	7	3	1	7	2	6	3	5
identifying the activities of the project	200	164	124	192	176	196	192	196
	8	2	1	4	3	6	4	6
defining dependencies between activities	196	136	168	192	184	196	180	188
	7	1	2	6	4	7	3	5
estimating durations of the activities	200	152	176	180	164	192	188	188
	8	1	3	4	2	7	5	5
determining lag and lead time	196	148	176	192	156	196	188	188
	7	1	3	6	2	7	4	4
define resource constraints during schedule development/update	184	168	168	188	164	200	172	196
	5	2	2	6	1	8	4	7
entering start and end dates	172	176	172	200	160	192	176	192
	2	4	2	8	1	6	4	6
setting working days (as per project calendar)	160	152	192	192	192	184	176	192
	2	1	5	5	5	4	3	5

Legend

Sum of individual rankings	###
Overall Rankings	#

Table 8a. Sum of individual rankings of each activity and overall rankings (contd.)

	mis-using tools	knowledge shortage	complex project scope	unfamiliar with project type	wrong/loss information from stakeholders	forgetting information	miscommunication	accidentally overlooking required verification processes
creating summary activities	176	136	168	196	184	200	188	192
	3	1	2	7	4	8	5	6
setting logics/dependencies between activities	176	136	168	196	184	200	188	192
	3	1	2	7	4	8	5	6
creating resource pool and assigning resources	176	156	180	184	172	192	188	192
	3	1	4	5	2	7	6	7
designing a 3D-Model (Architectural, Structural, MEP)	176	172	164	188	160	196	192	192
	4	3	2	5	1	8	6	6
linking schedule tasks with respective elements in 3D model using visualization or the sequence simulation software	164	152	172	192	192	196	184	188
	2	1	3	6	6	8	4	5
recording progress/status	164	188	196	200	164	176	168	184
	1	6	7	8	1	4	3	5
updating changes in activities and sequence	176	192	172	200	172	176	156	196
	4	6	2	8	2	4	1	7
updating resource availability/usage	180	176	184	196	164	180	164	196
	4	3	6	7	1	4	1	7

Legend

Sum of individual rankings	###
Overall Rankings	#

Table 8b. Sum of individual rankings of each activity and overall rankings

Activity	No. of responses	No. of Root Causes	Kendall's W	Chi-Square	p-value	Result
identifying the scope of work	40	8	0.045	12.533	0.084	Reject
identifying the activities of the project	40	8	0.069	19.200	0.008	Reject
defining dependencies between activities	40	8	0.042	11.733	0.110	fail to reject
estimating durations of the activities	40	8	0.026	7.200	0.408	fail to reject
determining lag and lead time	40	8	0.036	10.000	0.189	fail to reject
define resource constraints during schedule development and update	40	8	0.020	5.600	0.587	fail to reject
entering start and end dates	40	8	0.0186	5.200	0.636	fail to reject
setting working days (as per project calendar)	40	8	0.0267	7.467	0.382	fail to reject

Table 9a. Kendall’s coefficient of concordance for individual activities (contd.)

Activity	No. of responses	No. of Root Causes	Kendall's W	Chi-Square	p-value	Result
creating summary activities	40	8	0.0443	12.400	0.088	Reject
setting logics/dependencies between activities	40	8	0.0429	12.000	0.101	Reject
creating resource pool and assigning resources	40	8	0.0152	4.267	0.749	fail to reject
designing a 3D-Model (Architectural, Structural, MEP)	40	8	0.0200	5.600	0.587	fail to reject
linking schedule tasks with respective elements in 3D model using visualization or the sequence simulation software	40	8	0.0257	7.200	0.408	fail to reject
recording progress/status	40	8	0.0210	5.867	0.555	fail to reject
updating changes in activities and sequence	40	8	0.0229	6.400	0.494	fail to reject
updating resource availability/usage	40	8	0.0157	4.400	0.733	fail to reject

Table 9b. Kendall’s coefficient of concordance for individual activities

Research Findings:

RQ1: From the tables 9a and 9b, we could see that there is no agreement among the respondents in rating the potential root causes of human errors in all the activities except:

i. identifying the scope of work,

ii. identifying the activities of the project,

iii. creating summary activities,

iv. setting logics/dependencies between activities,

Identifying the scope of work (Planning and Scheduling Phase)

In this activity, there is a significant agreement among the respondents with a p-value of 0.084 less than the significance level of 0.1. The topmost potential root causes of errors in this activity are found to be “complex project scope”, “wrong/loss of information from stakeholders”, “miscommunication”, “knowledge shortage” from Table 8a.

Identifying the activities of the project (Planning and Scheduling Phase)

In this activity, there is a significant agreement among the respondents with a p-value of 0.008 less than the significance level of 0.1. The topmost potential root causes of errors in this activity are found to be “complex project scope”, “knowledge shortage”, “wrong/loss of information from stakeholders”, “miscommunication” from Table 8a.

Creating summary activities (Computer-Aided Scheduling Phase)

In this activity, there is a significant agreement among the respondents with a p-value of 0.088 less than the significance level of 0.1. The topmost potential root causes of errors in this activity are found to be “knowledge shortage”, “complex project scope”, “mis-using tools”, “wrong/loss of information from stakeholders” from Tables 8b.

Setting logics/dependencies between activities (Computer-Aided Scheduling Phase)

In this activity, there is a significant agreement among the respondents with a p-value of 0.1 equal to the significance level of 0.1. The topmost potential root causes of errors in this activity are found to be "knowledge shortage", "complex project scope", "mis-using tools", "wrong/loss of information from stakeholders" from Table 8b.

Note: Activities that are prone to human errors are mostly from "Planning and Scheduling" and "3D-modeling" Phase.

***RQ2:* Root Causes**

Complex project scope

Complex nature of projects often leads to organizations responsible for delivery being opposed with pressure to meet clients and stakeholders' needs. It is quite seen in the industry that the clients are frequently dissatisfied with the services and deliverables that construction professionals provide. Most of the errors that occur are due to the failure of designer to understand the clients' requirements [16]. According to Austin et al. 2002 [4], problems that contribute to errors in construction include:

- Inadequate support and guidance to clients regarding their requirements and what can be achieved,
- Difficulty understanding the needs of the client and providing suitable alternative of a conceptual nature to them.

Knowledge Shortage

To implement a new technology such as 4D-BIM and be successful, the organizations require education. 4D-BIM demands knowledge and expertise of planners, schedulers, designers right from the planning phase of the construction. Since one of the vital factors contributing the occurrence is knowledge shortage, it is important for an organization to have experienced staff, invest in trainings to develop in-house skills. Abanda et al. (2015) [1] claims that, BIM applications are completely related to computer knowledge whereas the on-site crew perform their daily tasks in traditional approach. This situation creates a collaboration gap and hence it is necessary that BIM knowledge covers both technology and process areas. Also, the costs incurred for these trainings can be offset to the benefits that BIM provides [5].

Miscommunication

The traditional method of procurement has been criticized as it separates design and construction process, which reduces the scope for communication between, coordination of design, preconstruction and construction teams [16]. Poor communications, both formal and informal, are widely claimed as reasons for errors leading to construction failures [3]. Atkinson (1996) [3] mentioned specific reasons for errors related to communication which include non-receipt, distortion, ambiguity and overwhelming amount of information. However, Reason (1990) and Norman (1998), suggest that, it is important to make procedures visible to make the path for good communication clear [20]. Some more examples according to Lopez (2010) [16] which may cause errors are:

- Inadequate understanding of the construction requirements by different construction teams,
- Divergent objectives between the design, preconstruction and construction teams

This implies that shortage of knowledge in scheduling process or scheduling software etc., can lead to human errors and assigning such types of jobs to individuals with expertise and good knowledge in the process and software would be recommended. Similarly, if the scope of the project is huge, it is common to have discrepancies in work breakdown structure, define and identify the activities and constraints during the schedule development. Also, if any of the elements in the 3D-model pertaining to certain activity in schedule is missing or vice versa, not only will it lead to errors but makes the process worse involving schedule updates or revisions in the model or design. Architects and engineers should make sure that every element and information of the process is broken down in detail, defined correctly and is not lost while transferring the information between different stakeholders. People involved in different phases may misread the requirements and decisions of certain work and communicate it differently from what is expected. This only results in rework including capital and time loss. Frequent supervision, double-checking the work done, discussing the what-to-dos and what-not-to-dos collaboratively, can help in reducing such human errors.

RQ3: **Error Reduction/Prevention:**

- Error reduction should always be viewed as an ongoing process rather than a product of certain activities that could be prevented just by implementing some defined tools. This process helps an individual, organization to learn from the errors and can be used in error prevention as a collective package. These also play a great role in defining margin of risks and safety. Organizations should develop a focus on behavior and methods of working during all the phases of construction including

4D-BIM to reduce the potential for human errors [17]. Given the complexity of the construction environment in which the designers, BIM practitioners, schedulers work, this process view helps the team produce a collective capacity that can generate individual, organizational and interorganizational error prevention practices [16].

- 4D-BIM demands knowledge of planners, schedulers, designers right from the planning phase of the construction. It is important for an organization to invest in trainings to develop in-house skills. During the pilot study, Travis mentioned "The knowledge of the user putting the files together plays a crucial role. If you do not know what you are looking for in a file, building composition and level of coordination, many errors will be overlooked".
- It is also important for an organization to consider an individual's expertise. An experienced professional not only helps in generating reliable models and schedules but also comes handy during training events, creating BIM Execution Plan for the organization, defining systematic work procedures at the workplace etc., contributing towards the error reduction/prevention.

CHAPTER SIX

CONCLUSION

Prevention of human errors in construction scheduling contributes to reliable schedule, timely completion and less capital loss. And since planning and scheduling is the crucial preconstruction phase, reduction of human errors in early stages can result in better schedule generation and subcontractor work scope. Therefore, a definite framework has been adopted trying to solve the problem. Initially, the problem statement has been defined to study the human errors in construction scheduling, later the likelihood of occurrence of these errors and their root causes in each phase of 4D-BIM has been measured from survey and pilot study. Then, after analyzing the survey results, the activities of each phase that are highly prone to human errors and their root causes are noted. Most of the activities of planning and scheduling phase and the only activity in 3D modeling phase are included in it. Next in the line are a few activities from computer-aided scheduling and schedule update phases. “creating summary activities” in computer-aided scheduling phase is found to be the activity which is less prone to errors. It is also found that the top root causes behind the errors to be “knowledge shortage”, “complex project scope”, “wrong information/loss of information from the stakeholders”, “miscommunication” and “mis-using tools”. Finally, these root causes were categorized into three types of human errors using a predefined cognition error theory (Human Error Taxonomy). When categorized, these root causes fall in two types of human errors i.e., Lapses and Mistakes implying that the main reasons are both “failure of execution” and “knowledge based” errors as shown in Table below:

Phases of 4D-BIM	Activities	Root causes of errors	Type of errors
Planning and Scheduling	identifying the scope of work	complex project scope	Mistake
		wrong/loss of information from stakeholders	Mistake/Lapse
		knowledge shortage	Lapse
	defining dependencies between activities	knowledge shortage	Lapse
		complex project scope	Mistake
		miscommunication	Mistake
	estimating durations of the activities	knowledge shortage	Lapse
		wrong/loss of information from stakeholders	Mistake/Lapse
		complex project scope	Mistake
	determining lag and lead time	knowledge shortage	Lapse
		wrong/loss of information from stakeholders	Mistake/Lapse
		complex project scope	Mistake
	define resource constraints during schedule development/update	wrong/loss of information from stakeholders	Mistake/Lapse
		complex project scope	Mistake
		knowledge shortage	Lapse
3D-Modeling	designing a 3D-Model	wrong/loss of information from stakeholders	Mistake/Lapse
		complex project scope	Mistake
		knowledge shortage	Lapse

Table 10 Phases and activities prone to human errors, their root causes and type of errors that can occur

Limitations and Future Research

- This study concentrates only on the activities that make up the basic skeleton of the 4D-BIM workflow providing a scope to dig into the core for future research. We expect to extend this research investigating into the deeper layers of each activity to help find the specific areas of error occurrence and their root causes.
- The survey responses for this study were received from individuals with mixed experience levels and roles in the industry. We expect to collect more information, responses and weight the level of experience in future study.

This knowledge can help us identify the type of errors and nature of errors that an individual (BIM practitioners/designers/schedulers) can make at a time or phase of 4D-BIM process which may help them in rectifying the errors in an ongoing practice. A taxonomy developed in this study will help practitioners and organizations to identify the most common types of errors so they can develop required error prevention techniques or policies (e.g. training) or center on the review procedures to identify and remove the results of these human errors. To mention, Love et al. 2011 [17] indicate that BIM will significantly improve the performance of projects only if used in contrast with the strategic and organizational innovations that have been pre-defined. Further research is required to better determine the strategies required to significantly reduce human errors in 4D-BIM Construction Scheduling.

APPENDICES

SURVEY QUESTIONNAIRE

Q1: email address: - ____

General Information:

Q2: Describe the type of your company/organization from the following categories.

- ☐ Construction
- ☐ Architecture
- ☐ Engineering
- ☐ Facility Management
- ☐ Other (please specify) ______________________________

Q3: Which of the following describes your role in the company/organization?

- ☐ Project Engineer
- ☐ Project Manager
- ☐ BIM Specialist/BIM Manager
- ☐ Superintendent
- ☐ Scheduler
- ☐ Estimator
- ☐ Other (please specify) ______________________________

Q4: Years of experience in the respective construction discipline. ____________

Q5: How many years of experience do you have using BIM for the projects? ____________

Q6: Do your company adopt 4D BIM in any/all the projects? (Survey ends if answered "No")

- Yes
- No

Planning and Scheduling:

This section deals with the likelihood of making errors during planning and scheduling. Rate the likelihood of each case as mentioned above the selection box. (Tick the appropriate box)

Q7: How likely is an individual prone to make errors in

	not likely at all	somewhat likely	moderately likely	very likely	extremely likely
identifying the scope of work					
identifying the activities of the project					
defining dependencies between activities					
estimating durations of the activities					
determining lag and lead time					
define resource constraints during schedule development/update					

Computer-Aided Scheduling

Q8: Which scheduling software does your company/you use?

- ☐ Microsoft Project
- ☐ Primavera
- ☐ Gantt Pro
- ☐ Other (please specify) ______________________

This section deals with the likelihood of making errors during computer-aided scheduling. Rate the likelihood of each case as mentioned above the selection box. (Tick appropriate box)

Q9: How likely is an individual prone to make errors in

	not likely at all	somewhat likely	moderately likely	very likely	extremely likely
entering start and end dates					
setting working days (as per project calendar)					
creating summary activities					
setting logics/dependencies between activities					
creating resource pool and assigning resources					

3D Modeling:

Q10: Which software does your company use for 3D Modeling?

- ☐ Revit
- ☐ ArchiCAD

- ☐ Sketch Up 3D
- ☐ Other (please specify) ____________________

Q11: How likely is an individual prone to make errors in 3D Model (Architectural, Structural, MEP)

- ○ not likely at all
- ○ somewhat likely
- ○ moderately likely
- ○ very likely
- ○ extremely likely

4D Visualization:

Q12: Which software do you use for 4D visualization?

- ☐ Navisworks
- ☐ Enscape
- ☐ Synchro Pro
- ☐ Other (please specify) ____________________

Q13: How likely is an individual prone to make errors when linking activities in the schedule with respective 3D model elements in visualization software.

- ○ not likely at all
- ○ somewhat likely
- ○ moderately likely
- ○ very likely
- ○ extremely likely

Schedule Update:

Q14: How likely is an individual prone to make errors in

	not likely at all	somewhat likely	moderately likely	very likely	extremely likely
recording progress/status					
updating changes in activities and sequence					
updating resource availability/usage					

Root Causes of Human Errors in 4D BIM

In this section, you are supposed to analyze the root cause of errors in the various activities of the construction scheduling, visualization and schedule update as mentioned and select the reason for the error i.e., type of human error applicable.

Q15: What do you think is the reason for errors in/during

	mis-using tools	knowledge shortage	complex project scope	unfamiliar with project type	wrong/loss information from stakeholders	forgetting information	miscommunication	accidentally overlooking required verification processes
identifying the scope of work								
identifying the activities of the project								
defining dependencies between activities								
estimating durations of the activities								
determining lag and lead time								
define resource constraints during schedule development/update								
entering start and end dates								
setting working days (as per project calendar)								
creating summary activities								
setting logics/dependencies between activities								
creating resource pool and assigning resources								
designing a 3D-Model (Architectural, Structural, MEP)								
linking schedule tasks with respective elements in 3D model using visualization or the sequence simulation software								
recording progress/status								
updating changes in activities and sequence								
updating resource availability/usage								

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