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

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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 visualization 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. Visualization 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 investigate and measure the effectiveness of communicating construction information of product and processes using 4D models over traditional 2D (two-dimensional) CAD drawings. A 4D experimental exercise has been developed and an experiment has been conducted among participants in different age groups (11 to 22 + yrs) 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). The experiments had been carried out with two groups (2D and 4D). One group used 2D CAD drawings describing the plans, elevation and section, and a bar chart showing the construction schedule. Other group used a 4D visualization model of the house showing the construction sequence. Participants in both the groups are required to construct the physical model of the house using Lego kit (423 bricks) in the allotted duration of two hours. The results of the experiments showed that the 4D group were able to communicate, coordinate and retain more information as compared to 2D group. The outcomes of the research has provided quantitative evidence of the benefits of 4D planning as an efficient communication tool as compared to two-dimensional paper approach.

Keywords**:** communication, information retention, 2D CAD, 4D planning, visualization, Lego bricks.

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 is 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 visualization technique is

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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 visualize the components in their mind and then link the visualized component with the individual activity represented in CPM network. The whole process of interpretation of information from the 2D drawings is 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 visualize, 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. 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 researchers.

Various research efforts have been undertaken in an attempt to demonstrate the benefits of 3D and 4D technologies using experimental based exercise. *Songer et al. 2001* has carried out two experimental exercises to investigate the efficacy of using 3D and 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 visualization 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 visualization on detecting logical errors in the construction schedule. The outcomes of the experiment showed that Web-based 4D visualization team were able to detect more logic errors as compared to the participants in 2D team. *Messner and Horman 2003* has carried out experiments to test the ability of advanced visualization (4D CAD modelling technique) as a tool to assist students in understanding the construction process and planning. The outcome of the experiments has demonstrated the benefit of 4D as a planning tool that has assisted students in understanding the intent of construction plan. *Wang et al. 2006* developed a problem based 4D CAD module to demonstrate the benefits of 4D models as a visualizing 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, 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 have 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 has motivated us to develop an experimental exercise consisting of constructing a physical model to evaluate the effectiveness of 4D as a communicative tool as compared to 2D paper based approach. The reminder of the paper discusses the research methodology, experimental results and questionnaire discussion.

RESEARCH METHODOLOGY

The effectiveness of 4D as a communicative tool was investigated through the comparison of the performance measures calculated for two groups (2D and 4D) and a questionnaire. Groups were required to construct the physical model of the house (fig1) using Lego kit (423 bricks) in the allotted duration of two hours. The participants were randomly divided into two groups, 2D group and 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 visualization model of the house showing the construction sequence. Both the groups were given the same house model to be constructed.

Figure 1: Picture 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 construction industry. This paper describes the outcome of the experiments conducted with GCSE achieved students (15-18 yrs). Each group (2D and 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

	Experiments	
Group	**2D**	**4D**
GCSE Achieved Students (15 - 18)	7	7

EXPERIMENT PROCEDURE FOR 2D GROUP

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.

An instructor was appointed to brief the team regarding their objectives and task to be performed by the participants. A power point presentation was used by instructor to describe about their role, procedure to be followed, familiarizing them with Lego elements and basic building components. The whole experiment was divided in 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 and 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. Group would lose points in their final scoring if they requested to see the drawings and schedule programme again.

Figure 2: Elevation view of House Model

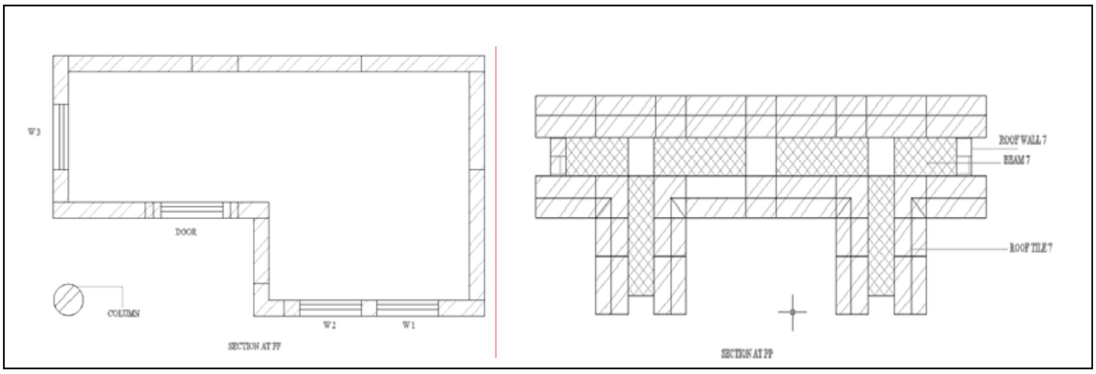

Figure 3: Sectional view of House Model

In second stage, participants were required to construct the physical model of the house in the remaining duration of 1 hour and forty five minutes using the Lego kit.

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 brief the team regarding their objectives and task to be performed by them. A power point presentation was used by instructor to demonstrate the basic Lego elements, building components and to guide the participants regarding how to run the 4D model in the computer. The whole experiment has been divided in two stages.

In first stage, participants were required to run the 4D model several times to visualize 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 visualizing 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 1 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. Figure 4 and 5 show participants at University of Teesside constructing the physical model of house using the Lego bricks.

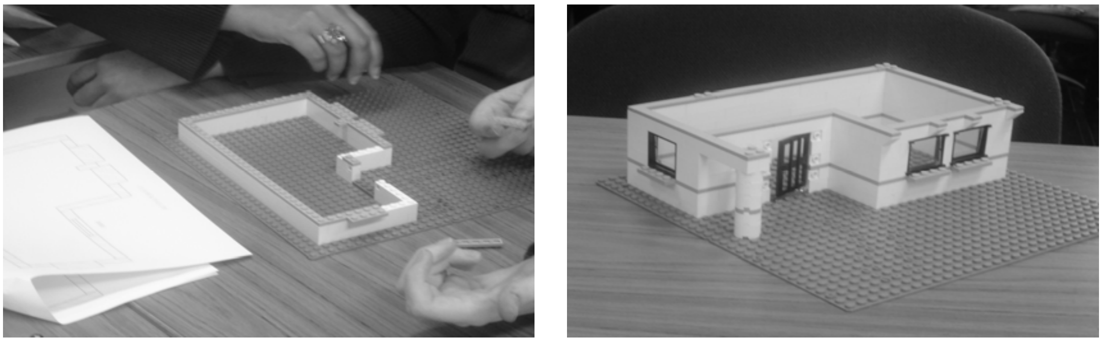

Figure 4: Step-by-Step Assembly of Lower Part of House Model

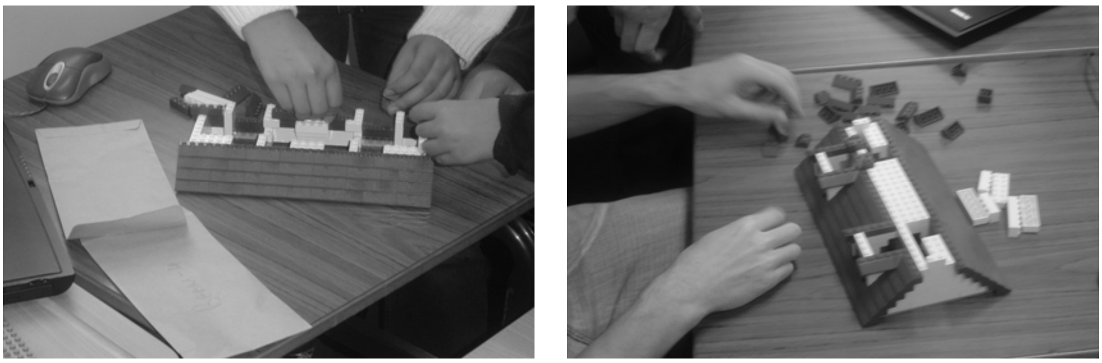

Figure 5: Step-by-Step Assembly of Upper Part of House Model

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 visualization 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. 4D group which uses visualization models could finish a task faster than 2D group which uses 2D CAD drawings because participants in 4D group is more experienced in using 4D models as compared to participants in 2D group. If the experiments were performed with different groups, the result could be the opposite. So, in order to avoid the occurrence of individual variability the experiments were repeated with all the groups 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 the 4D group has requested 11 times to have an access to information as compared to 21 times request made by 2D group. This indicates that the 2D group were finding it difficult to interpret and understand the sequence of construction activities. As consequences they have requested more number of times to get an access to information.

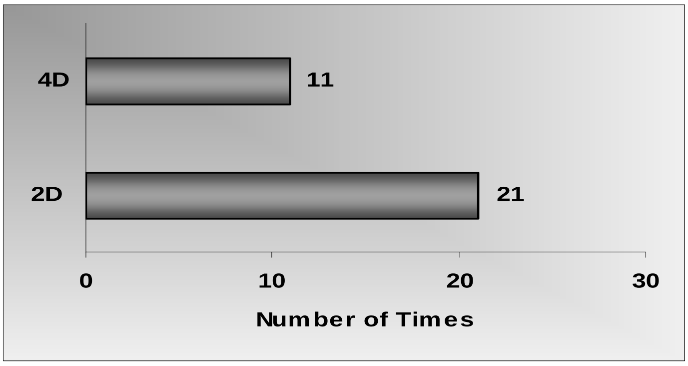

Figure 6: Average number of times information accessed

The results described in Figure 7 show that the 2D group had spent 26% of their time in evaluating the information from the 2D CAD drawings and rest 74% of their time in constructing the model. Where as, 4D group spent 11% of their time in evaluating the information from the 4D model and rest 89% of their time in constructing the model. This indicates that 2D group faced difficulties in interpreting and communicating the information from the drawings with other members of their group. Visualization of 4D model (PAL Software) helped the participants to easily evaluate and review the logic used in developing the sequence of construction activities.

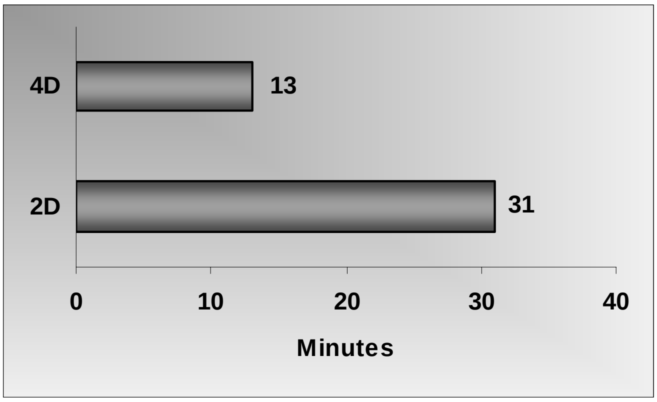

Figure 7: Average total time spent on understanding building information (Minutes)

The results described in Figure 8 shows that the 4D group had reconstructed the Lego bricks 98 times as compared to 169 times done by 2D group. The rate of reconstruction of Lego bricks by 2D group were 0.4 times more than 4D group. This indicates that the 2D group spent most of their time in reconstructing the Lego bricks.

Participants in 4D group had the biggest 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 front in the timeline has provided them lot of confidence in constructing their model and eventually they were able to save lot of their time by avoiding the reconstruction of Lego bricks. The prominent reason behind this was mainly because the 2D group has requested more number of times to get an access to information and has spent 15% more time in interpreting and understanding the information (2D drawings and bar chart) as compared to 4D group.

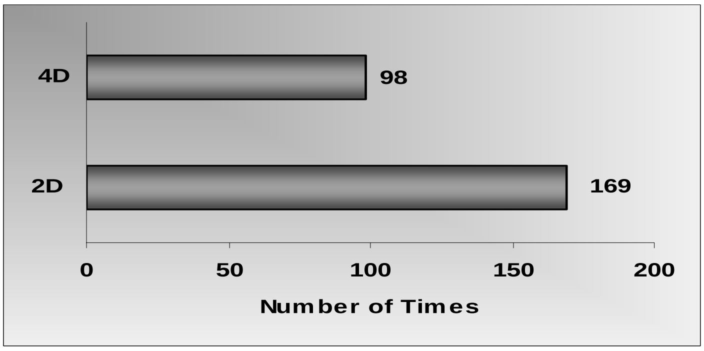

Figure 8: Average number of times Lego bricks were reconstructed

The results described in Figure 9 show that the 4D group communicated 75 times as compared to 127 times communication done by 2D group. It is evident from the Figure 9 that 4D visualization helped participants in collaborative decision-making and communicating efficiently with their group members in the construction of the physical model. However, sometime participants communicated more when they used 4D models.

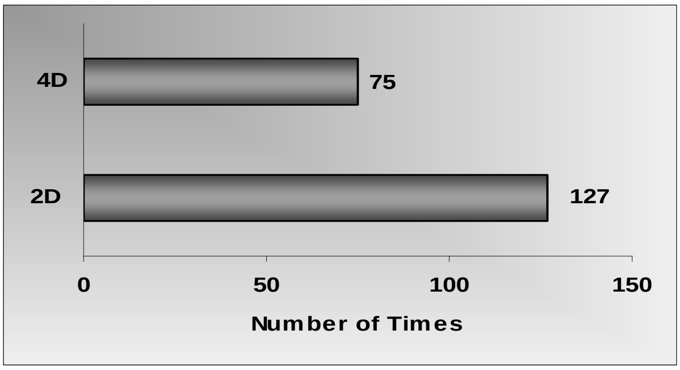

Figure 9: Average number of times communication done by team members

The results described in Figure 10 show that the 2D group were able to complete 95% of their physical model of the house as compared to 4D group which were able to construct only 91% of their physical model within the allotted duration of two hours. The potential reason for 2D participants to outperform 4D participants is mainly because participants in 2D group has an access to a more detailed drawing information (sectional drawings at each wall and roof level) as compared to 4D group.

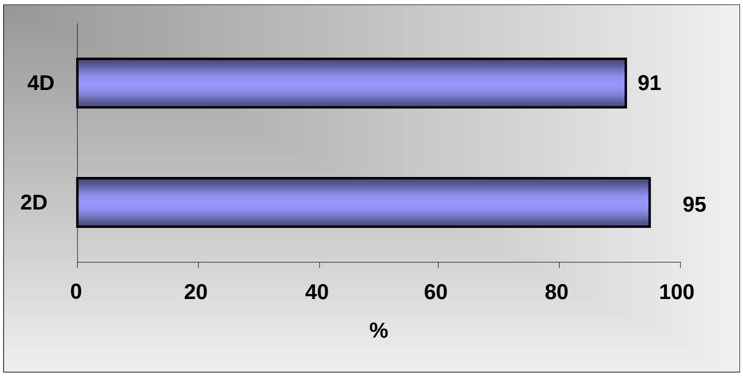

Figure 10: Average percentage of model completed (%)

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.

CONCLUSION

The experimental results provide valuable insights into the effectiveness of the 4D planning as an interpretative and communicative tool compared to 2D drawing approach. We observed during the experiments that 4D was assisting participants in interpreting and communicating information effectively with rest of the team members. Whereas, 2D participants were finding it difficult to interpret the drawing information clearly and were blindly following the drawing information to complete the physical model as compared to participants in 4D group.

The result illustrate that the 4D planning provides an additional value in understanding the construction process, as participants in 4D group were able to:

- Communicate efficiently among their group members.
- Easily evaluate and review the logic used in developing the sequence of construction activities.
- Assist in collaborative decision-making in constructing the physical model.
- Best use of information as compared to 2D group.

The future research activities will include:

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

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