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

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SUMMARY: 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 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 of different age groups (11 to above 22 years) and profiles. Participants had been divided in two groups (2D & 4D). 2D group used 2D CAD drawings describing the plans, elevation and sectional drawings, and a bar chart showing the construction schedule. While 4D group used a detailed 4D model of the house showing the construction sequence. Participants in both groups are required to construct the same physical model of the house using a Lego kit (423 pieces) 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 pieces compare to 2D group. Participants in 4D group were able to communicate and coordinate better as compared to participants in 2D group. It can be concluded from the experiments that percentage of physical model completed is directly related to the time spent in understanding the building information and number of times Lego pieces were reconstructed. It implies that the participants with good leadership style when coupled with 4D technology can understood the building information clearly and has constructed the physical model faster and thereby reducing the number of times rework required to construct the Lego pieces.

KEYWORDS: communication, 2D CAD, 4D planning, visualisation, Lego pieces.

1. INTRODUCTION

4D planning is a technique that integrates 3D CAD models with construction activities (schedule) which enables clear visualisation of a construction programme as an animated sequence. 4D model assists project participants to 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 stakeholders, 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 exercises 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 (IVE). 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. Dawood et.al (2005) has developed a strategic decision support system (VIRtual CONstruction - VIRCON) for practical use to manage construction schedules, and in particular space planning. The VIRCON system allows planners to trade off the temporal sequencing of tasks with their spatial distribution, resulting in a more robust and rehearsed project schedule. Also, the VIRCON visualisation tools allow planners to better understand construction schedules through 4D (3D plus time) simulation and ability to visualise congestions and hot execution spaces on sites. 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 research work 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 did not consider 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 of a house 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 four different age groups.

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 as shown in Figure 1 (consist of 423 Lego pieces) in an allotted duration of two hours. The participants were divided into two groups, 2D & 4D groups. Participants in 2D group, used 2D CAD drawings describing the plans, elevation and section, and a bar chart showing the construction schedule. Participants in 2D group had to 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 4D model of the house to visualise the construction sequence. Both the groups were given the same house model to be constructed.

FIG. 1: Lego House Model

The number of participants involved and number of experiments conducted is shown in table 1.

Table1: Summary of Experiments Performed with Different Groups

Groups Involved	Total Number of Participants		Number of Experiments Performed	
	2D	4D	2D	4D
1. School students (11 – 15 yrs)	12	12	6	6
2. GCSE Achieved Students (15 – 18 yrs)	12	12	6	6
3. Engineering Graduates Students (18 – 22 yrs)	12	12	6	6
4. Industry Professionals (Above 22 yrs)	6	6	3	3
Total	**42**	**42**	**21**	**21**

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

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

The experiments have been conducted with participants in four different age groups (11 to above 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 processes and CAD drawings.
- GCSE Achieved Students (15 – 18 yrs) - Participants in this group have a moderate knowledge about the construction processes and CAD drawings.
- Construction Engineering Graduate Students (18 – 22 yrs) - Participants in this group have a moderate to strong knowledge about the construction processes and CAD drawings.
- Industry Professionals (Above 22 yrs) - Participants in this group have a strong knowledge and experience about the construction processes and CAD drawings.

Each group (2D & 4D) comprised of two participants. 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* rated as 0.3 (95% confidence interval) which was measured 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.

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 the instructor to brief the team regarding their objectives, role and task to be performed. Due emphasise was led on to make sure that participants become familiarise with CAD drawings and schedule.

Accessories used to conduct 2D experiments were:

- Lego kit: Lego base plate and Lego pieces of walls, roof tiles, roof walls, beams, column, fence panel and fence post.
- Two Dimensional CAD drawings of the house model (i.e. 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 drawings.

Experiment was designed in two stages.

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

After duration of fifteen minutes the CAD 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 pieces had to be assembled.
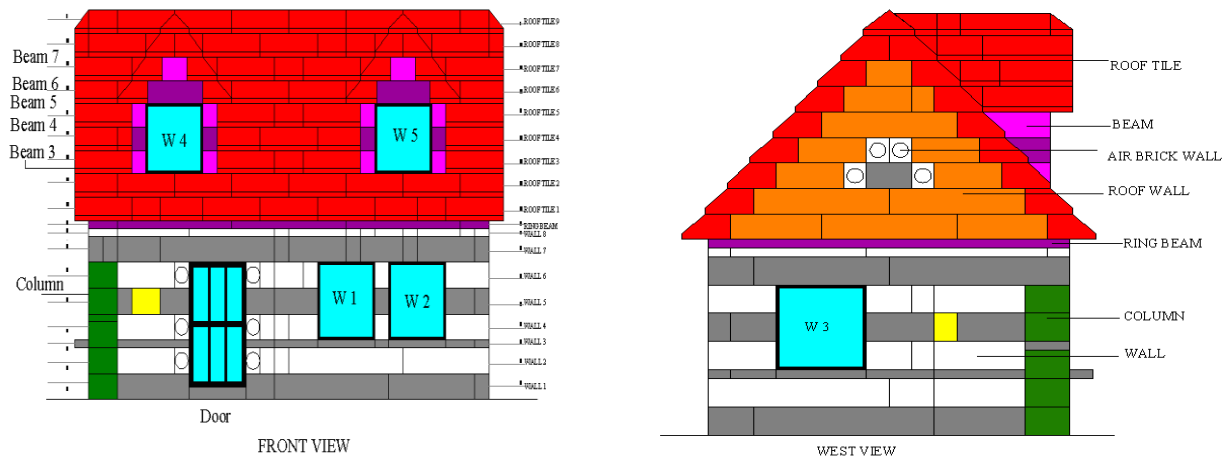
FIG. 2: Front and West View of Lego House Model

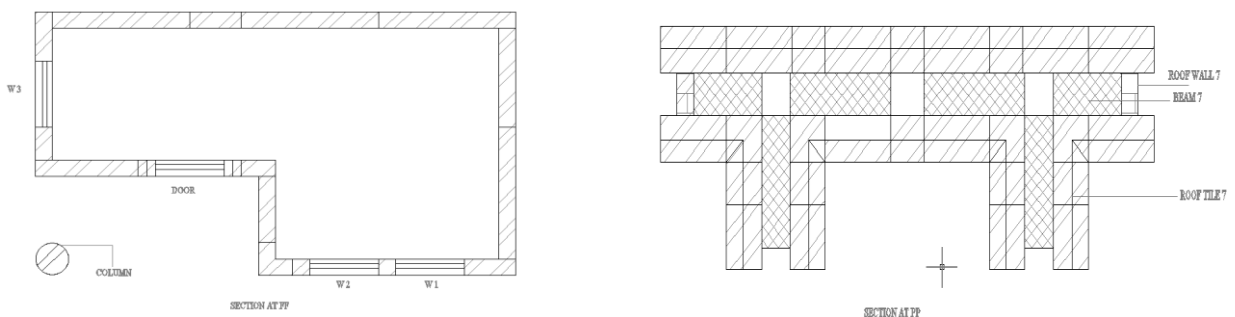*FIG. 3:Two examples of horizontal sections of the Lego House Model, section FF was taken at the lower part of the house and section PP was taken at the upper section of the roof.*

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 (see appendix).

4. EXPERIMENT PROCEDURE FOR 4D GROUP

An instructor was appointed to monitor and to facilitate the experimental exercise. A power point presentation was used by the instructor to brief the team regarding their objectives, role and task to be performed. A due emphasise was given to make it sure that they become familiarise with 4D software. Accessories required to conduct 4D experiments are:

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

Experiment was designed into 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. A time frame of fifteen minutes was allotted in the first stage 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.

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. Figure 4 & 5 show participants constructing the physical model of house using the Lego pieces (see appendix). Participants could request to have an access to 4D model to review the sequence in which the Lego pieces had to be assembled.
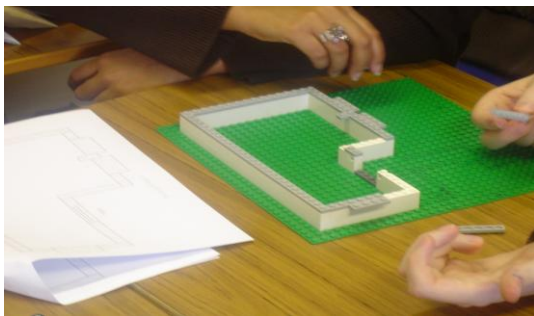

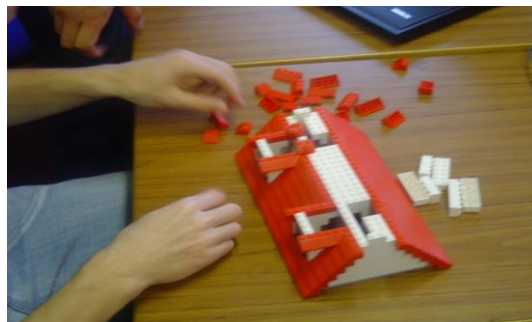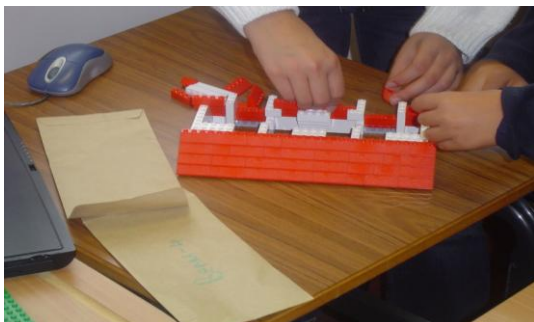FIG. 4: Step-by-Step Assembly of Lower Part of House Model

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

5. EXPERIMENT RESULTS AND ANALYSIS

The performance of the participants was investigated through the evaluation of the following four performance measures:

- Percentage of model completed (%)
- Number of times information accessed during the session of two hrs
- Total time spent on understanding building information (Minutes)

- Number of times Lego pieces were reconstructed

A due consideration had been given to investigate the difference of the performance between two identical human groups involved by using two different graphic representations. There are various reasons for a one group to outperform the other by completing the experiments well before the given duration. One prominent reason that participant in a particular group is more experienced than other group. So, in order to avoid this variability the participant had been divided in each group by keeping the above constraint.

5.1 Analysis of Experiments for School Students (11 to 15 years)

The objective of the experiment was to evaluate how much information participants were able to retain in their mind from the two different graphical representations (2D CAD drawings & 4D model) shown to them. This section analyse the outcomes of the experiments conducted with school students in the age group of 11 to 15 years. The results described in Figure 6 shows that 4D group were able to complete 81% of physical model of the house as compared to 2D group which were able to construct only 74% of physical model within an allotted duration of two hours.
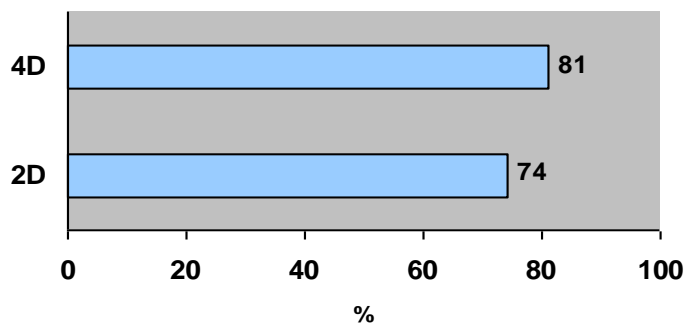
FIG. 6: Average percentage of model completed (%)

2D group were unable to complete their model because they spent most of their time in reconstructing the Lego pieces as compared to 4D group. The rate of reconstruction of Lego pieces by 2D group were 1.8 times more than 4D group.

The results described in Figure 7 show that the 4D group requested 26 times to have an access to information as compared to 21 times request made by 2D group. It is evident that though the 4D group requested more times to have an access to 4D model but they spent less time in interpreting the information from 4D model.
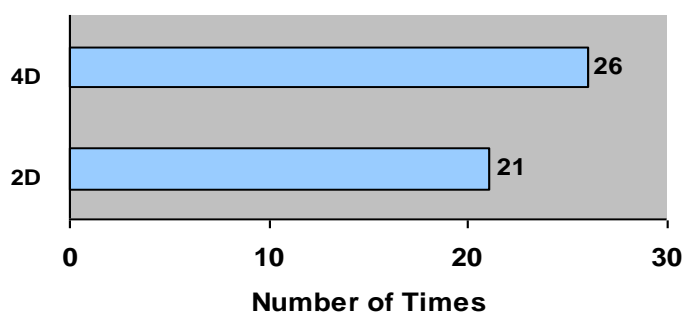

FIG. 7: Average number of times information accessed

The results described in Figure 8 show that the 4D group had spent 27 minutes in interpreting information provided to them as compared to 33 minutes spent by 2D group. As a result 2D group spent 28% of their time in evaluating the information from the 2D CAD drawings and rest 72% of their time in constructing the model. Where as, 4D group spent 23% of their time in evaluating the information from the 4D model and rest 77% of

their time in constructing the model. This implies that 2D group spent 22% of more time in interpreting information from 2D CAD drawings as compared to 4D group.
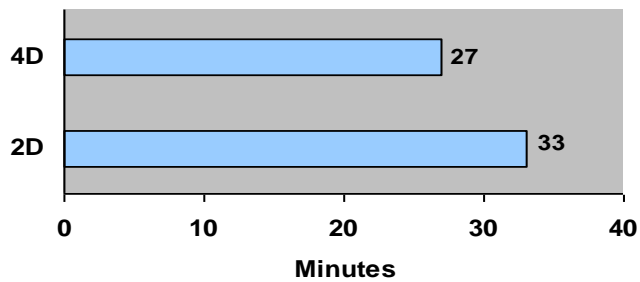

FIG.8: Average time spent in understanding building information (Minutes)

The results described in Figure 9 show that 4D group had reconstructed the Lego pieces 90 times as compared to 159 times constructed by 2D group. The rate of reconstruction of Lego pieces by 2D group were 1.8 times more than 4D group. This indicates that the 2D group spent most of their time in reconstructing the Lego pieces and as a result they were only able to construct 74% of their model in an allotted duration of two hours.
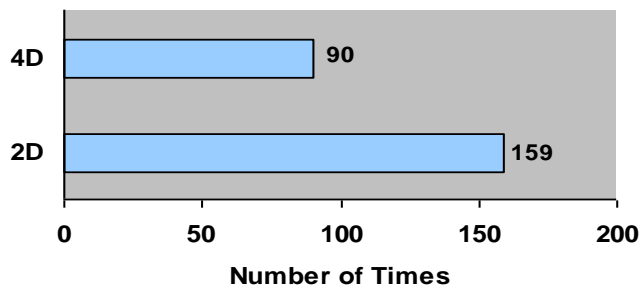
FIG.9: Average number of times Lego pieces were reconstructed

It is evident from the Figure 9 that 4D model helped participants in collaborative decision-making and communicating efficiently among group members to construct the physical model. Figure 10 show a comparative analysis between the performances of 2D and 4D group in the age group of 11 to 15 years.
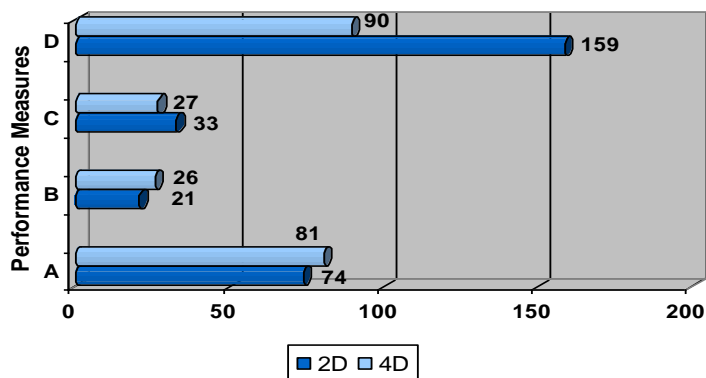
Where, A= Percentage of model completed (%), B = Number of times information accessed during the session of two hrs, C = Total time spent on understanding building information (Minutes) and D = Number of times Lego pieces were reconstructed

FIG.10: Comparative performance analysis for participants in age group of 11 to 15 years

Following conclusions can be drawn from the experiments performed with participants in the age group of 11 to 15 years:

- 4D group were able to construct on an average 81% of the physical model of the house as compared to 74% of model constructed by 2D group in an allotted duration of 2 hours.
- 4D group had requested 26 times to get an access to 4D models as compared to 21 times request made by 2D group to get an access to drawing information.
- 4D group had spent 33 minutes in extracting information form 4D models as compared to 28 minutes spent by 2D group in extracting information from drawings.
- 4D group had reconstructed 90 times Lego pieces as compared to 159 times Lego pieces reconstructed by 2D group.

4D group performed better than 2D group by constructing 9% faster physical model, spent 23% less time in extracting information from 4D model and reconstructed 77% less Lego pieces compared to 2D group.

5.2 Analysis of 4D Experiments for GCSE Students (15 to 18 Yrs)

This section analyses the outcomes of the experiments conducted with school students in the age group of 15 to 18 years. The results described in Figure 11 show that 4D group were able to complete 95% of physical model of the house as compared to 2D group which were able to construct only 91% of physical model within the allotted duration of two hours.
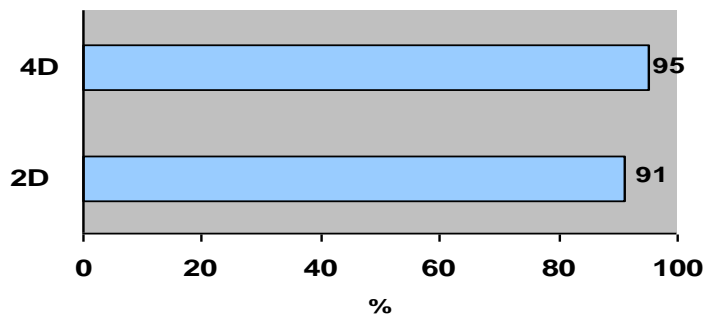

FIG.11: Average percentage of model completed (%)

During the experiment most of the time 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 12 show that 4D group has requested 20 times to have an access to information as compared to 22 times request made by 2D group. It is evident from Figure 12 that though the 2D group requested more times to have an access to drawing information to understand the sequence of construction activities.
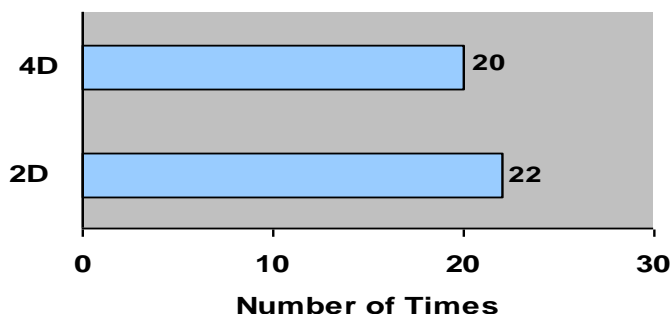

FIG.12: Average number of times information accessed

The results described in Figure 13 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 4D model.
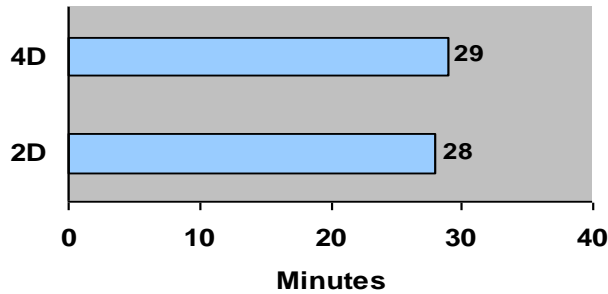
FIG.13: Average time spent on understanding building information (Minutes)

The results described in Figure 14 show that the 4D group had reconstructed the Lego pieces 48 times as compared to 68 times done by 2D group. The rate of reconstruction of Lego pieces 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 pieces because they were finding it difficult to interpret the sequence in which Lego pieces had to be constructed.
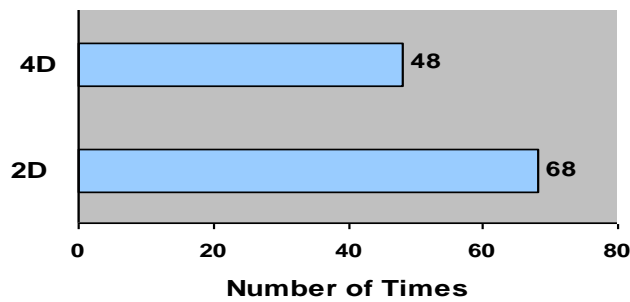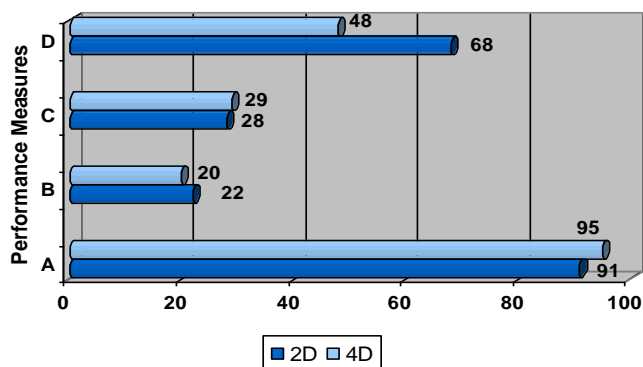

FIG.14: Average number of times Lego pieces were reconstructed

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

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 pieces were reconstructed

FIG.15: Comparative performance analysis for participants in the age group of 15 to 18 years

Following conclusions can be drawn from the experiments performed with participants in the age group of 15 to 18 years:

- 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 20 times to get an access to 4D models as compared to 22 times request made by 2D group to get an access to drawing information.
- 4D group had spent 29 minutes in extracting information form 4D models as compared to 28 minutes spent by 2D group in extracting information from drawings.
- 4D group had reconstructed 48 times Lego pieces as compared to 68 times Lego pieces reconstructed by 2D group.

4D group performed better than 2D group by constructing 4% faster physical model and reconstructed 37% less Lego pieces compared to 2D group.

5.3 Analysis of 4D Experiments for Engineering Graduate Students (18 to 22 Yrs)

This section describes the outcomes of the experiments conducted with engineering graduate students in the age group of 18 to 22 years. The results described in Figure 16 show that the 4D group were able to complete 86% of physical model of the house as compared to 2D group which were able to construct 78% of physical model.
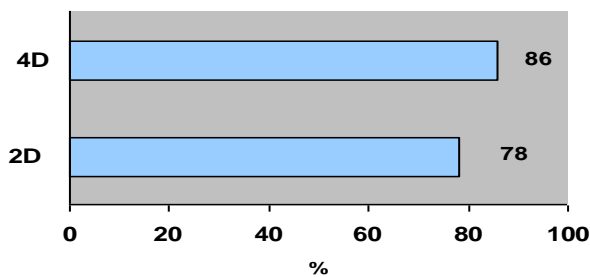

FIG.16: Average percentage of model completed (%)

The results described in Figure 17 show that the 4D group had requested 20 times to have an access to information as compared to 26 times request made by 2D group. Visualisation of 4D model assisted the participants to easily evaluate and review the logic used in developing the sequence of construction activities.
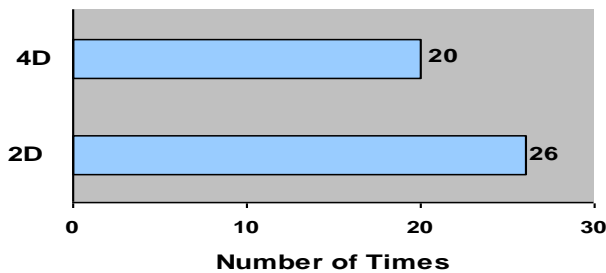

FIG.17: Average number of times information accessed

The results described in Figure 18 show that the 2D group had spent 26 minutes in understanding the information provided to them as compared to 27 minutes spent by 4D group. As a result 2D group spent 21% of their time in evaluating the information from the 2D CAD drawings and rest 79% of their time in constructing the model. Where as, 4D group spent 22% of their time in evaluating the information from the 4D model and rest 78% of their time in constructing the model.
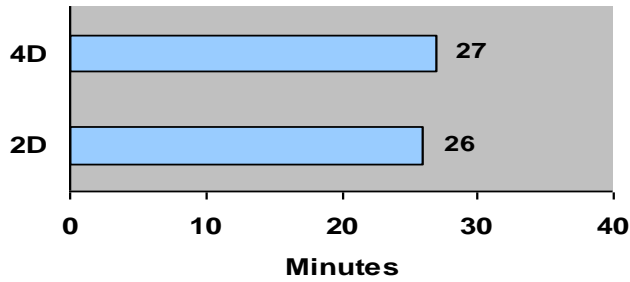
FIG.18: Average time spent on understanding building information (Minutes)

The results described in Figure 19 show that the 4D group had reconstructed the Lego pieces 36 times as compared to 62 times reconstructed by 2D group. The rate of reconstruction of Lego pieces by 2D group were 1.7 times more than 4D group. As a result 2D group were able to complete only 78% of their physical model in an allotted duration of two hours.
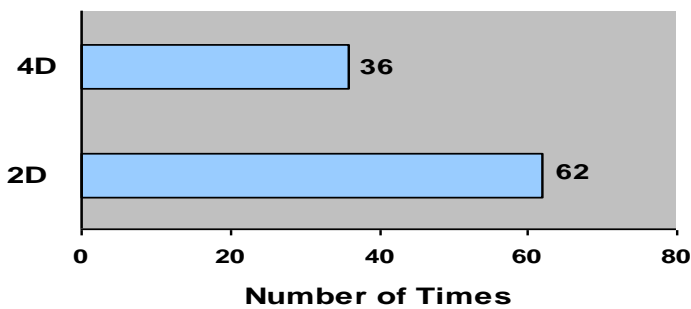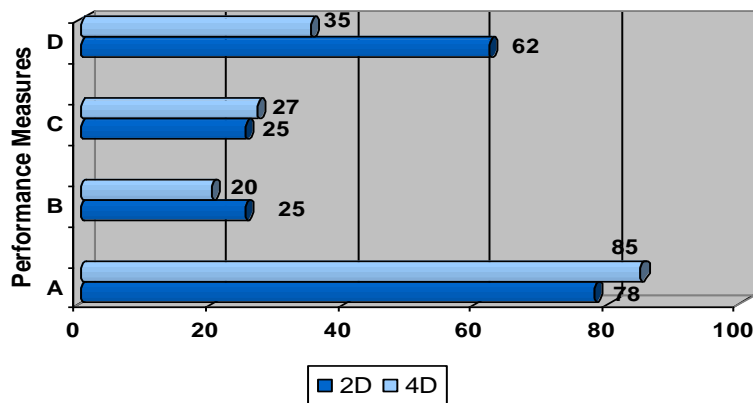

FIG.19: Average number of times Lego pieces were reconstructed

Figure 20 show a comparative analysis between the average performances of 2D and 4D group in the age group of 18 to 21 years.

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 pieces were reconstructed

FIG.20: Comparative performance analysis for participants in the age group of 18 to 21 years

Following conclusions can be drawn from the experiments performed with participants in the age group of 18 to 21 years:

- 4D group were able to construct on an average 85% of the physical model of the house as compared to 78% of model constructed by 2D group in an allotted duration of 2 hours.
- 4D group had requested 20 times to get an access to 4D models as compared to 25 times request

- made by 2D group to get an access to drawing information.
- 4D group had spent 27 minutes in extracting information form 4D models as compared to 25 minutes spent by 2D group in extracting information from drawings.
- 4D group had reconstructed 35 times Lego pieces as compared to 62 times Lego pieces reconstructed by 2D group.

4D group performed better than 2D group by constructing 7% faster physical model, requested 25% less times to have an access to 4D model and reconstructed 77% less Lego pieces compared to 2D group.

5.4 Analysis of 4D Experiments for Industry Professionals (Above 22 Yrs)

This section describes the outcomes of the experiments conducted with industry professionals. The results described in Figure 21 show that the 4D group were able to complete 100% of physical model of the house as compared to 2D group which were able to construct 80% of physical model during the allotted duration of two hours. We had concluded during the experiments that the level of experience and knowledge plays a vital role in understanding or extracting the information from the given graphical representation formats (CAD drawings or 4D model).
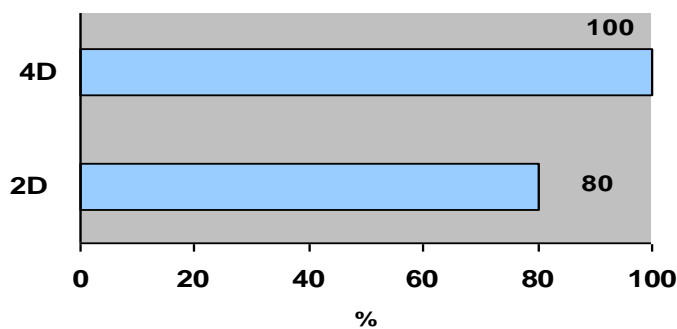

FIG.21: Average percentage of model completed (%)

Participants had used 4D model as a visualisation and communicative tool to evaluate the right sequencing of key Lego components (based on their shapes) to speedily construct the physical model.

The results described in Figure 22 show that the 4D group has requested 22 times to have an access to information, whereas 2D group has requested 40 times. 4D group have kept the number of times request made for information down by retaining as much as information while rehearsing the 4D model. 2D group were finding it difficult to extract the information from the 2D CAD drawings and as a consequence they have requested 1.8 times more than the 4D group to get an access to information.
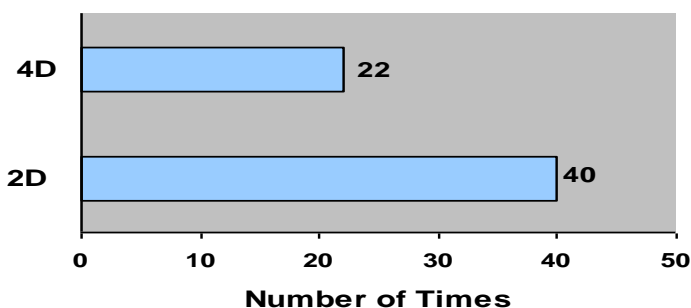

FIG.22: Average number of times information accessed

The results described in Figure 23 show that the 4D group has spent 14 minutes in understanding the information provided to them as compared to 22 minutes spent by the 2D group. 4D group has spent 14% of time in evaluating the information from the 4D model and rest 86% of time in constructing the model. Where as, 2D group has spent 22% of time in evaluating the information from the 2D CAD drawings and rest 78% of time in

constructing the model. 2D group had spent more time in evaluating the information from drawing was mainly because they were finding it difficult to interpret the sequence in which Lego pieces had to be assembled.
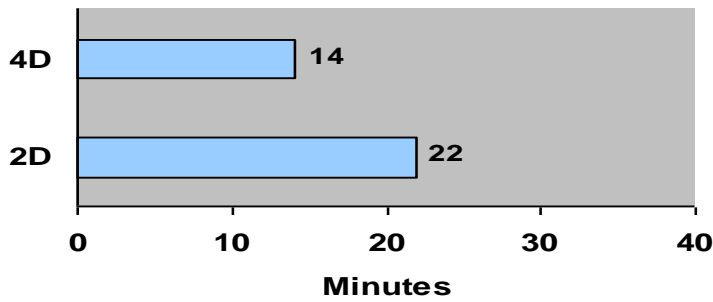

FIG.23: Average time spent on understanding building information (Minutes)

The results described in Figure 24 show that the 4D group had reconstructed the Lego pieces 20 times as compared to 25 times reconstructed by 2D group. The rate of reconstruction of Lego pieces by 2D group were 1.25 times more than 4D group. As a result 2D group were able to complete only 80% of their model in an allotted duration of two hours. We have associated the reconstruction of Lego pieces with the rework while analysing the outcomes of these experiments. In this case, rework is arising mainly because the participants were unable to understand the sequence in which the Lego pieces had to be assembled.
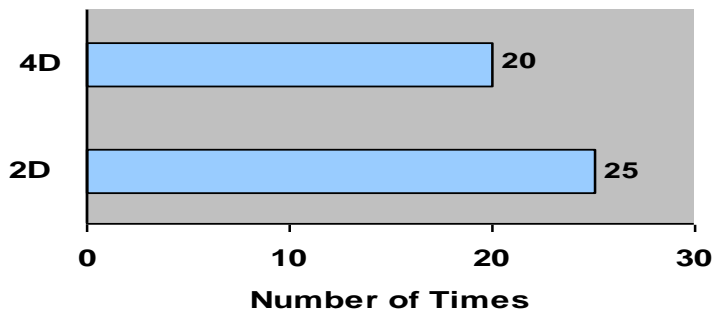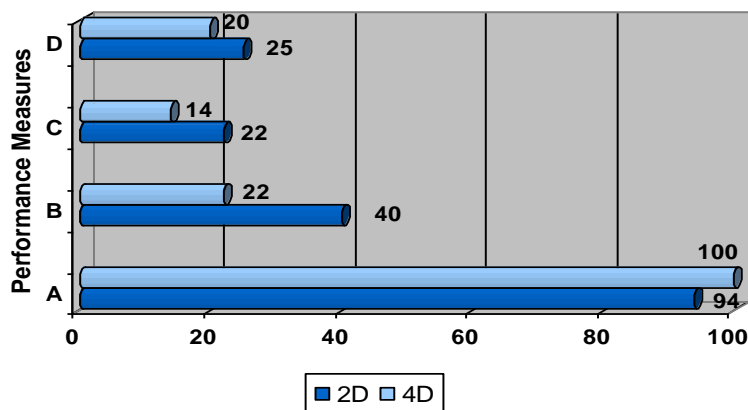

FIG.24: Average number of times Lego pieces were reconstructed

Figure 25 show a comparative analysis between the performances of 2D and 4D group in the age group above 21 years.

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 pieces were reconstructed

FIG.25: Comparative performance analysis for participants in the age group above 22 years

Following conclusions can be drawn from the experiments performed with participants in the age group above 22 years:

- 4D group were able to construct on an average 100% of the physical model of the house as compared to 80% of model constructed by 2D group in an allotted duration of 2 hours.
- 4D group had requested 22 times to get an access to 4D models as compared to 40 times request made by 2D group to get an access to drawing information.
- 4D group had spent 14 minutes in extracting information form 4D models as compared to 22 minutes spent by 2D group in extracting information from drawings.
- 4D group had reconstructed 20 times Lego pieces as compared to 25 times Lego pieces reconstructed by 2D group.

4D group performed better than 2D group by constructing 16% more physical model, spent 57% less time in extracting information from 4D model and reconstructed 25% less Lego pieces compared to 2D group.

6. GENERAL DISCUSSION

Figure 26 shows a comparative analysis between the average performances of school students, GCSE students, graduate students and industry professionals in the 2D group. The result illustrated in Figure 26 show that GCSE students outperformed the rest of the groups by constructing 91 % of physical model of the house in an allotted duration of 2hrs. School students outperformed the rest of the groups by requesting fewer times to have an access to drawing information. Where as graduate students outperformed the rest of the groups by spending less time in interpreting the drawing information. Industry professional outperformed the rest of the groups by reconstructing fewer number of Lego pieces.
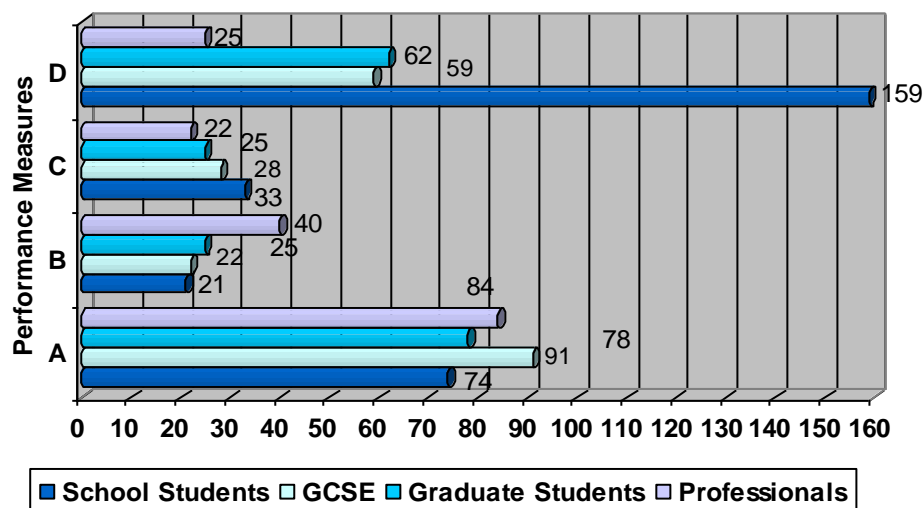
Where, A= Percentage of model completed (%), B = Number of times information accessed during the session of two hrs, C = Total time spent on understanding building information (Minutes) and D = Number of times Lego pieces were reconstructed

FIG.26: Comparative performance analysis for 2D groups

The result illustrated in Figure 27 show a comparative analysis between the average performances of school students, GCSE students, graduate students and industry professionals in the 4D group. Figure 27 show that industry professionals outperformed the rest of the groups by constructing the physical model of the house in an allotted duration of 2hrs. GCSE students outperformed the rest of the groups by requesting fewer times to have an access to computer model. Industry professionals outperformed the rest of the groups by spending less time in interpreting the information from computer model and by reconstructing fewer number of Lego pieces.

The percentage of physical model completed by each group depends upon the time spent in extracting the building information and the time taken for reconstruction of Lego pieces.

The main reasons for the frequent reconstruction of Lego pieces by 2D participants are mainly because they were not able to understand the construction sequence logic in which the Lego pieces have to be assembled and

they have focused more on 2D drawings and gave little or no consideration to the plan presented as a Gantt-chart. As a consequence they were not able to understand the interrelationships between different construction activities. This has resulted to the wrong interpretation of the plans and consequently mistakes in placing the Lego brick. As a consequence this has led to a more reconstruction of the Lego bricks.

On an average the 2D participants have taken more time in extracting information from 2D CAD drawings as compared with the 4D group. This is mainly because they have to interrelate different views (plan & elevation) of drawings to develop a mantle image of the components present at each level of the house model and then participants had to link the activity represented in the bar-chart with the image developed in their minds to understand the logical construction sequence in which the Lego pieces had to be assembled. Each participant has his own ability to interpret and communicate the drawing information on the basis of his skill set. As a consequence they required more time to communicate the information to each other. This is a very important function of the 4D planning in which communications can be vastly improved.

The participants in the 4D groups had an advantage of rehearsing the sequence of construction of Lego pieces by evaluating what they have already constructed and what they will be constructing. This process of looking back and forward in the timeline provided them a bundle of confidence in constructing the model and eventually they were able to save lot of their time by avoiding the reconstruction of Lego bricks and sharing the information among each others.
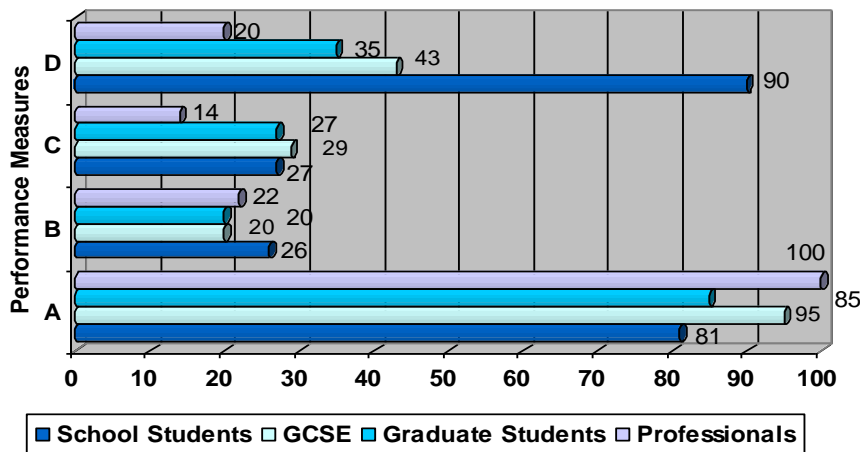
Where, A= Percentage of model completed (%), B = Number of times information accessed during the session of two hrs, C = Total time spent on understanding building information (Minutes) and D = Number of times Lego pieces were reconstructed

FIG.27: Comparative performance analysis for 4D groups

7. CONCLUSION

Participants responded that experimental exercise assisted them to develop skills and knowledge that could not be understood using two-dimensional drawings. Participants provided a positive feedback regarding the computer model approach and suggested to implement this approach as an interactive educational tool in classrooms. Outcomes of 4D experimental exercise provides valuable insights into the effectiveness of 4D planning as a communicative tool compare to 2D drawing approach. 4D model assisted participants in interpreting and effectively communicating information with team members. 4D also assisted participants in collaborative decision-making and understanding the logical sequencing of construction activities. Whereas, 2D participants were finding it difficult to interpret the drawing information compare to 4D group.

Following are the overall outcomes of the experiments irrespective of the age group of the participants:

- 4D group were able to construct on an average 89% of the physical model of the house as compared to 82% of model constructed by 2D group in an allotted duration of two hours.
- 4D group had requested on an average 22 times to get an access to 4D models as compared to on an average 25 times request made by 2D group to get an access to drawing information.
- 4D group had spent on an average 26 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 51 times Lego pieces as compared to on an average 85 times Lego pieces reconstructed by 2D 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 pieces compared to 2D group. In conclusion, this research work has provided evidence that the utilisation of 4D planning can assist in improving the construction processes by effectively communicating construction information of product and processes among construction team members. This will provide a bundle of confidence in the plans and consequently in the delivery of such plans.

8. ACKNOWLEDGEMENTS

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10. APPENDIX 1
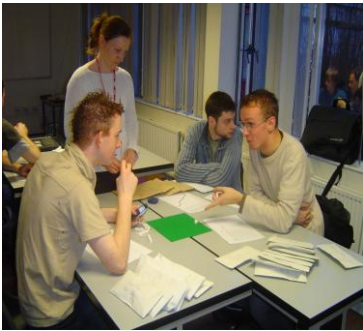
2D Participants in Action

4D Participants in Action