MEASURING THE EFFECTIVENESS OF 4D PLANNING AS A VALUABLE COMMUNICATION TOOL

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ABSTRACT: *Construction industry is very much information hungry and is often described as a slow adopter of new IT technologies. The importance of sharing and communicating information is becoming increasingly important through out the whole life of a construction project. Communication of information among different stakeholders is becoming critical as each stakeholder possess different set of skills. As a result, extraction, interpretation and communication of complex design information from drawings is a time consuming and difficult process. Advanced visualisation technologies, like 4D planning (3D product model integrated with schedules) have tremendous potential to increase the communication efficiency and interpretation ability of the project team members. Visualisation is the process of displaying information which assists in understanding and evaluating information. However, its use as an effective communication tool is still limited and not fully explored. The main objective of this research is to measure the effectiveness of communicating construction information of product and processes using 4D models compare to traditional 2D (two-dimensional) CAD drawing approach. An experimental exercise was developed and experiments had been conducted among participants in different age groups (11 to above 22 years) and profiles. The purpose of this research is to evaluate how much information participants are able to extract and retain in their mind by analysing two different graphical representation formats (2D CAD or 4D models). Participants had been divided in two groups (2D & 4D). One group used 2D CAD drawings describing the plans, elevation and sectional drawings, and a bar chart showing the construction schedule. While other group used a detailed 4D model of the house showing the construction sequence. Participants in both the groups are required to construct the same physical model of the house using a Lego kit (423 bricks) in the allotted duration of two hours. Outcomes of the research has provided the quantitative evidence that 4D group has performed better than 2D group by constructing 7% faster the physical model, spent 22% less time in extracting information from building information and reconstructed 77% less Lego bricks compare to 2D group. Participants in 4D group were able to communicate and coordinate better as compared to participants in 2D group.*

KEYWORDS: c*ommunication, 2D CAD, 4D planning, visualisation, Lego bricks.*

1. INTRODUCTION

Construction industry is a project oriented industry where each project is unique and could be considered as a prototype, although a similar set of process stages are involved in every project. Different stakeholders on a project have different objectives and expectations from the project. An architects concern is to deliver uniqueness in aesthetics as the project success criteria, while the construction manager rank profitability the highest. As a consequence application of visualisation technique is becoming increasingly important to communicate the schedule and design intent to all project participants involved in the project. Schedule generation is an important part of the construction planning process. The process of schedule generation is usually modified and carried out several time during the whole life of a construction project. In order to develop a construction schedule, a planner has to first interpret what has to be constructed on the basis of available information (design documents, 2D CAD drawings and 3D model). Planner then identifies a list of activities required to construct the project. Finally, on the basis of construction method and based on available resources, the planner creates sequential relationship among the activities and calculates activity and project duration to generate schedule. During construction stage, a constructor faces difficulties in interpreting the information from 2D CAD drawings, because they need to visualise the components in their mind and then link the mentally visualised component with the individual activity represented in Critical Path Method network. The whole process of interpretation of information from the 2D drawings is a complicated and difficult process to understand the schedule intent. As a consequence constructors spend most of their valuable time in the interpretation of information from 2D CAD drawings (Ganah et al. 2001).

4D planning and scheduling technique that integrates 3D CAD models with construction activities (time) has proven beneficial over the traditional tools. In 4D models, project participants can effectively visualise, analyse, and communicate problems regarding sequential, spatial, and temporal aspects of construction schedules. As a consequence, more robust schedules can be generated and hence reduce reworks and improve productivity. As per Webb and Haupt (2000) 4D CAD enhances communication of construction schedules to various parties, such as construction managers, clients, designers, subcontractors, and community members. However, the perceived value and benefits of such technologies have not been identified. This has contributed to a slow intake of such technologies in the industry. The subsequent section describes the review of past literature on experimental based exercise carried by various researchers.

Various research efforts had been undertaken in an attempt to demonstrate the benefits of 3D and 4D technologies using experimental based exercise. Songer et al. 2001 had carried out two experimental exercises to investigate the efficacy of using 3D & 4D technologies over 2D paper based representation. The first study investigates the impact of 2D, 3D and walk-thru technologies on the project schedule development. The research demonstrated the benefits of using 3D and walk-thru technologies as an important tool in the development of more complete and accurate schedules. Whereas, second study focuses on the impact of 3D / 4D visualisation on project schedule review. Experimental results provide the quantitative evidence of the benefits of 3D/4D representation in terms of identifying missing activities, out of sequence work, invalid relationships and potential overcrowding issues during the schedule review process for a construction project. *Kang et al. 2002* developed a Web-based experiment tool to measure impact of Web-based 4D visualisation on detecting logical errors in the construction schedule. The outcomes of the experiment showed that Web-based 4D visualisation team were able to detect more logic errors as compared to the participants in 2D team. *Messner & Horman 2003* had carried out experiments to test the ability of advanced visualisation (4D CAD modelling technique) as a tool to assist students in understanding the construction process and planning. The outcome of the experiments had demonstrated the benefit of 4D as a planning tool that has assisted students in understanding the intent of construction plan. *Whisker et al. 2003* had carried out a study to investigate the feasibility of using an Immersive 3D Virtual Environment to view and generate 4D models to improve construction planning process. Two experiments were performed to test the application of 4D models to develop schedule and in construction project planning using 4D models in an Immersive Virtual Environment. The outcome of experiment shows that IVE assisted in reducing the planned schedule duration by 28%, to identify constructability issues and to evaluate schedule dependences. Wang et al. 2006 had developed a problem based 4D CAD module to demonstrate the benefits of 4D models as a visualising tool to rehearse the construction plans, identify construction consequences, space conflicts and improve communication of the project team members.

All the above experiments were carried out to identify and analyse schedule errors, trade conflicts, missing activities, missing relationship, logic of sequencing and safety issues through a review of a CPM schedule or 2D CAD drawings or 3D CAD models or through the analysis of a 4D model of a building project. As described, the above research has considered computer simulation as an important element to carry out their experiments. They had not considered any physical modelling aspects to evaluate the efficiency of 4D models as an information interpretative and communicative tool in their research experiments. This situation motivated us to develop an experimental exercise consisting of constructing a physical model to evaluate the effectiveness of 4D as a communicative tool as compare to 2D paper based drawing approach. Two-dimensional drawings were used as a benchmark because most of the current construction projects are using 2D as a main source of communicating information and there are very few projects which actually uses 3D CAD in their real practices.

The subsequent sections of the research paper discusses about the research methodology, experiment procedures and experimental results for the experiments performed with participants in 15 – 18 years of age group.

2. RESEARCH METHODOLOGY

The effectiveness of 4D as a communicative tool was investigated through the comparison of the performance measures calculated for two groups (2D & 4D). Groups were required to construct the physical model of the house (Fig. 1) using Lego kit (423 bricks) in the allotted duration of two hours. The participants were randomly divided into two groups, 2D group & 4D group. Participants in 2D group, used 2D CAD drawings describing the plans, elevation and section, and a bar chart showing the construction schedule. Participants had to then link the activity represented in the bar chart with the 2D CAD drawings in their mind to develop a logical construction sequence. Participants in 4D group, used a 4D visualisation model of the house showing the construction sequence. Both the groups were given the same house model to be constructed.

FIG. 1: Image of the Lego House Model

A Lego kit of a house building was selected from the list of Lego designer creator kit. The main criteria for the selection of Lego kit were:

- Most of the users are familiar with Lego bricks as a basic construction tool.
- A real life situation can be easily depicted using Lego bricks.
- Lego bricks can be easily taken apart and reassembled.
- Lego bricks with different colour and shapes assist participants to identify its significance as building components.

The experiments have been conducted with participants in four different age groups (11 to 22 + yrs) and profiles. A brief overview of participants involved in this experiment is explained below:

- School students (11 – 15 yrs) – Participants in this group have a little knowledge about the construction process and components.
- GCSE Achieved Students (15 – 18 yrs): Participants in this group have a moderate knowledge about the construction process and components.
- Construction Engineering Graduate / Post Graduate Students (18 – 22 yrs) - Participants in this group have a moderate to strong knowledge about the construction process and components.
- Industry Professionals (Above 22 yrs) - Participants in this group have a strong knowledge and experience about the construction process and components.

The reason for conducting the experiments with different age group and profile was to investigate the potential of 4D as a communicative tool beyond its application in the construction industry. This paper describes the outcome of the experiments conducted with GCSE achieved students (15-18 yrs). Each group (2D & 4D) comprised of two participants. Table 1 represents the total number of experiments performed with GCSE students (15 – 18). Sample size was decided on the basis of Cohen's *d* benchmark (Cohen 1998) which is the appropriate effect size measure to use in the context of a t-test on means. The value of Cohen's *d* comes out to be 0.3 (95% confidence interval) which lies on a scale of small to medium size effect (0.2 to 0.5). This indicates that the sample size considered was significant to represent the outcomes of the research.

TABLE 1: Number of experiments performed to date

Group	**Number of Experiments Performed**	
	2D	**4D**
1. GCSE Achieved Students (15 – 18 Years)	6	6

3. EXPERIMENT PROCEDURE FOR 2D GROUP

An instructor was appointed to monitor and to facilitate the experimental exercise. A power point presentation was used by instructor to brief the team regarding their objectives, role and task to be performed by them. A due emphasise was given to make it sure that they become familiarise with CAD drawings and schedule. Following experiment accessories were used to conduct the experiments with 2D groups:

- Lego kit: Lego base plate and Lego bricks of walls, roof tiles, roof walls, beams, column, fence panel and fence post.

- Two Dimensional CAD drawings (plan, elevations, and sectional plan drawings).
- Bar-chart representing the sequential interrelationships between the construction activities.
- Stop-watch was used to record the time spent by each group in interpreting the information from 2D CAD drawing given to them.

The whole experiment was divided into two stages.

In first stage, participants had to interpret and analyse the information required to construct the model from the two dimensional CAD drawings (Fig. 2 & 3) and bar-chart given to them. Participants had to then link the activity represented in the bar-chart with the 2D drawings using their mental model to develop a logical construction sequence in which the Lego bricks were to be assembled. Time duration of fifteen minutes was allotted in the first stage of the experiment to the participants to discuss and share their ideas within the group.

After duration of fifteen minutes the drawings and schedule programme in bar chart given to the group was taken back from the participants. Participants could request to have an access to building information to revise the sequence in which the Lego bricks had to be assembled.

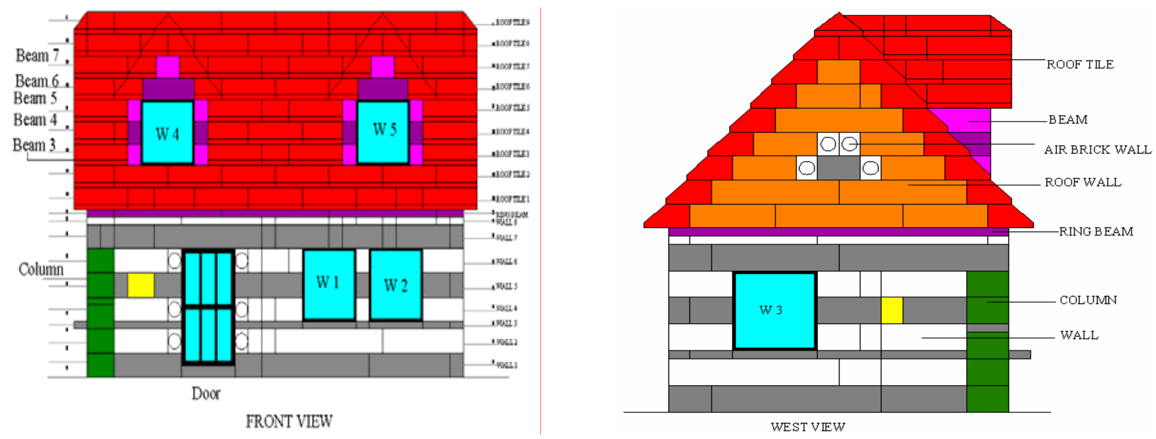

FIG. 2: Elevation view of House Model

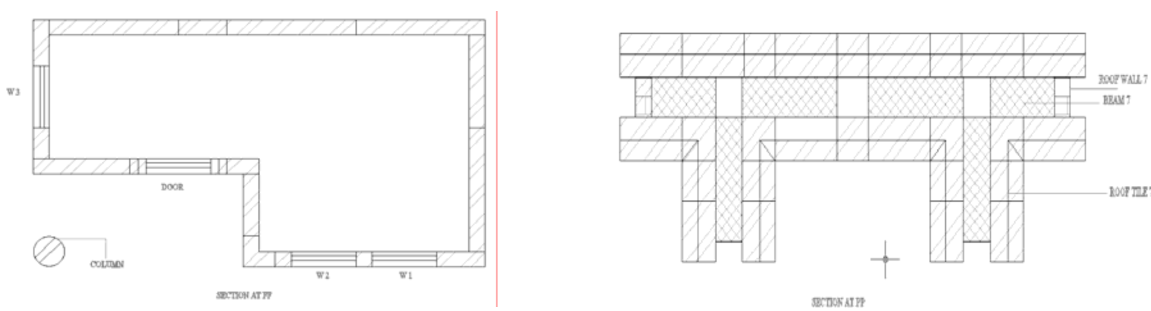

FIG. 3: Sectional view of House Model

In second stage, participants were required to construct the physical model of the house in the remaining duration of an hour and forty five minutes using the Lego kit.

4. EXPERIMENT PROCEDURE FOR 4D GROUP

Following experiment accessories were used to conduct the experiments with 4D groups:

- Lego kit: Lego base plate and Lego bricks of walls, roof tiles, roof walls, beams, column, fence panel and fence post.
- Four Dimensional model of house developed using PAL software (A3D Ltd).
- A computer or laptop to run the 4D model.
- Stop-watch was used to record the time spent by the group in interpreting the information from the 4D model.

An instructor was appointed to monitor and to facilitate the experimental exercise. A power point presentation was used by instructor to brief the team regarding their objectives, role and task to be performed by them. A due emphasise was given to make it sure that they become familiarise with 4D model and software. The whole experiment has been divided in two stages.

In first stage, participants were required to run the 4D model several times to visualise the sequential logic of the various construction activities to construct the physical model of the house. 4D group had the benefit of rotating, moving and visualising the model in different views as compared to 2D group. Time duration of fifteen minutes was allotted in the first stage of the experiment to the participants to discuss and share their ideas within the group. After duration of fifteen minutes the 4D model of the house given to the group was taken back from the participants. Group lost points in their final scoring if they request to see the 4D model again.

In second stage, participants had to construct the physical model of the house in the remaining duration of an hour and forty five minutes using the Lego kit. The performance of the groups had been evaluated on the basis of the following performance measures: frequency of communications between the team members; Time taken to construct the house (if the house is constructed within 2 hours); Percentage of model constructed (if the house is not constructed within 2 hours); Number of times information accessed during the session of two hrs; Total time spent on understanding building information (minutes) and Number of times Lego bricks were reconstructed. Fig. 4 & 5 show participants constructing the physical model of house using the Lego bricks. Participants could request to have an access to 4D model to review the sequence in which the Lego bricks had to be assembled.

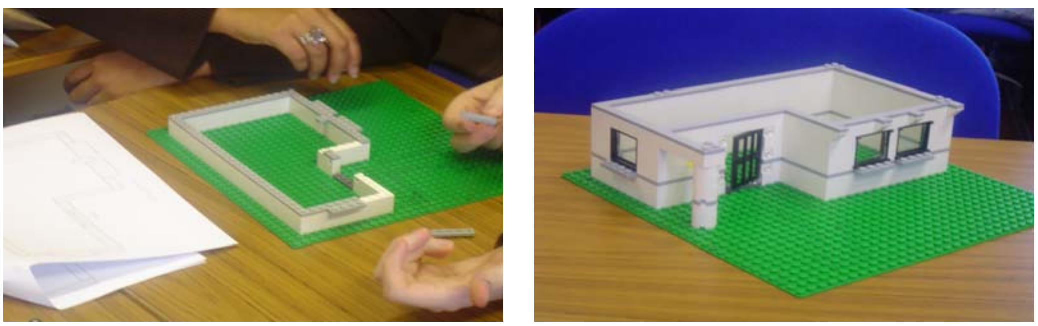

FIG. 4: Step-by-Step Assembly of Lower Part of House Model

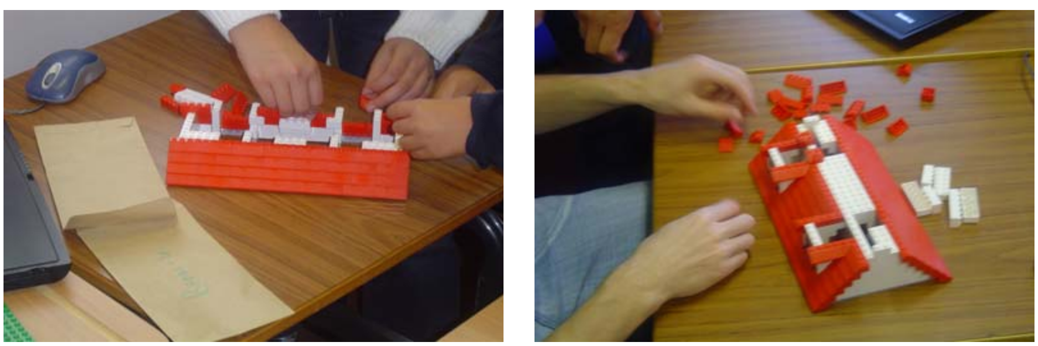

FIG. 5: Step-by-Step Assembly of Upper Part of House Model

5. EXPERIMENT RESULTS AND ANALYSIS

The experiments were conducted with school students (11 to 15 years), GCSE students (15 – 18 years) and engineering graduate students (18 to 22 years). Each group comprised of two participants. The teams were selected randomly and were divided into two groups, 2D group and 4D group. First group i.e. 2D group used Two-Dimensional drawings describing the plans, elevations of the house, and a Bar-chart showing the construction schedule; while the second group i.e. 4D group used a 4D visualisation tool (PAL Viewer – A3D Ltd). This paper describes the outcomes and analysis of the experiments conducted with GCSE students in the age group of 15 to 18 year old. The experiment was designed to investigate the difference of the performance between two identical human samples due to different graphic representations. In order to avoid the occurrence of individual variability the experiments were repeated with both the groups (2D or 4D) using both graphic representations. Therefore, the experiment made use of a within-subject design to control individual variability.

The results described in Figure 6 show that 4D group were able to complete 95% of their physical model of the house as compared to 2D group which were able to construct only 91% of their physical model within the allotted duration of two hours. The standard deviation value for the average percentage of model completed between the two groups was 2.83.

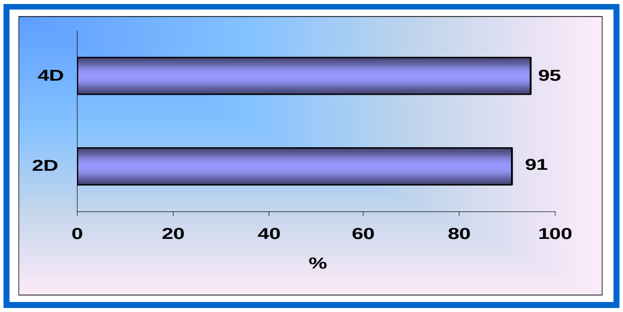

FIG. 6: Average percentage of model completed (%)

During the experiments 2D group had kept the CAD drawings with them while constructing the physical model. Whereas, 4D group used their ability to retain information in their mind to construct the physical model of the house.

The results described in Figure 7 show that 4D group has requested 20 times to have an access to information as compared to 22 times request made by 2D group. The standard deviation value for the average number of times information accessed between the two groups was 1.41.

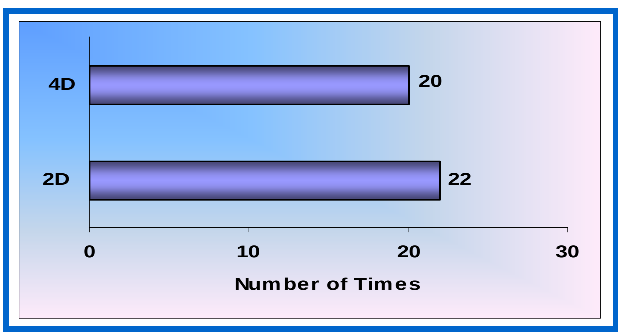

FIG. 7: Average number of times information accessed

The results described in Figure 8 show that the 4D group had spent 29 minutes in understanding the information provided to them as compared to 28 minutes spent by 2D group. As a result 2D group spent 23% of their time in evaluating the information from the 2D CAD drawings and rest 77% of their time in constructing the model. Where as, 4D group spent 24% of their time in evaluating the information from the 4D model and rest 76% of their time in constructing the model. This indicates that both the groups had spent the same time in interpreting the information from CAD drawings and computer model.

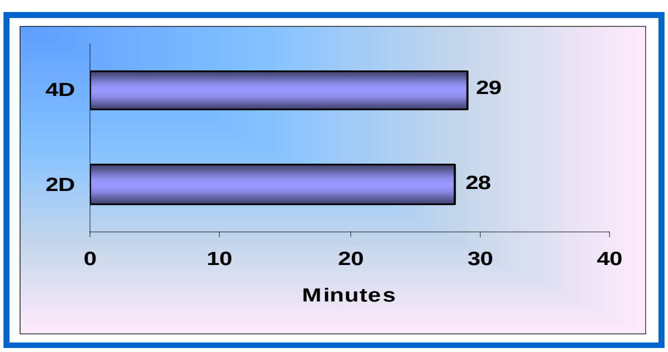

FIG. 8: Average time spent on understanding building information (Minutes)

The results described in Figure 9 show that the 4D group had reconstructed the Lego bricks 43 times as compared to 59 times done by 2D group. The rate of reconstruction of Lego bricks by 2D group were 1.4 times more than 4D group. This indicates that the 2D group spent most of their time in reconstructing the Lego bricks because they were unable to interpret the sequence in which Lego bricks had to be constructed. The standard deviation value for the average number of times Lego bricks were reconstructed between the two groups was 11.31. The main cause of reconstruction of Lego bricks were mainly because the participants were not considering the sequence (schedule) in which the activities are required to be constructed.

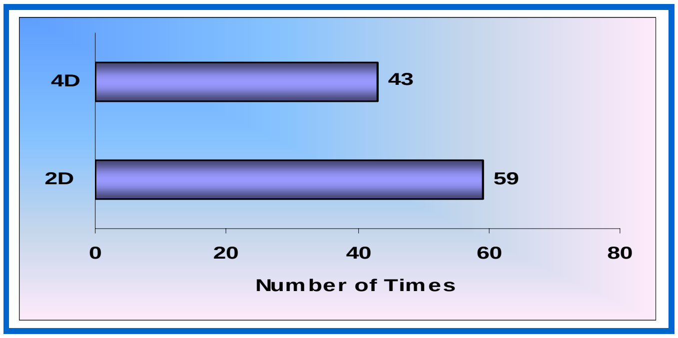

FIG. 9: Average number of times Lego bricks were reconstructed

One of the participants has responded that the 4D experiment has assisted him to develop skills and knowledge that could not be understood using two-dimensional drawings. Participants has provided a positive feedback regarding the 4D planning (PAL Software) approach and suggested to implement this approach as an interactive educational tool in classrooms.

Figure 10 show a comparative analysis between the performances of 2D and 4D group for the participants in the age group of 15 to 18 years.

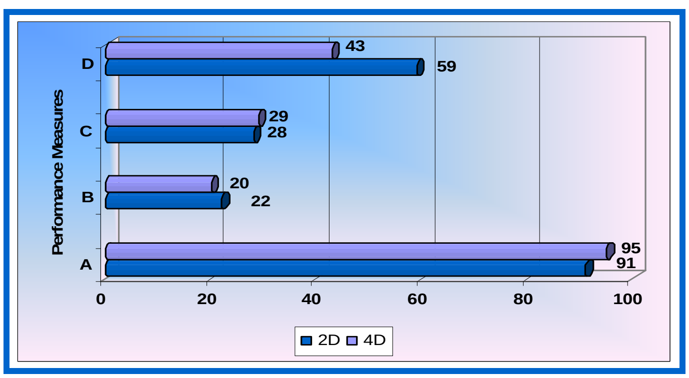

Figure 10: Comparative performance analysis between 2D & 4D group

Where, A= Percentage of model completed (%), B = Number of times information accessed during the session of two hrs, C = Total time spent on understanding building information (Minutes) and D = Number of times Lego bricks were reconstructed

Following outcomes can be concluded from the Figure 10:

- 4D group were able to construct on an average 95% of the physical model of the house as compared to 91% of model constructed by 2D group in an allotted duration of 2 hours.
- 4D group had requested on an average 20 times to get an access to 4D models as compared to on an average 22 times request made by 2D group to get an access to drawing information.
- 4D group had spent on an average 29 minutes in extracting information form 4D models as compared to on an average 28 minutes spent by 2D group in extracting information from drawings.
- 4D group had reconstructed on an average 43 times Lego bricks as compared to on an average 59 times Lego bricks reconstructed by 2D group.

6. CONCLUSION

The experimental results provide valuable insights into the effectiveness of the 4D planning as compared to 2D drawing approach. 4D model was assisting participants in 4D group in understanding concepts, interpreting information and communicating it effectively among themselves. Participants in 4D group had the advantage of rehearsing the sequence of construction of Lego bricks by evaluating what they had constructed and what they will be constructing. This process of looking back and forward in the timeline has provided them lot of confidence in constructing their model and eventually they were able to save their time by avoiding reconstruction of Lego bricks. Whereas, 2D participants were finding it difficult to interpret the drawing information clearly compared to 4D group.

4D group performed better than 2D group by constructing on an average 7% faster the physical model, requested on an average 14% less times to have an access to building information, spent on an average 8% less time in extracting information from building information and reconstructed on an average 67% less Lego bricks compared to 2D group. As advancements continue, 4D construction planning will eventually become the part of construction project to be used in all the phases of construction (design, planning, engineering and maintenance).

The future research activities will include:

- Conducting more experiments with participants in different age group and profiles.
- Statistical analysis will be performed to evaluate the statistical relationship between the performances of participants in different age group and to validate the outcomes of research.

7. ACKNOWLEDGEMENTS

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