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Evaluation of 4D CAD Approach as a Construction Communication Tool

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Abstract
Construction industry as one of the related fields of IT has proved information hungry in the latter day. The mere presence of different stakeholders and their specialized sets of skills and information in this field proves the significance of communication of information. The whole process of extraction, interpretation, and communication of information from drawings in general and in complex designs in particular is a time consuming process. 4D (four-dimensional) planning as an advanced visualization technology can be utilized in increasing the efficacy of information communication among construction team members. Although helpful in understanding and evaluating information, visualization has limited usage and is not fully explored. The main objective of this research is to measure the effectiveness of communicating construction information using 4D approch compared with the traditional 2D (two-dimensional) CAD approach. In this paper, we tried to conclude the extent to which information can be extracted and retained from 2D CAD compared to 4D CAD Model. For this purpose, a two-story house model were designed by Lego pieces. Participants in this experiment were selected from civil engineering students of University of Tehran and Iran University of Science and Technology. Half of the participants were supposed to build the house model by Lego pieces using the 2D plan and the other half using the 4D model. In both methods participants were working in groups as well as individually. The outcomes of the research revealed that all the participants outperformed using a 4D compared to a 2D model. Also it was concluded that the difference between 4D and 2D approaches can be more significant when a group participated in the experiments.

Keywords
2D CAD, 4D CAD, 4D CAD Planning, Visualization, Construction Communications Methods

1. Introduction

The uniqueness of each project makes construction a totally project oriented industry. Involving numerous stakeholders makes it inevitable to assume different objectives and expectations i.e. an architect's main concern is to reach its ideal aesthetics whereas in a construction manager's point of view

profitability comes first. This makes the application of visualization techniques essential to link schedule and design intent with schedule generation as an important part of construction planning process which is severally carried out all through the construction life. As Dawood and Sikka (2007) stated, scheduling is usually carried out in three steps:

- Interpretation of what has to be constructed on the basis of available information (design documents, 2D CAD drawings and 3D model).
- Identification of activities required to construct the project.
- Creating sequential relationship among the activities.

4D planning and scheduling technique that integrates 3D CAD models with construction activities has proven beneficial over the traditional tools. Less rework and improved productivity can be resulted from 4D models by visualization and analysis of sequential, spatial, and temporal aspects of construction schedules.

Songer et al. (2001) investigated the efficacy of using 3D and 4D technologies over 2D paper-based representations. In the first experiment the impact of 2D, 3D and walk-thru technologies on project schedule development was investigated. In the second experiment the superiority of 3D and walk-thru models in more complicated schedules were proven. Experimental results provide the quantitative evidence of the benefits of 3D/4D representation in terms of identifying missing activities, invalid relationships, and potential overcrowding issues during the schedule review process. The outcomes of a study conducted by Messner & Horman (2003) demonstrated the benefit of 4D as a planning tool in assisting students in understanding the intent of construction plan.

All the above mentioned studies and many other similar ones have been conducted to identify and analyze schedule errors, trade conflicts, missing activities, missing relationships, logic of sequencing and safety issues through a review of a CPM scheduler or 2D CAD drawings or 3D CAD models or through the analysis of a 4D model of a building project. Considering the described studies, an experiment was designed to test the effectiveness of a 4D model as a communicative tool compared with 2D paper-based drawing approach. For this purpose, civil engineering students who had basic knowledge of using 2D CAD drawings were selected to participate in the study. Details of the experiment and the results are presented in the next parts of the paper.

2. Research methodology

The participents which were randomly devided in to two groups were asked to construct the same model of a two-story house using Lego kit. The 2D participants used 2D CAD drawings describing the details of floor plans and sectional views. The 4D participants used a 4D model of the house for construction. The idea of using Lego kit for this experiemnt is taken from the work by Dawood and Sikka (2007). It is a suitable tool for this study because Lego bricks can be easily taken apart and reassembled. Lego bricks with different color and shapes also assist participants to identify its significance as building components. Figure 1 shows the model designed for this study.

Figure 1: Image of the Experiment Model

The Lego kit used in this experiment comprised of 82 different types of a total of 419 pieces. The present experiments have been conducted with 16 participants. They consisted of undergraduate and graduate students of civil engineering studying at University of Tehran and Iran University of Science and Technology. The participants were divided into 2 groups of 2D and 4D. In each group, two participants worked as a team and two students also participated in the experiment individually. Table 1 shows the number of participants in the experiment and their average age.

Table 1: Experiments and Participants Information

	Approach	2D	4D	Average Age
Number of participants	Individual	4	4	22.5
	Group	2(2)	2(2)	22.7
Total		8	8	22.6

3. Procedure for 2D participants

An instructor was appointed to monitor and facilitate the experimental exercise and also to make sure that the participants are competent enough to use CAD drawings and schedule. Following experiment accessories were used to conduct the experiment by 2D participants:

- Lego kit: Lego base plate and Lego bricks of walls, roof tiles, roof walls, beams, column, and other necessary pieces to build the model.
- 2D CAD drawings including plans for each row of bricks, elevation, and sections.
- Stop-watch was used to count the time spent by each group in interpreting the information from 2D CAD drawing given to them.

Two separate phases were assumed for the experiment:

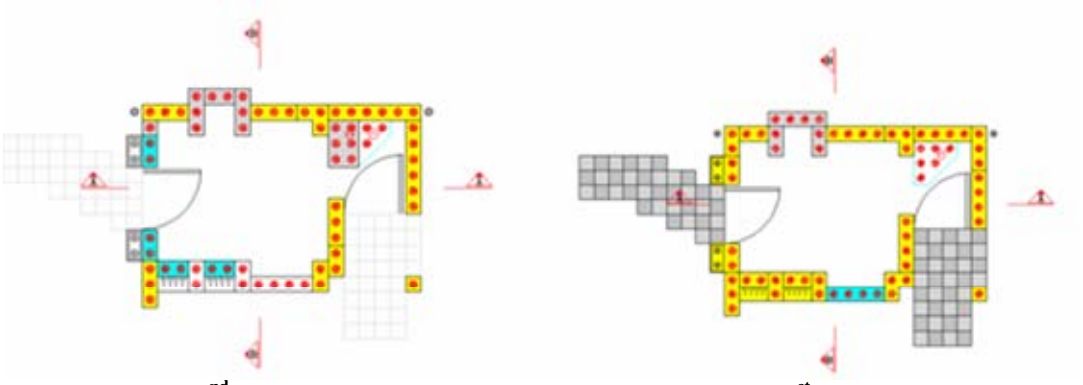
- In first phase, the instructor in each group briefly explained the whole procedure to the participants. This stage took not more than 5 minutes.
- In the second phase, participants tried to construct the physical model of the house, within time duration of 90 minutes. The participants had access to the drawings all thorough the second phase. Additionally, the participants' questions regarding the experiment were answered in detail during the second phase by the instructor. As it will be explained later in the paper, total number of questions answered to each group has been considered as one of the criteria for comparing the two approaches.

Figures 2 and 3 show all the details of floor plans and sectional views provided to the participants of the 2D group. Figure 4 shows two sample pictures of an individual and a group of two students working on the 2D experiment.

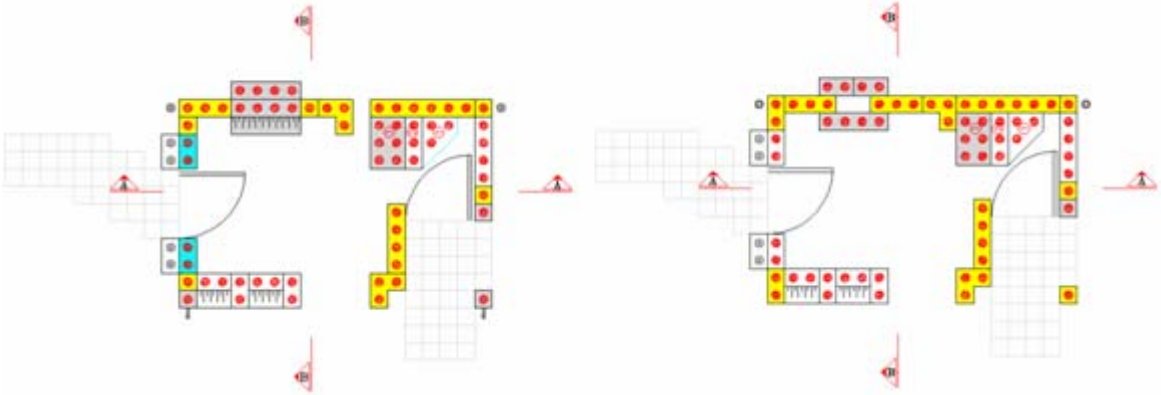
4. Procedure for 4D Participants

Just like the 2D experiment, general guidelines were provided to the 4D participants to make sure they were all familiar with the procedure of construction. Following experiment accessories were used to conduct the experiment with 4D participants:

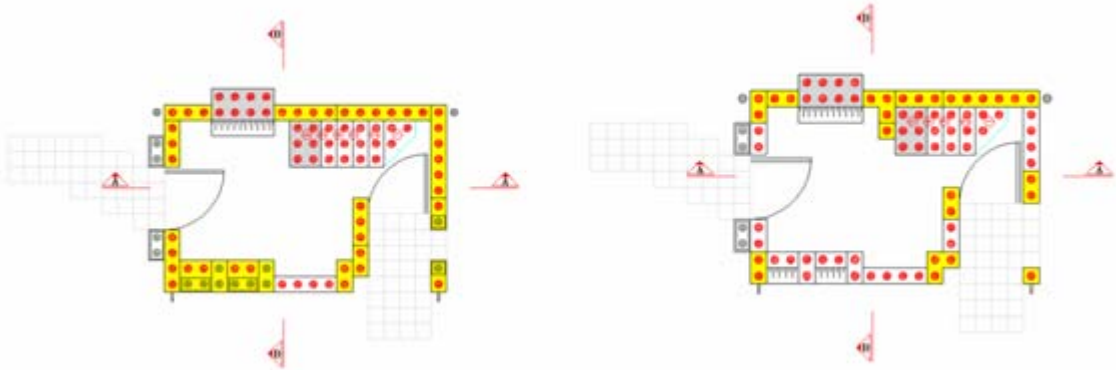
- Lego kit: Lego base plate and Lego bricks of walls, roof tiles, roof walls, beams, column, fence panel and fence post.
- Four Dimensional model of the house.
- A computer or laptop to run the 4D model.
- Stop-watch was used to record the time spent by the group in interpreting the information from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



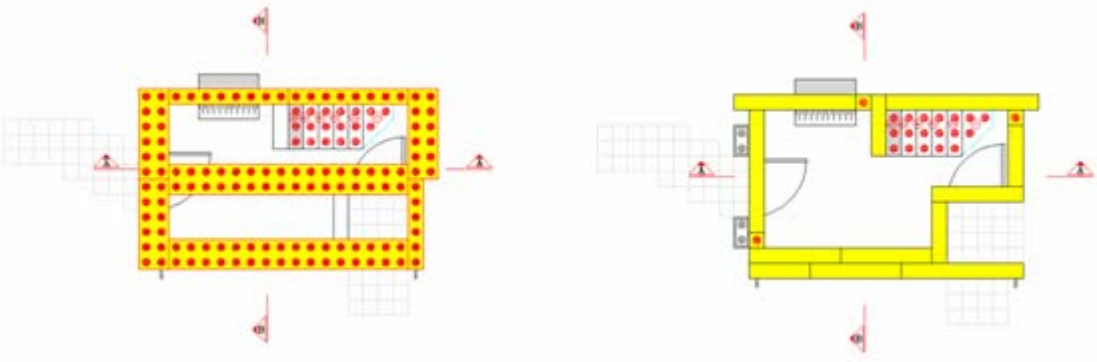
2nd level plan **1st level plan**



4th level plan **3rd level plan**



6th level plan **5th level plan**



8th level plan **7th level plan**

Figure 2: Eight First Floor Plans of the Experiment Model

Figure 3: Elevations and Sectional views of the Experiment Model

Figure 4: Sample Participants Constructing the Experiment Model by 2D drawings. (Left: Individual experiment, Right: Group experiment)

Similar to the 2D, the present experiment also composed of 2 stages:

- In the first stage the participants were presented with a general explanation of the task they were supposed to perform. Also, the 4D software was introduced to them. The main focus here was to make sure that they are competent enough to run the program and get the required information from it. This stage took around 5 minutes.
- In the second stage the participants were given 90 minutes to construct the physical model of the house using the Lego kit by referring to the software. Within the 90 minutes duration of construction of the house model, the participants could ask for more information and guidance and consequently were provided with more detailed information. It's worth noting here that both groups as well as the participants working individually had unlimited time to complete the construction. But their performance within the first 90 minutes is compared with the 2D group in this paper.

Figure 5 shows an individual and a group of two students working on the 4D experiment.

Figure 5: Sample Participants Constructing the Experiment Model by 4D Computer Software. (Left: Individual experiment, Right: Group experiment)

5. Experiment Results and Analysis

In the present work, performance of the participants had been evaluated on the basis of the following performance measures:

- percentage of the model constructed in 90 minutes,
- number of times further information was asked for,
- rebuilding (number of times the wrongly chosen Lego pieces were replaced with correct ones)

The 2D participants used 2D drawings describing the plans, elevations of the house showing the construction pieces installation, while the 4D participants used a 4D visualization model. As it can be seen in Figure 6, 4D participants succeeded to complete 98.3% of the physical model of the house as compared to 2D participants which managed to do 88.0% of the same task within the allotted duration of 90 minutes. As it can be seen the difference between the 4D and 2D results is higher when group of two have been working compared with the individually carried out experiences. The results in Figure 7 demonstrate 4D participants asked 2.33 times for more detailed information about the construction while the average number of times the 2D participants did so was 3.3 times.

As far as the rate of rebuilding is concerned, the average number of times 4D participants had reconstructed Lego bricks was 3.8 times while this figure for the 2D participants had been 5.5 times. The rate of reconstruction of the Lego bricks by 2D participants was 1.44 times more than 4D participants. This indicates that because 2D participants were unable to interpret the sequence in which the Lego bricks

had to be constructed used most of their time in rebuilding. 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 done. Same conclusion about the comparison between group and individual performances can also be made.

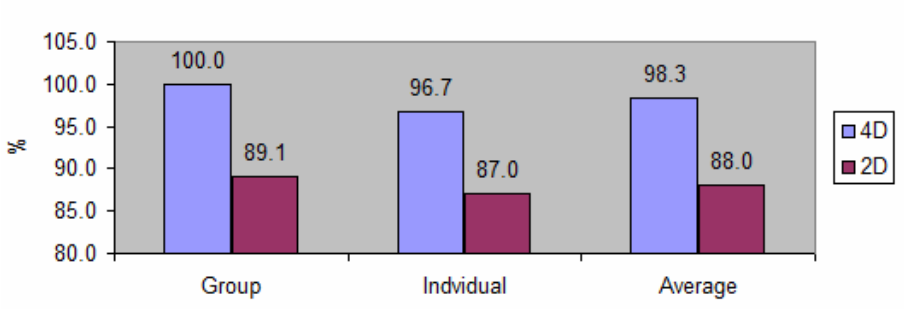


Figure 6: Average Percentage of Model Completed (%) within 90 Minutes.

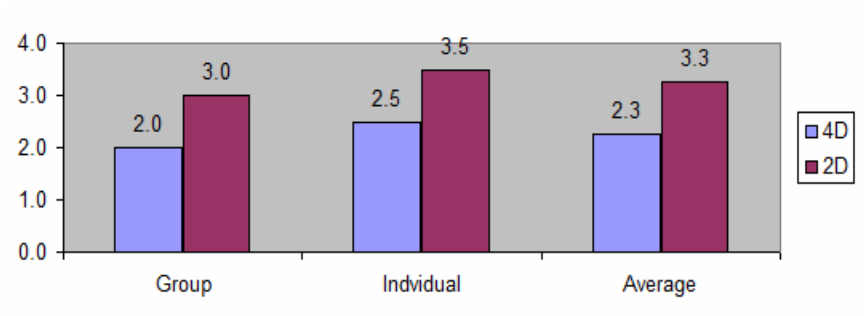


Figure 7: Average Number of Times Asked for More Detailed Information.

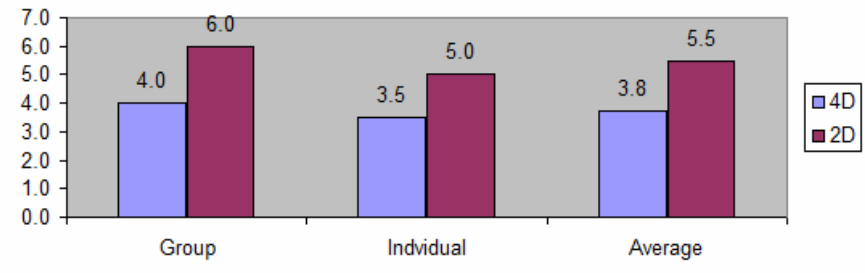


Figure 8: Average Number of Times Bricks Were Reconstructed.

6. Conclusions

Based on the outcomes of this study, 4D has been proved to be more efficient compared with 2D approach based on all different criteria which have been used in this study. 4D approach is helpful in understanding concepts, interpreting information, and communicating it effectively among constructors. 4D participants had opportunity to rehearse the sequence of construction by looking back at what they had constructed and evaluating what they will be constructing. Consequently, they managed to save much time by avoiding rebuilding. Unlike the 4D participants, 2D participants had difficulty interpreting the drawing information.

Overall, 4D participants out perform 2D ones by constructing on an average 11.4% faster the physical model, requested on an average 41% less times to have access to detailed information and reconstructed on an average 44% Lego bricks compared to the 2D participants. More over in all experiments, participants working in groups had better performance compared to those working individually. The future research activities can include:

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

7. Acknowledgments

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