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Real-time collaborative participation feedback for F2F-CSCW

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Abel Maciel, Artemis Skarlatidou, James Tompkin, Patrick Weber

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Recent studies [14,21,22,23,24] have explored the possible benefit of participation feedback to computer supported collaborative working. We attempt to further knowledge in this field by using a multi-touch surface computer to track task-specific input and provide real-time participation feedback. We perform an experiment using a collaborative version of the board game Carcassonne. As well as describing the background, methodology, results and conclusions to our experiment, this document also describes the research, design and construction of the multi-touch surface and all attached software.

Contents

1.0 Introduction

Collaboration is a structured, recursive process where two or more people work together toward a common goal—typically an intellectual endeavour [26] [27] that is creative in nature [28]—by sharing knowledge, learning and building consensus. Collaboration does not require leadership and can sometimes bring better results through decentralization and egalitarianism [29]. In particular, teams that work collaboratively can obtain greater resources, recognition and reward when facing competition for finite resources [30].

However, collaboration problems can be seen in both small- and large-scale projects, across all skill levels; from the construction industry to the software industry to academia (even including doctoral student group projects). Inefficiencies can be prohibitively high and make a project economically unviable, leading to project discontinuation.

Structured methods of collaboration encourage introspection of behaviour and communication [29]. These methods specifically aim to increase the success of teams as they engage in collaborative problem solving. Forms, rubrics, charts and graphs are useful in these situations to objectively document personal traits with the goal of improving performance in current and future projects.

Recent work [14,22,23,24] has highlighted the possible benefit to the collaborative process of real-time collaboration analysis. Specifically, we concentrate on participation as part of the collaborative process. Studies have shown both promising and significant results suggesting that visualisation of participation can aid the collaborative process itself. This aid manifests itself in many ways: as greater performance, as more equal levels of participation, or as greater satisfaction of individual participants in the collaborative process.

However, such studies are presented with a problem: task-specific actions (and their corresponding metrics) are often hard to define and time-consuming to track. We investigate use of a tracked interaction environment (namely, a multi-touch surface computer) to better understand: a) the process of interaction in such an environment on participation, and b) how table interaction relates to more traditional measures of participation (e.g., speaking time).

As multi-touch surface computers are uncommon and not commercially available, we designed and built one. We identified a suitable task for experimentation (the board game Carcassonne) and modified it accordingly for our collaborative participation investigation. We then conducted an experiment using the table, task, and 40 people to try to answer five hypotheses. The report proceeds as follows:

- Chapter 2 conducts a literature review of collaboration, computer supported collaborative work, participation studies, and finally recent table computing studies.
- Chapter 3 outlines the process of finding a suitable task, along with justification for the modifications made to the game.
- Chapter 4 describes the hypotheses and methodology for our experiment, outlining the requirements for and data necessary from our table.
- Chapter 5 explains the design and construction processes of the multi-touch table along with all associated software. This includes the implementation of the game.
- Chapter 6 details our experimental data analysis and attempts to answer our hypotheses.
- Chapter 7 discusses the table and the experiment; explaining pitfalls, oversights and failings.
- Chapter 8 concludes and presents possible areas for future work.

2.0 Background

2.1 Computer-Supported Collaborative/Cooperative Work (CSCW)

There is an extensive body of literature describing computer-supported activities and how they can enhance learning, problem solving, communication and other skills simultaneously in a group of people, not only for promoting the decision-making outcomes but also for coordinating and improving the decision-making process. In several studies, tabletop displays were investigated as such computerised tools which can support and guide the activities of collaborating individuals.

Before further describe some of the studies explored the use of such interactive – or not – tabletop displays, it is important to briefly review some examples from Computer-Supported Collaborative/Cooperative Work (CSCW) in small or larger groups of people. In fact, many researchers call this area "Computer Supported Cooperative World" and they suggest that it includes *"all contexts in which technology is used to mediate human activities such as communication, coordination, cooperation, competition, entertainment, games, art, and music"* [2]. Therefore, CSCW shifted the focus from the traditional man-machine approach to group-machine or better to person-to-person activities.

CSCW covers a wide area of mechanisms and technologies such as electronic mails, online shared displays, conferencing systems, shared whiteboards, tabletop displays and many others. The choice of the medium is an important decision as it can affect the collaborative task and the effort of the collaborating individuals. As for example, Clark and Brennan discussed extensively the idea of costs and constraints that different media can impose on grounding in communication [3].

Gutwin and Greenberg present an interesting taxonomy of some collaborative situations in an attempt to introduce the importance of workspace awareness [4]. Their taxonomy provides a different description of the traditional media-based collaboration and distinguishes the constraints of collaboration based on:

1. The environment ("*shared workspaces"*);
2. The systems (*"real-time distributed groupware"*);
3. The tasks (*"generation and execution"*) and finally
4. The groups ("small groups and mixed-focus collaboration).

They further suggest that *"Within these boundaries, a rich variety of small-group collaboration is possible"* [4].

It should be clear by now, that the two most important factors which differentiate current CSCW research are time and space [5]. Internet was an essential - if not the controlling - factor which influenced and empowered remote collaboration. In a sense, the increasing popularity and use of Internet, not only by individuals but also by industry and academia, might be the driving wheel of that area of research. More and more companies use intranet and other online collaborative tools for communication and other purposes with a focus on the increase of productivity and the diminution of costs. However, Distributed CSCW (D-CSCW) can differ significantly from the so called face-to-face (F2F) collaboration. In F2F collaboration, conversation and thus communication is direct and therefore there are more possibilities for achieving group consensus. In fact, in both cases the team can be tightly or loosely coupled and the contextual factors play their important role, too. Therefore, although this project involves a face-to-face collaborative situation using a tabletop display, paradigms and studies from D-CSCW were also examined.

Several studies explored and describe different elements of remote collaboration. For example, [6] present some models and frameworks for evaluating D-CSCW; [7] explored the establishment and maintenance of necessary and appropriate conventions in D-CSCW and suggest that successful conventions can improve group's performance and outcomes; [8] and [9] describe some interoperability issues, as well as, the importance of interactivity of the media used. However, as it was mentioned earlier, other studies illustrate how CSCW -both remote and face-to-face can improve learning, participation, problem solving, and, in some cases, minimize conflicts. It is this body of literature which integrates small groups' research that it is of importance for the purposes of this project.

CSCW in small groups' research involves elements from psychology and sociology which can help understand cognitive -both cognition between people and the world- contextual factors and constructs which affect remote and face-to-face collaboration.

Indicatively, [10] describe some constructs identified in a literature review process which amongst others include the attitude towards science, collaborative experience, collaborative skills, leadership abilities, motivation and so on. Moreover, identification of the way that people work together in different settings as well as identification of their needs as for the collaborative tools to be used are necessary as these should be reflected in the design of any computerised collaborative device.

Computer-Supported Collaborative Learning is a wide area of research and as [10] points out it is *"one of the more dynamic research directions in educational psychology".* Within a computer-supported - or not - collaborative environment individuals can discuss a given problem, exchange ideas, share their knowledge or even compete which can finally *"direct towards better understanding of the subject matter"* [11]. Piaget [12,13] pointed out that in collaborative learning participation is equally shared, although, it should be added, that this is not always the case and thus cannot be provided as a reasoning for the effectiveness or not of the collaborative process. In [14], Janssen discusses participation problems in CSCL and they propose as a solution the visualisation of participation because as they suggest can make *"contribution identifiable"*, *"enhance motivation to participate"*, *"raise awareness of group processes and activities"* and *"can be used to evaluate group processes"*. Moreover, the importance of previous collaborative experience was also highlighted by [15] especially concerning planning and problem-solving tasks.

In [16], Muhlenbrock describes the development of a computer-based system (which was tested with several applications i.e. puzzle games, arithmetic exercises etc.) which provides mechanisms for the analysis of the collaborative process together with visualisation and feedback. The system was developed to understand and improve problem solving activities of collaborating peers, and visualises conflicts, aggregation, revision etc.

It has been argued, and it is clear from the studies discussed previously, that if individuals are aware of the collaborative process then the last can be improved significantly. The participation levels of the collaborating individuals are a significant measurement which affects how much each person will participate and as such can further affect the result of the process. There are several studies which investigated participation in online environments and traditional F2F meetings. As this project is concerned with the same collaborative attribute, it is necessary to review some of these studies.

2.2 Participation

Participation as a term has been discussed in several different settings from management and planning to involvement in political and environmental decision-making. Different terms such as e-participation were evolved, referring to e-voting and e-government and the importance of the participation is continuously recognised in settings such as local councils, national, European and international legislation.

Similarly, the state of the art for group participation was discussed in several different settings not only because of its complexity but also because small groups are becoming a crucial part of many organisations. Therefore, a significant contribution to this area comes from the so called small groups' research, where the focus is mostly on psychological and cognitive factors which influence the participatory process. Furthermore, developments in Group Decision Support Systems (GDSS) should not be ignored. This research area *"provides evidence that computer technology can and does impact the quality of decision making in groups"* [17] and there are several GDSS applications which were developed not only for the improvement of communication between peers but also as persuasive technologies which can influence individuals.

As mentioned earlier, it has been suggested in many studies that it is most possible for a group to produce more effective outcomes when each member participates his/her distinctive information and knowledge [18,19,20]. Moreover, J. Bonito highlighted that *"Because participation patterns are often associated with group outcomes, modelling the antecedents and effects of participation offers important insights into problem solving and decision making"* [21].

Of significance and very influential for this project, is a study by Kulyk et al., which focuses on social dynamics [22]. In this study during a meeting process, real-time visualisation feedback – representing the speaking time of each participant, the duration of each turn, the visual attention for speakers and listeners (eye gaze) was projected on a table. The study aimed to investigate whether the time speaking will be more equally distributed, as well as, whether the attention and the group's satisfaction will be higher in the presence of feedback visualisation. Although the results were not statistically significant, they were promising and the authors also highlight that the participants felt satisfied and found the visualization useful and a positive experience. Also, some participants indicated that the visualization feedback indeed influenced their behaviour.

A critical question to be considered is whether such visualization could be distractive with a negative impact and thus reduce the group's performance. In [22], Kulyk et al. mention that according to the post-experiment questionnaire, some participants pointed that they felt distracted by the visualization, only in the beginning of the experiment. DiMicco et al. also suggest that *"users reported looking at the displays, not being distracted, and being comfortable seeing the information"* [23].

Finally, [24] used a CSCL online environment which incorporated a Participation Tool (PT) for visualising individual contribution, and then two groups of students (one with access to PT and one without access) compared in terms of different factors which amongst others included the group performance and equality of participation. Although this study differs significantly from the previously described and from what it is examined in this project, it should be mentioned that the students who had access to the PT participated more, but the results referred to the equality of participation were not statistically significant between the two groups.

Before summarising some of the problems identified in the literature concerned with participation, it is necessary to briefly mention that another significant body of research in this area focuses more on the formation of the groups and how this constellation can affect the decision-making process and its outcomes.

An extensive summary of these analytical and conceptual factors can be found in [21]. One important factor to be considered is interdependence which means that the participants' opinions, ideas and behaviours can be linked, that is what a participant will say, to whom, when and how will have an influence on the other participants. But interdependence is not the only factor which influences the outcomes of a decision-making process. The demographics of the participants and how they are formed into groups (based on the demographics) can further affect group performance. Some of the most important factors documented in the literature are the age, sex, motivation, skills, background, intelligence, and social skills of the participants [25].

2.3 Tacit knowledge and the deployment of work

It is evident that everyone develops and makes use of tacit knowledge in their style of thinking and expressing ideas. The word 'tacit' is used to characterize exchanges that are carried out without the use of words or speech and to describe shared arrangements that have arisen without explicit agreement or discussion [32]. Therefore, tacit knowing represents a person-environment exchange that is not articulated and that arises without explicit attempt to link environmental stimulation to phenomenological experience of the use of a medium or tool, in this case, a multi-touch surface.

Although the idea that people's actions are subject to unconscious influences dates to Sigmund Freud in the late 1800s, scientist and philosopher of science Michael Polanyi discussed formally the concept of tacit knowledge, noting its influence on perception and scientific thinking. He argues that "we can know more than we can tell" [33] and that tacit knowledge underlies a wide range of skills, from tool use to application of the scientific method. The sensations and abilities developed during the use of a tool remain tacit as people solely attend to the actions of the tool. In effect, the tool becomes an extension of the person, such that the person cannot articulate how they use the tool any more than they can articulate how they use their own hand. Polanyi also emphasized the experiential nature of tacit knowledge which it must be passed on collectively by example and practice, often implicitly [34].

This practical intelligence defines the ability to acquire tacit knowledge from handling everyday practical problems such as drawing compositions, making models and determining a solution strategy, making them of critical importance to the existence of distinctive psychological construct and eventually overlapping with other psychological constructs.

This evolving intuition is relevant in, for example, architectural research methods, where architects are trained to be generalists of many different areas of knowledge ranging from psychology to civil and structural systems. The medium for strategy development is constant and favoured as a platform for applying tacit knowledge and practical intelligence. They are large graphic representations of concepts and ideas manipulated directly and collectively to capture the collaborative endeavours of the wide spectrum of skills relevant to the task.

On this project, we agreed that a new medium that resembles an established medium can promote the transference of critical psychological constructs for the effective accomplishment of a task that otherwise could not be executed in a conventional way. A multi touch tabletop display seemed to have this property.

2.4 Tabletop displays

Although touch interfaces have been researched for over 25 years, only in the past 5 years have multi-touch surfaces been available. As such, the body of relevant work is small, and many published works presents anecdotal evidence. Whilst it may seem that the difference between single-touch and multi-touch interfaces is small, this assumption is only true for single user applications. Multi-touch in a large table or wall format is inherently multi-user, and this co-located, simultaneous input environment demands small group study. Still, even though existing literature is slight, there is much that can be learned.

One of the first questions asked when planning any construction is 'how big?' This question describes many things for a table-top display: the surface's width and length, its height from the floor, the size of bezel surrounding the surface; but it also demands something of the technology. Certain multi-touch technologies are only applicable for certain formats of surface. Mitsubishi Electric Research Labs have been investigating this and many other tabletop dimension questions with the capacitive multi-touch DiamondTouch system. In [35], Wigdor et al. studied one participant's use of a DiamondTouch for a period of one year. The participant was given a choice between two sizes of display: 810mm or 1070mm diagonal. The participant chose the larger display as they preferred the larger field of view. Contrary to previous study, the participant did not experience arm fatigue when having to reach farther on the larger display.

MERL also studied many different DiamondTouch surfaces in various multi-user roles in [36]. Ryall et al. discuss four years of anecdotal evidence gathered throughout these studies. They also suggest a size of no less than 1070mm, as otherwise participants start to bump elbows and arms. This is especially important if participants do not know each other, as these accidental touches violate 'personal territory' and increase the likelihood of bad behavior. They suggest that some participants may be weary of touching the surface for hygiene reasons.

Ryall et al. also discuss the size of the non-interactive area surrounding the surface. Participants often accidentally touch the surface with their forearms if the surface bezel is too small. Bezel sizes of 62mm were thought to be insufficient for many table applications. The severity of this problem changes with table height: a table for standing use is less susceptible to accidental touch than a table for sitting use, as participant's arms reach down to the surface rather than across.

A review of the technical aspects of multi-touch technology heads Section 5 for readability reasons.

2.5 Conclusion

The fact that it was decided to build an interactive tabletop system to observe the attribute of participation within a decision-making process was not random. It is believed that such tabletop systems are going to be used as participation mediums very soon and for different purposes, as for example in meetings with designers or architects.

Furthermore, it was previously described that within different collaborative settings the attribution of participation was examined for both small groups and larger groups of people. There were two main limitations to the previous studies. Firstly, the tasks given were quite ambiguous and the outcomes very subjective as they mainly involved a conversation based task or discussion based on a role-playing task. Therefore, the measurement of the performance of each group is subjective, too. For example, it is hard to define how you will measure the performance of a group where participants discuss.

For this reason, it was decided to use a game-based scenario where the group's performance can be measured objectively using the score that the team achieved. Such a measurement can also help to compare the groups accordingly.

Moreover, previous studies used the visualization of participation in such a way that it was the centre of attention. Although these studies suggest that the users reported that they were only distracted in the beginning of the session, it is believed that distraction cannot be easily identified and accounted for in such a situation. Concurrently, the distraction due to visualisation could affect the group's performance. Therefore, our second aim was to incorporate the visualisation of participation into the interface in such a way that it is not the centre of attention. The presentation of information should not be so brash as to lead the participants to turn the visualization into a game itself.

3.0 Carcassonne

We attempted to find a task suitable for studying collaborative group working. After initially discussing applied examples (master plan design, office layout design) we were guided into looking at more abstract problems; specifically, games.

Very few games are collaborative by design. Certain games have collaborative elements, but often these come about by the nature of the game's players (e.g., Diplomacy, in which players form alliances). After attempting to modify the rules of games to fit collaborative group working and not achieving satisfaction, we approached the problem from a different angle. We would present a scenario within a game to the participants as a puzzle, and ask them to achieve a maximal score. In this way, groups of participants can be easily ranked against each other.

We chose to use the 2001 Spiel des Jahres award winning board game 'Carcassonne', designed by Klaus-Jürgen Wrede. Carcassonne was chosen for many reasons: Firstly, it is a relatively simple game – the rules can be learned in 10 minutes. Secondly, it does not take a long time to complete. Games last around 45 minutes. Thirdly, the game is two-dimensional and translates well to a table computer. Fourthly, and perhaps most importantly, the game allows for complex decisions to appear in a short amount of time from simple concepts. Participants in a collaborative group working experiment need tasks which are engaging and contain significant decision making for any kind of complex behaviour to arise.

3.1 The Rules[I]

The concept of the game is for the players to build a medieval landscape. Players gain points by controlling features of this landscape with their followers (or 'meeple', abbreviating 'my people'). The game starts with a single terrain tile face up and 71 others shuffled face down for the players to draw from. On each turn, a player draws a new terrain tile and places it adjacent to tiles that are already placed. The new tile must be placed in a way that extends features on the tiles it abuts: roads must connect to roads, fields to fields, and city walls to city walls.

After placing the new tile, the placing player may opt to station a meeple on that tile. The meeple can only be placed on the just-placed tile, and must be placed in a specific feature. A follower claims ownership of one terrain feature—road, field, city, or cloister—and may not be placed on a feature already claimed by another player's follower. A placed follower is named according to the feature he is placed upon:

A knight if placed on a city tile;
A thief if placed on a road segment;
A farmer if placed on a field segment;
A monk if placed on a cloister segment.

To score points, during the turn, when a city, cloister, or road is completed - cities and roads when there is no unfinished edge from which to expand, cloisters when surrounded by eight tiles—the followers on that feature earn points for their owning players. Points are awarded to the players with the most followers in a feature. If there is a tie for the most followers in any given feature, then all tied players are awarded the full number of points.

Completed roads and incomplete roads score identically: one point for each tile the road passes over.

[I] Parts of this section are taken from the Wikipedia entry for Carcassonne.

Followers on cloisters award points based on the number of neighbouring tiles: a cloister is considered complete when it is fully surrounded by eight neighbouring tiles. Cloisters score one point (for the cloister tile itself) and up to eight points for the surrounding tiles.

Closed cities consisting of two tiles score two points (one per tile) and one extra point for every shield that reside in the city.

The game ends when the last tile has been placed. At that time, all features (including fields) score points for the players with the most followers in them. The players with the greatest number of followers adjacent to a city are awarded four points. Thus, followers from different fields may contribute to the scoring for a city, and followers on a field may contribute to the scoring for multiple cities. The player with the most points wins the game.

Our first modification was to place all players on the same team such that the game would be purely collaborative, meaning that, following Zagal et al., “all the participants work together as a team, sharing the payoffs and outcomes; if the team wins or loses, everyone wins or loses” [39].

Our second modification is in presenting players with a board that is partially complete. In this way, we create a game scenario for them to solve much in the way a puzzle would be solved; whilst still retaining the complex trade-offs involved in meeple placement.

3.2 Tutorial Scenarios

We prepared a short, pre-set tutorial to demonstrate the basic concepts and rules of the game for the benefit of the participants.

Stage 1: Road and Thief concept

In this example, we demonstrate the concepts of completing a road and placing a thief follower on the road to claim points.

Figure 1: Preset tiles, player needs to place road tile.

Figure 2: Player puts down thief and claims points for road feature.

Stage 2: Building a city

This scenario explains the city concept and how to complete and claim points from a city using a knight.

Figure 3 : Player places tiles to build city building on previous example. Puts knight in City to claim points.

Stage 3: Generating a farm

Here we show how to build a farm, and how we can claim points for a farmer placed which supplies a city.

Figure 4: Continue building tiles, adding a second city and way.

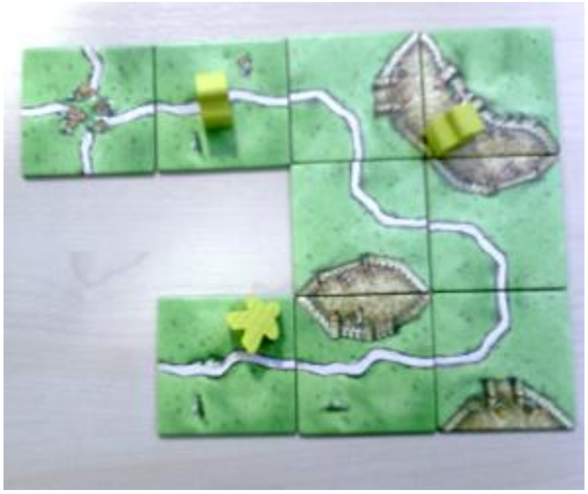


Figure 5: Place a farmer on the inside farm, after having built a city next to him.

Stage 4: Cloisters

Here we will show that a cloister needs to be surrounded by 8 tiles to gain points

Figure 6: Build ways round to complete the cloister.

Figure 7: Final situation. The cloister is complete, and a follower has been placed on it to earn points.

3.3. The Task Scenario

The task scenario was composed of a given set of fixed starting tiles together with 14 free tiles and 6 meeple. The fixed tiles were laid out in a predefined pattern like a puzzle for the participants as a starting point. The participant group was to be given guidance to complete the set pattern using the remaining 14 free tiles, according to the rules of the game. All 14 free tiles were to be presented to participants at once. Participants would work together to discuss where best to place the 14 free tiles and 6 meeple such that the team scores the maximum number of points. This scenario should allow the players to build and complete features to gain points, such as maximizing the potential score from road building, city and/or farm building. Trade-offs must be made and a strategy agreed between players to maximize the scoring potential.

The scenario does not require a leader to control or direct the game activity; however, based on examples from other applications it might be possible for a member to be assigned the role of the leader by their group.

The task scenario and tutorials were used in a pilot study to observe their effectiveness at generating discussion. We used experienced Carcassonne players to help us test: if the scenario caused sufficient discussion amongst experienced players, it was likely that it would be sufficient to elicit doubt (and hence, discussion) in the minds of novice players.

Figure 8: The task scenario contains 20 fixed tiles, 14 free tiles and 6 meeple.

4.0 Methodology

We will attempt to obtain 56 people to participate in this study. Each collaborative group will consist of 4 people; thus, we will have 14 groups.

In the first 7 experiments participants were not provided with any visualisation feedback of their participation, as was happened with the last 7 experiments. The visualisation feedback of the last 7 experiments presented to the group member's information associated with their participation in terms of their interaction with the table i.e. number of successful tile/meeple placements by each person. It is believed that in the experiments with the visualisation feedback the interaction of each participant with the table will be more equal compared to the session without the visualisation feedback. Previous studies used several behavioural or other metrics, to quantify and compare participation levels. However, the purpose of this study was to observe participation levels in a more controlled environment where the users must concentrate on a different activity rather than on their participation, as it can be argued that the focus must be firstly on the task and then on how the task can be improved. In our case the central point of attention is on the activity of playing the game which can only be achieved through interaction with the table. As a result, the amount of the individual interaction with the table can be an indicator of the individual participation. This leads to the first hypothesis, which can be defined as following:

Hypothesis 1: *Interaction with the table will be balanced more equally in sessions with feedback than in sessions without feedback.*

A pilot study took place using the traditional Carcassonne board game but with the collaborative scenarios that were developed for the purposes of this study, and it was observed that while most of the members were participated in the process, only one member moved the tiles on the table. Therefore, as an attempt to minimise any biases caused by a similar behaviour, it was further decided to measure the time speaking.

Generally, the time speaking is the most common measurement used, to quantify participation and a *"determinant of social dynamics"* [22]. Kulyk et al. further suggests that *"speaking means having the opportunity to control the flow of conversation and influence the other participants"* [22]. Through speaking the participants can suggest a strategy, an alternative solution, agree, disagree with the other members of the group or even direct the whole conversation. The latter depends mainly on the participant's personality.

It should be mentioned here that in a focus group meeting arranged to discuss problems that people usually encounter in meetings, it was identified that "*they all [the participants of focus group] had experience with problems during the meetings related to social dynamics, such as: two people discussing for a long time in a subgroup; one person talking for a long time and behaving like a chair of the meeting without being appointed as such, etc."* [22]. Furthermore, several studies, and based on the theory of social pressure, suggest that the measurement - and in some cases the visualisation of the time speaking - can result in equal participation, because individuals become consciously aware of the participation process [40,41]. For example, DiMicco & Bender underline that "if a group becomes aware of extreme imbalances in its turn-taking and participation, it can assess and determine the best method for correcting its own processes" [23,37]. Morris used a tabletop display to present information about the participation levels in terms of time speaking and they concluded that such displays can result in greater participation equity [38]. Similarly, Kulyk et al. found additional preliminary evidence that in the presence of feedback visualisation the participation levels tend to be more equal [22]. Therefore, this leads to the second hypotheses to be tested.

Hypothesis 2: *Speaking time will be balanced more equally in sessions with feedback than in sessions without feedback.*

Moreover, several studies link equalities of participation to individual and group performance. This means that if anyone in a group meeting, can express his/ her ideas, opinions, share his/her knowledge, express questions etc, then it is expected that better individual and group performance will be achieved. As this study involves playing a game, it is much easier to test such a hypothesis. As indicators of the group performance, it was decided to define the task's completion time and obviously the resulting score achieved by each group. Firstly, it should be mentioned that the different alternatives were evaluated and the best solution (in terms of scoring) was identified.

This assumption leads to the formation of two hypotheses, one concerned with the equality of participation as this indicated by the time speaking and the other one concerned with the equality of participation in terms of the interaction with the table.

Hypothesis 3: *The more equal the speaking times (equality of participation), the better the score the team will achieve.*

In previous studies, speaking time is the most common measurement.

Hypothesis 4: *In the presence of feedback visualization the group will achieve better scores.*

For hypothesis 3, it was necessary to identify the time speaking for all 14 groups and compare their performance (as score and task completion). For hypothesis 4, firstly, the interaction metrics were used for all the 14 groups and the groups were compared again based on both these metrics and the group's performance. To further clarify hypothesis 4, it is believed that the groups that will be provided with the feedback visualisation it is most possible to achieve better scores, exactly because they will be more aware of their participation levels and thus it is more possible to achieve equal participation.

Finally, it is of equal importance, to how participants perceived and what they believe about their participation levels, their individual performance and the group performance. Previous studies (again references here), found that in the existence of feedback visualisation participants tend to be more satisfied about their individual, participation and group performance. This leads to the formation of hypotheses 5, which will be investigated by a means of a questionnaire.

Hypothesis 5: *Participants' satisfaction about participation and performance (individual & group) will be higher in the presence of feedback visualization.*

Olaniran and Sarrina Li both compared a Computer-Mediated Communication (CMC) with a Face-To-Face (FTF) meeting [42,43]. In both studies questionnaires were used, to collect the subjective judgements of the participants concerned with the members' perceived group outcomes. Similarly, Kulyk et al., to test the hypothesis "Participant's satisfaction about group communication and performance will be higher in the presence of feedback visualisation", collected the perceived individual judgements by a means of questionnaire [22]. Therefore, it was decided that a similar approach should be followed.

Table 1 describes the perceived group outcomes as used by Sarrina Li to identify the perceived group outcomes [43]. For these two categories it was decided, to use the same variables together with a 5-level Likert scale, so that participants after the completion of the experiment, they specify their level of agreement to these statements.

The 5-level scale used is: 1. Strongly Disagree; 2. Disagree; 3. Neither agree nor disagree; 4. Agree; 5. Strongly agree.

To identify the perceived participation levels, it was decided to directly ask the users in the questionnaire to rate the participation levels of themselves and the other group members. This will be then compared with the time speaking and interaction metrics to see how participation is perceived.

Table 1: Post-test questionnaire: Factors for perceived group outcomes – both individual and group performance.

Perceived Group Outcomes	
Perceived Group Performance	**Perceived Individual Performance**
1. Employed the best way	1. Played an essential role as an individual
2. Good Understanding of Process	2. Contributed to the discussions
3. Communication was necessary	3. Consulted by members
4. Communication helped	4. Rewarded by other members
5. Feel satisfied from process followed	-
6. Communication was smooth	-

5.0 Design and Construction

Our investigation into participation required a working environment which could accurately track the inputs of participants. That is, the task-specific interactions of participants needed to be individually identified and measured.

There are many existing technologies for this task. The closest fit to such an environment available at UCL is an interactive whiteboard. However, the systems in place do not allow sufficient flexibility for collecting data and are effectively closed. Instead, inspired by the work of Han et al. [44], Jordà's Reactable [45], and Microsoft's Surface table, we decided to build our own multi-touch surface.

Professionals and hobbyists the world over have been attempting to build such systems since their popularization in the mid-2000s. Part of their appeal is their simplicity and low cost. All three systems generate their images by rear-projection. All three systems also employ vision-based finger tracking that uses infrared light reflecting from objects in contact with or near the surface. Han's system relies on the principle of Total Internal Reflection, and can be seen in the figure below [44]. Infrared light is passed through the interaction surface such that it runs perpendicular in a plane to any objects on the surface. This light totally internally reflects within the interaction surface until some object affects the cladding and breaks the reflection. The infrared light then bounces outside the surface and into an IR sensitive camera. The sum effect of this system is that objects in contact with the surface appear bright to the camera, whereas objects not in contact do not appear at all. These systems are labeled as Frustrated Total Internal Reflection (or FTIR) devices.

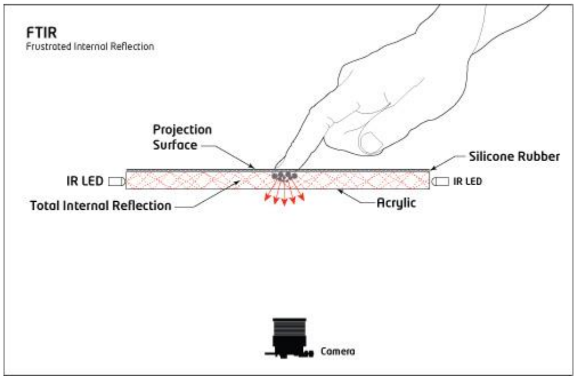


Figure 9: Frustrated Total Internal Reflection (courtesy of Tim Roth's blog).

Both the Reactable and the Surface work differently to FTIR systems. Instead of passing light perpendicularly to the surface, light is propagated up through the surface. In this case, any object above the table will be illuminated (not just those in contact with the surface). A diffuser is placed underneath the interaction surface so that objects distant to the surface become out of focus and blend into the background. With sufficient diffusion, the only objects that remain illuminated by the infrared light are those touching or very near to the surface. Such systems are labeled as Diffusion Illumination (or DI) systems. DI systems are advantageous to FTIR systems as fiducials placed on the surface of the table can be tracked; however, the contrast between objects touching the surface and not is less in a DI system.

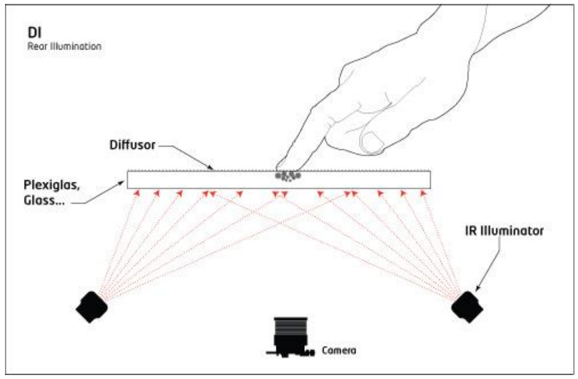


Figure 10: Diffusion Illumination multi-touch surface (courtesy of Tim Roth's blog).

Other multi-touch systems exist, most notably capacitive systems such as those used by the DiamondTouch or Apple iPhone. Transparent sensing circuits are inserted between the display layer and surface layer at regular intervals to form a grid. Each sensing circuit detects changes in the capacitance of a small area above the surface layer. When a finger is placed above a sensing circuit, the value of the capacitance changes because the finger has different dielectric properties than air. Building such systems require precision fabrication and a significant knowledge of electronic engineering.

Generally, capacitive touch systems are more robust than both FTIR and DI systems as their performance does not vary with the ambient lighting conditions. FTIR and DI systems require very powerful IR illumination to work successfully in bright environments. Capacitive systems can also be much smaller than FTIR or DI systems as no camera is necessary to view the entire surface. FTIR and DI systems also suffer from needing an equal amount of luminance across the surface to enable accurate detection. Of course, there are many variations which attempt to address these issues, such as placing IR sensors in a grid rather than using a single IR sensitive camera; but these are beyond the scope of this discussion.

We chose to construct a DI system for its low cost and ease of construction.

5.1 Table Design

Our priority was defining how large our surface needed to be. From the review of recent literature, we learned that the surface should be at least 1070mm large by the diagonal. Larger areas can accommodate more people, and reduces ‘personal area’ problems. As our DI system produces its image by projector, the size of the surface demands that the projector be a certain distance away. Short-throw projectors are employed in professional systems such as the Microsoft Surface and allow the table housing the surface to be squat if desired. However, we did not have access to a short-throw projector and so there existed a much larger minimum height required to produce an image at least as large as 1070mm diagonal. A mirror is employed to increase the projection distance and reduce the height required. Some table designs using ‘long’-throw projectors choose to employ a separate housing that is higher than the table surface. Such a design is only suitable if the table is only to be used from certain sides.

Tables using ‘long’-throw projectors often have a large non-interactive space on one side of the table in which the projector sits. However, the literature review informed us of the need for a wide bezel on all sides of the table such that participants can rest their elbows without triggering false touches with their forearms. Satisfying this need by having a large bezel gives us a place for the projector whilst still having a symmetric design. The size of our projector demanded a bezel of at least 110mm.

Thus, the total top surface size should be at least 1076x862mm. Given that the smallest standard door width is 600mm our table design needs to allow easy disassembly. Unlike a regular table, the space between the table legs is occupied with equipment and so it cannot be angled into doorways on its side.

One final consideration is working height. As discussed, there exists a minimum height necessary for the projector to produce the required image size. However, it is often convenient for the surface to be higher than this. Specifically, when using the surface as a working desk when standing. Our design should allow for varying height.

The final design can be seen in the appendices, along with construction photographs documenting the process.

5.2 Finger Tracking Design

There are two noteworthy components to the finger tracking: the camera, and the infrared light.

The camera needs sufficient resolution to allow for small finger movements. A table surface one metre squared would require a camera resolution of 1000 pixels squared to detect movements as small as a millimetre. The camera also needs sufficient frame rate to capture fast hand movement. The frame rate effectively limits how far a finger can move between any two video frames before tracking is lost.

High-resolution, fast frame rate cameras are often expensive and physically large. Fortunately, we could acquire a Point Grey Research DragonFly2 Firewire camera. At 75x65x25mm without lens, the camera is compact. It can capture an 8bit greyscale image of size 1024x768 pixels at 30Hz. This allows our surface to be 1024x768mm (or 1280mm diagonal) whilst still retaining millimetre precision. Of course, such a situation demands that the surface fill exactly every pixel in the camera's imaging sensor, and that each pixel covers exactly 1 millimetre. When using a mirror to bounce the projected image, this is impossible as the natural position for the camera (directly underneath the surface) obstructs the projection.

We chose to place the camera to the side of the projector, observing the surface via the mirror. As well as maximising the size of the surface in the imaging plane, this position also produces the minimum parallax between projector and camera. Barrel distortion is also a factor. However, after calibrating the camera and correcting for distortion, it was found that the computation cost was too great to justify the improvement.

Given that, we maintain a rough 1mm:1pixel ratio. Certain areas of the surface have more imaging plane resolution than others due to barrel distortion, but this does not significantly affect performance.

Digital cameras (both CCD and CMOS) are sensitive to light beyond the visible spectrum. Camera manufacturers insert low-pass filters with a cut-off frequency around near-infrared wavelength into their cameras to remove this sensitivity. For our purpose, however, we want to keep the camera's infrared sensitivity. As such, we removed the low-pass filter from our DragonFly2 camera. However, we would also like to block visible light from our camera. If we do not, the image projected onto the surface will interfere with the tracking. We place an infrared long-pass filter in front of our camera to filter out anything shorter than near-infrared wavelength. Note that if the wavelength of infrared light being used can be assured to be within specific bounds, then a band-pass (or notch) filter is much more effective at eliminating unwanted frequencies. This effectiveness comes at a higher cost, however.

Infrared illumination is often said to be the trickiest part of setting up a DI surface. To allow for accurate image processing, the entire surface should be illuminated uniformly. The larger the surface, the harder it is to light uniformly. To add difficulty, ambient lighting significantly affects performance. If the infrared light from underneath the table is less bright than the surrounding infrared light, the tracking will fail. Even though we attempt to block visible light from entering the camera, most light emitted from lamps has some infrared component. Worse still, natural light is incredibly bright and has a very strong infrared component. Finding a reliable lighting solution is an exercise in patience.

Our first attempt involved wiring together groups of 850nm infrared LEDs and placing bundles strategically inside the table. The light from a single LED was sufficient (in a dark room) to reflect from our fingertips. However, even after wiring 42 LEDs, we found that they did not cover sufficient area – LEDs typically have an angle of illumination of approximately 20 degrees. This setup was also unfortunate to burn itself out: the LEDs purchased did not perform to their written specification.

After consulting with Dr. George Roussos from Birkbeck College, we purchased a wide-angled CCTV night-vision illuminator. This unit contains 48 850nm LEDs arranged such that a horizontal angle of 140 degrees is achieved. The units are produced by hand and sold by Tim Moore through eBay (tim55ukuk). As such, ours took three weeks to arrive. Upon arrival, this unit could not illuminate the entire surface directly. However, when pointed against the white-painted internal surfaces and used indirectly, there was sufficient illumination for the tracking to function in a darkened room.

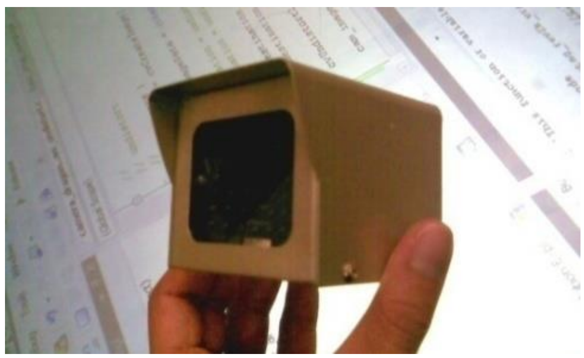


Figure 11: Infrared LED illuminator. As this is a 'night-vision' CCTV illuminator, black tape was placed over the unit's light sensor to force it to turn on.

Alas, face-to-face collaboration demands that you can see your collaborators. With four wide-angled units we would comprehensively cover the surface of the table; however, their long delivery time dictated that we buy different units. What was available to us at short notice and reasonable cost was limited. We purchased two similar units using 48 of the same LEDs but with a specified angle of illumination of 60 degrees. These arrived in 2 days. Our arrangement was non-typical but provided both sufficient illumination and consistent illumination across the surface.

We investigated using different internal surfaces to aid diffusion/reflection (notably, aluminium foil). We found that it made little difference above and beyond the white-painted surface. We considered purchasing professional reflective surfaces (Lee filter: Soft Silver Reflector 273), however, the cost was prohibitive for our dimensions. We also investigated the use of simple lenses to improve coverage. Again, professional lenses are expensive and so we purchased inexpensive malleable plastic Fresnel lenses. Whilst in certain configurations they made small improvements, they did not become part of our final solution.

We did employ one reflection trick. The edges of our surface were somewhat darker than other areas. We placed white card at angles toward the surface such that reflected light brightened the edges of the surface where required. Note that this technique is only applicable for our non-typical DI setup, and would not aid traditional DI setups.

Our final solution works under normal levels of ambient lighting. It does not work under sunlight. The illuminator/reflector arrangement can be seen in Figure 12.

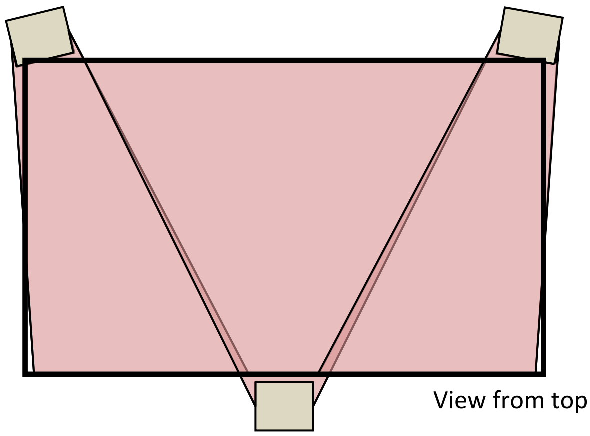


Figure 12: Illuminators are placed such that their emission is parallel to the surface, not perpendicular. Angles are suggestive.

Various finger-tracking software exists and is free to use. The two solutions we investigated are both open-source: Reactivision (the software that powers the Reactable) and TouchLib.

Both solutions employ OpenSoundControl to generate TUIO protocol events. TUIO was specifically designed for transmitting the state of tangible objects and multi-touch events on a table surface. Its creation was part of the Reactable project.

Reactivision is primarily a marker-based tracking solution for tangible objects and only recently supported finger tracking. Even though the software is well-written and robust, its image processing abilities are limited and we found it difficult to accurately identify fingertips.

TouchLib was created and is maintained by NUI group along with its community of hobbyists. TouchLib provides a flexible image processing pipeline as a filter-graph defined in XML, allowing great diversity between the software approaches of different setups. However, TouchLib is not as well-written and occasionally exhibits odd behaviour.

We decided to progress with TouchLib as its flexibility in the image processing stages allowed us to more accurately identify fingertips. We start by manually setting the camera shutter time to the lowest possible (with automatic exposure and gain control) which will still register fingers. From camera input of 1024x768 8bit greyscale pixels at 30Hz we perform:

1. Background subtraction:
   The background is recalculated at regular intervals to cope with minor changes in illumination.
2. High-pass filter:
   This effectively removes out-of-focus elements (i.e., those that are distant from the surface).
3. Scale:
   This helps improve the contrast for the final stage.
4. Rectify:
   Threshold to remove as much as possible of what remains that is not fingertips.

Calibration is performed by barycentric coordinates: by identifying 20 points in a grid across the surface of the screen, a mesh is located on the processed image. The three closest calibrated points are used to triangulate the finger position. X and Y position on the surface are then presented as relative values between 0 and 1. Width and height of blob are presented similarly.

TouchLib identifies fingertips uniquely and tracks them from frame-to-frame. Some oddity creeps in here as TouchLib employs a recursive algorithm for this. Complexity reaches O(n!): for ten fingertips, TouchLib recurses 3628800 times. This problem is difficult for us as it is likely that, with four participants, many more fingers than ten could be detected. Unfortunately, we did not have time to fully understand and re-implement finger tracking. Instead, a hard-limit was placed on the number of recursions after which point no more fingers are detected. The alternative is to allow TouchLib to become lost in recursion for seconds or even minutes at a time.

Minor other changes were made to TouchLib to speed up processing.

5.3 Participant Identification Design

Our experiment demands that we can identify who has touched the table and where. Vision-based multi-touch surfaces cannot identify people uniquely from just fingertips, and so another method had to be devised.

Although the expectation was that people would use their fingertips to interact with the table, there was no guarantee. A perfect tracking system would be able to cope with any hand position and rotation. This thought motivated our initial investigations.

Vision-based tracking is often very simple to setup as in many instances requires only a camera and software. More robust tracking methods exist; however, these generally require more equipment or are more time-consuming to integrate. As time was short and our experience was with vision-based trackers, we decided to investigate using a camera mounted above the table for tracking.

In discussion, we went through many options. The first suggestion was to place small identification marks on the tips of people's fingers. However, the diffuse surface sitting between the camera and people's fingers makes it difficult to resolve small markers.

Our first real attempt used gloves. The CAMShift algorithm was employed to track four hue-distant colours. We found that whilst the tracking was fast, it failed to be robust. Local variations in lighting affected performance significantly, and matching colours in the projected image occasionally affected accuracy. The major problem was of seeding – once tracking was lost, there was no simple way of re-seeding (save manually). We briefly considered using a human operator to aid the tracking in re-seeding, but decided it unwieldy.

Another suggestion was to use rings. Rings would be visible through many different positions and rotations. As colour was not sufficiently robust, each participant would wear (on one finger) many UV-reflective rings. A UV sensitive camera and UV light would sit above the table, and a software solution would attempt to count (by area or number of connected components within proximity) how many rings each person was wearing. A further suggestion was to construct a barcode with rings. Four bits would be necessary to code identity, plus a predictable pattern either side to aid localisation. This would require four rings per person (or six with a more reliable two-ring pattern either side). A single-finger tracking solution would be less robust than a hand tracking solution for the simple reason that fingers are smaller and so more difficult to reliably resolve. As an unobtrusive solution rings may be worth further investigation; however, we decided against implementing this method as we did not know of any previous published examples.

Our second attempt moved on to texture. Still using gloves, we attempted to employ feature-based tracking to identify four different texture patterns; and, further to this, four different images as might be found on gloves (e.g., Christmas themed gloves). We employed a real-time Lucas-Tomasi-Kanade (LTK) feature tracker; then a real-time GPU based Scale Invariant Feature Transform (SIFT) tracker implementation; and finally, a Speeded Up Robust Feature (SURF) tracker – all to no avail. We found these feature-based trackers to be excellent at tracking the table itself, but not at tracking the rather large variation in size, position, and rotation that a hand exhibits when interacting with the table.

We decided to make concessions and restrict the range of motion that would be available to participants. We investigated marker-based tracking as is often used for augmented reality. Placing a marker on the back of the participant's hands allows the marker to be quite large without being restrictive to finger movement. Marker-based tracking does not suffer from the seeding problem of colour histograms, and is sufficiently robust to scale, rotation and position sizes. We used the ARTag system as it can reliably track many markers at frame rate. A DragonFly2 was used as the overhead camera.

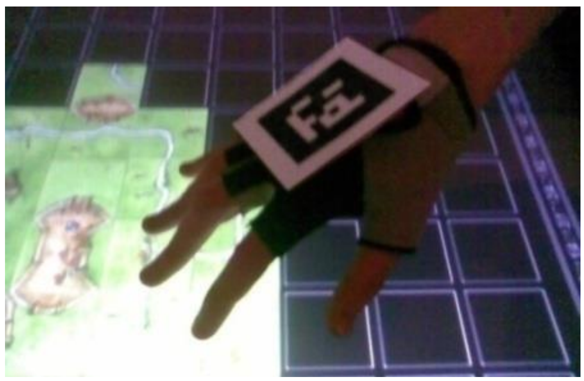


Figure 13: ARTag marker attached to a fingerless glove.

5.4 Participant Identification Software Implementation

ARTag Rev. 2 is not open source, and so no changes could be made. Fortunately, ARTag is robust. A simple calibration was implemented to align data from ARTag and TouchLib. Position and rotation data is sent over OpenSoundControl in the same way as TUIO messages. One noteworthy addition was the inclusion of barrel distortion correction. The lens on the DragonFly2 above the table suffered from significantly more distortion than the lens inside the table, and so correction was necessary.

5.5 Carcassonne Game Design

When designing the software, we looked at existing Carcassonne computer games for inspiration: Koch Media's PC version published in 2004, and the Xbox Live Arcade version by Sierra Online published in 2007.

Both computer versions aid the user in showing where tiles and meeple can be placed. This is especially useful for our experiment: most participants will be unfamiliar with the game and, given the limited time that they will have to play our scenario, any reduction in choice is a good thing.

Both computer versions also automate scoring. Whilst perhaps easy to take for granted as a benefit, automated scoring coupled with little participant knowledge of the rules could lead to 'trial and error' – participants placing tiles and meeple without fully understanding why score was obtained.

After conducting the pilot study with the board game, we identified aspects of the game that were necessary to translate the feel of the game to the multi-touch surface.

To aid them in planning their strategy, participants often placed tiles near to possible positions without finalizing the tile's position on the board. Thus, participants should be able to move and rotate tiles at will without being forced to place tiles on the board. This also extends to meeple. This is at odds with both existing computer versions, in which the only action is to place a tile or meeple on the board. Having said that, this participant behaviour stems from the collaborative, puzzle solving nature of our scenario and would have limited use with the traditional competitive rules.

Participants often changed their minds on how best to proceed with the scenario. In the pilot study, we allowed tiles to be removed if the participants changed their minds. Comprehensive multi-move undo should be provided to participants. This allows all participants to fully use the time allotted instead of perhaps making mistakes early in the game and closing off too many possible paths.

Finally, participants in the pilot requested a score help card (informing how many points each tile/meeple combination gained) for each group member for reference.

5.7 Carcassonne Game Software Implementation

OpenGL drives the rendering of the display through JOGL. To allow for flexibility, a 2D compositing scheme was devised: different panes/layers are rendered individually into an off-screen Framebuffer Object. Once rendered to texture, a composition manager locates/scales/rotates each element as desired. Although this functionality is extremely useful for certain multi-touch interfaces, it was not enabled for Carcassonne as it served no real purpose.

A simple physics simulation engine, Phys2D, was employed to allow realistic collisions between tiles and meeple. This helps bridge the gap between the board game pieces and the virtual pieces. Fingers placed on the board also act as physical operators, allowing arbitrary tile/meeple manipulation.

Game logic works recursively. As feature size is unbound and features can extend in strange ways, we propagate out from tiles/meeple in four or eight neighbor hoods to find relevant information: whether a tile/meeple placement is legal, whether a possible meeple position is legal, whether a feature is complete, how many meeple are on a feature, and so on.

A TUIO event listener receives three types of message from the finger tracker: finger added, finger updated, finger removed. It also receives hand position and rotation events from the marker tracker. Two bounds are placed on the distance a finger touch can be from any hand position: a simple radius test, then, if passed, a more complicated bounding box test. We ask participants whether they are right or left handed before starting to better fit the bounding box to their expected finger placements. If a finger is not within the bounds of a hand, the game does not register touches. Hand positions timeout if an update has not been received for one second. Misattribution is possible if hands are too close – this manifested itself as tiles/meeple occasionally jumping between the fingertips of participants.

To pick up a tile/meeple, participants placed their finger onto the object. It would then highlight as notification of a successful grasp. To drop a tile/meeple, participants removed their finger. If a tile/meeple was dropped over a possible position, a sound would signal success or failure. Tiles/meeple can also be moved by using fingers as physical operators within the physics simulation. Fingers placed not over a tile/meeple became white dots on the board which then acted as physical operators.

Rotation was implemented in two ways: using the physical operators to push the tile off-centre, coupled with universal drag constant, caused the tile to rotate; and a more typical two-finger rotation method where the first finger placed on a tile was a pivot, and the second an actor. By rotating the second finger around the first finger, the tile would rotate. After user testing, the first method was chosen. Whilst not as intuitive, the small size of the tile made it difficult to accurately place two fingers and accurate rotation was found to be more difficult.

A timeline was implemented, allowing participants to navigate through the game. Every time a tile/meeple was successfully placed, a new position was added to the timeline. By touching the timeline, the game would revert to the selected previous state. Adding a new tile/meeple would delete states ahead in time from the current position.

Score, time remaining, and participation visualization were presented in each corner of the surface with a different rotation. This allowed each participant to observe this vital information without straining.

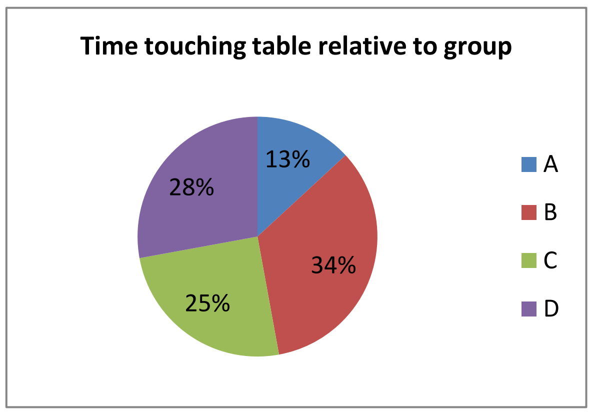
Metrics are stored for all inputs. Game states are serialized and stored after every game significant move for possible analysis and replay.

6.0 Experimental Results

Due to time constraints, only 11 experiments were run. The first experiment was void due to a software error, leaving 10 good experiments: 5 with visualization and 5 without. Unfortunately, this is an insufficient number for statistical reliability. Thus, those results pertaining to groups and not individuals should be interpreted as merely suggestive. Further experiments must be run to verify our results.

Data from the game, two video cameras, pre-test and post-test questionnaires was collated. Speaking time was recorded manually with software help (Mangold Interact). Statistics were computed using a variety of packages, including SAS and Excel with the Analyze-it add-in.

To statistically test the hypotheses described, the independent t-test was used. Generally, the t-test is applied when the sample sizes are small enough to use an assumption of normality. The independent version of the t-test is used when the sample is selected randomly for each group and not, for example, when the same sample used in two different groups is the same (in this case, a paired t-test would be employed).



Furthermore, it is generally accepted that the larger the sample size, the more accurate the variables' comparison will be (historically, the t-test is linked with a sample size equal to 30). Due mainly to time restrictions, the population sample of this study involved 20 people participated in the visualization sessions (5 groups of 4 people) and another 20 in the non-visualization sessions. However, for most of the variables that tested in this study, the two groups (visualization vs. non-visualization) differed slightly and as such a non-significant statistical difference was expected. Therefore, it is not believed that the t-test was biased because of the sample size. However, it would be recommended to conduct some more experiments (under the same conditions) and observe whether the results remain the. It should be mentioned, that as the team had limited knowledge and experience of statistical issues such as the t-test's dependence on sample size, professional advice was given by Dr. Kostas Konstantinou (PhD in Statistics, Imperial College).

6.1 Pre-test Analysis

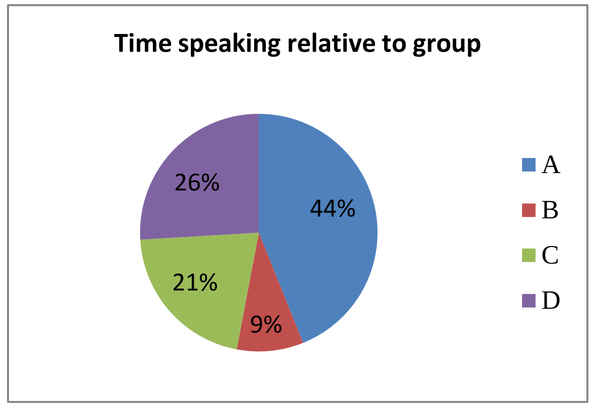
Most groups were composed of both men and women (17 women and 23 men), with only one all-female group, and two all-male groups. The predominant age group was 25-34 (24 participants); followed by age group 18-24 (12), and finally age group 35-44 (4). Most participants were postgraduate students or other UCL research staff.

One specific question asked each participant what was the frequency at which they participate in group meetings in their professional life. We wanted to obtain a better understanding of their experience in group decision making to evaluate against the outcome of the experiment. Responses varied from 'never' to 'almost every day', but most participants indicated they had at least one meeting a week. It is interesting to note that the group with the highest score is also the group in which the participants indicated that they attend meetings very often (once a day).

There were very few participants who had prior knowledge of the game Carcassonne, and fewer still who had played it before. Groups with experienced participants scored highly in the scenario. Individual participants with previous experience of the game (and its rules with knowledge of the strategic trade-off evaluation necessary to succeed) were always the leading group members by time speaking.

For example, in group "07-01 1800", group member A indicated that he had played Carcassonne before and was familiar with the rules. He subsequently emerged as the main contributor in terms of speaking time for the group, with over 44 percent of the group's 'speaking time' attributed to him (see Figure 15). However, when comparing with another participation metric, 'time touching table', we can clearly see that there was no dominance from player A in terms of interaction with the table (see Figure 14). It seems that player A mostly led the discussion of possible strategies and tile placements with the group, but let other players make most of the tile placements.

Figure 14: Pie chart showing that participant A (with knowledge of Carcassonne) spent less time interacting with the table than other participants.



We observed similar behaviour with other groups where players with previous Carcassonne experience contributed most to group discussion, but did not necessarily spend the most time interacting with the table.

6.2 Hypothesis 1

Interaction with the table will be balanced more equally in sessions with feedback than in sessions without feedback.

Table 4.2 (Appendix 4) presents the data for the variable 'time touching table'. It can be observed that the standard deviations of the non-visualization groups are smaller. This means that the variable is more 'equally distributed' in the second session (non-visualization) and as such the hypothesis that the time touching the table would be more equal in the visualization sessions is probably false.

Time Touching Table	n	Mean	SE	STD
Visualization Group	20	131.0	14.38	64.3
Non-Visualization Group	20	159.0	22.44	100.3

Furthermore, as the participants were chosen randomly the standard deviations were calculated as for all the participants regardless their groups and it was found that the standard deviation for the visualization groups was $\sigma^{visualization}$ =100.3368, while the standard deviation for the no-visualization groups was $\sigma^{no-visualization}$= 64.3154.

A 2-tailed p, independent t-test was conducted for testing the two groups (visualization and non-visualization), left.

Mean Difference	-28.1
95% CI	-82.0 to 25.9
SE	26.65
T statistic	-1.05
DF	38.0
2-tailed p	0.2992

Although the hypothesis was not found to be true and although the non-visualization group involved more equally distributed time for touching the table between the participants, the difference is not statistically significant. The same was also found when the interaction was measured in terms of tiles picked up and tiles successfully placed.

As explained, the interaction with the table was also measured in terms of the number of tiles picked up and the number of the tiles successfully placed (useful-successful contribution). The data for these metrics can be found in the appendix, and Tables 4.3 and 4.4. It should be mentioned that all the metrics revealed the same result (Tables 4.5, 4.6), which is that the non-visualization group had more equally balanced interaction compared to visualization group. Again, a statistically significant difference between the two groups was not found. The standard deviations are presented for all the metrics between the visualization and non-visualization groups in Figure 16. The results from the t-tests for the other metrics can be found in Appendix A4.

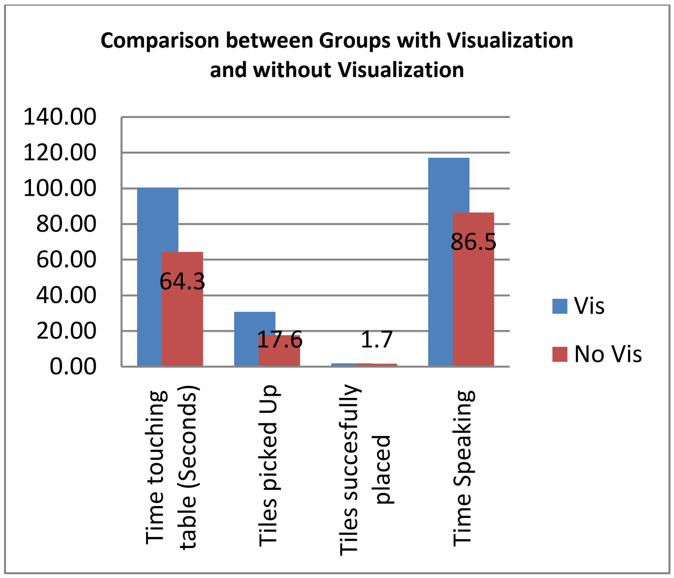


Figure 16: Comparison of standard deviations between visualization/no visualization groups.

To summarise, it was found that the first hypothesis is not valid for all the interaction metrics used, and thus it would be wrong to assume that interaction times will be balanced more equally in the presence of visualization. In fact, whilst not statistically significant, we found the data to be suggestive of the opposite. Groups with visualization had a greater average standard deviation of time spent touching the table between participants than for groups without visualisation (100 seconds vs. 67 seconds).

6.3 Hypothesis 2

Speaking time will be balanced more equally in sessions with feedback than in sessions without feedback.

The time speaking data were gathered through video analysis and are summarised in the appendix, table 4.7.

Interaction with a tabletop display has not, to our knowledge, been examined before as a participation metric especially within a decision-making process in small groups' research. Instead, speaking time was the most commonly observed participation metric in previous studies. As can be seen from Figure 16, the standard deviation of the speaking time was again higher in the visualization groups, exactly as happened with the other participation metrics.

Both the mean and standard deviation values for the time speaking are smaller in the non-visualization group. This reveals more equally distributed speaking time but again, as can be seen from the t-test results below, the difference is not statistically significant.

Speaking Time by Group	n	Mean	SE	STD
No-Visualization Group	20	132.290	19.3494	86.553
Visualization Group	20	146.052	26.1834	117.096

Previous studies [14] had suggested that speaking time was more balanced (whilst not statistically significant) in the presence of visualisation. However, our results suggest otherwise. Again, whilst not statistically significant (as mentioned previously), groups with visualisation had a greater average standard deviation of time spent speaking between participants than for groups without visualisation.

Mean Difference	-13.8
95% CI	-79.7 to 52.1
SE	32.6
T statistic	-0.42
DF	38.0
2-tailed p	0.68

The failure to validate both hypothesis 1 and 2 is not surprising given that previous studies failed to produce statistically significant results. What is surprising, however, is that our data sways in the opposite direction – that participation visualisation may act to unbalance participation in real-time situations.

As neither sets of data are significant, and both suggest opposites, it would strongly suggest that there is a hidden variable unmonitored in both experiments causing a greater variance on speaking times (and perhaps, interaction times) than participation visualization.

6.4 Hypotheses 3 and 4

3: *The more equal the speaking time (equality of participation) the better scoring the team will achieve.*

4: *In the presence of feedback visualization the group will achieve better scores.*

We found that neither hypothesis 3 nor hypothesis 4 were true. The score did not improve in any statistically significant way in the presence of visualisation. The p value from the t-test was 0.9263. There is no hint of statistical significance.

	Visualization	**No Visualization**
Group 1	97	102
Group 2	81	97
Group 3	66	95
Group 4	101	60
Group 5	83	69
Average	85.6	84.6

Table 2: Scores achieved by all groups.

Vis	Time touching table (average)	Time Speaking (average)	Score
1	89	145.73	97
2	236.5	176.73	81
3	147	163.96	66
4	141	44.36	101
5	181.5	199.48	83
Non-Vis	**Time touching table (average)**	**Time Speaking (average)**	**Score**
1	138.25	164.48	102
2	129.5	174.89	97
3	125	30.31	95
4	156.25	121.33	60
5	105.75	170.44	69

Table 3: Interaction times, speaking times and scores for all groups. Times are mean averages and are in seconds.

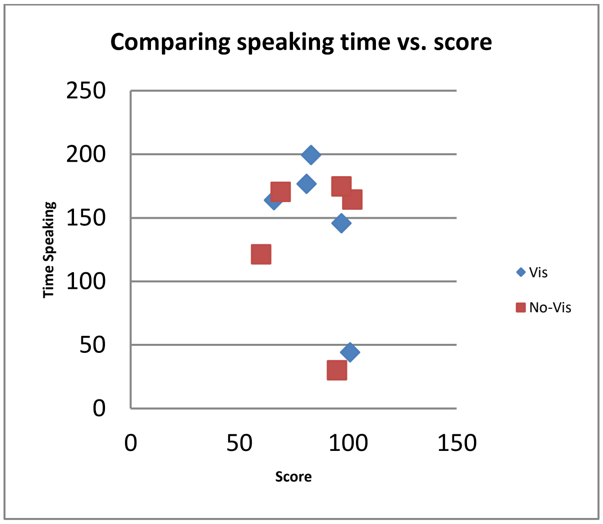


Figure 17: Scatter plot showing no correlation between time speaking and score.

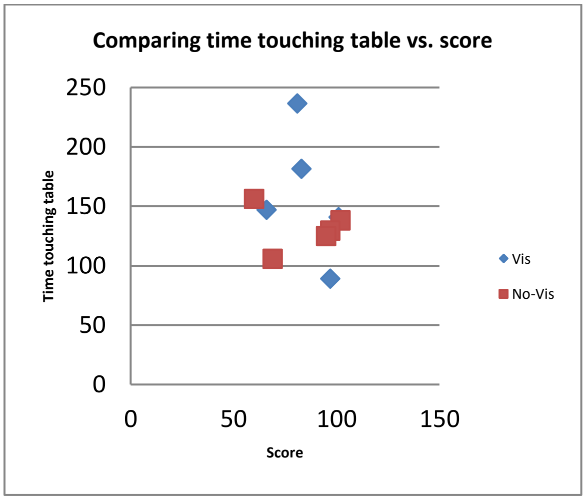


Figure 18: Scatter plot showing no correlation between time touching table and score.

Figure 17 and Figure 18 demonstrate that there is no correlation between speaking time and score, and between time touching the table and score.

6.5 Hypothesis 5

Participants' satisfaction about participation and performance (individual & group) will be higher in the presence of feedback visualization.

For individual performance, we found that personal ratings did not vary in any statistically significant way under the presence of participation visualisation. It is noteworthy but not unexpected that almost all participants rated their personal participation lower than the rating given to their participation by other team members (tables 4.7, 4.8).

However, personal ratings of group performance did vary significantly under the presence of participation visualisation. Those groups with visualisation rated group performance uniformly higher than those without, even though individual performance and score remained the same for groups with and without visualisation. We computed t-tests in two different ways – one with individuals and another with groups still intact (averaging perceived group performance between individuals). P-values for these two tests were <0.0001 and 0.0001 respectively. Figure 19 demonstrates this result with a scatter plot. Notice that score does not correlate with visualisation, as discussed with hypothesis 4.

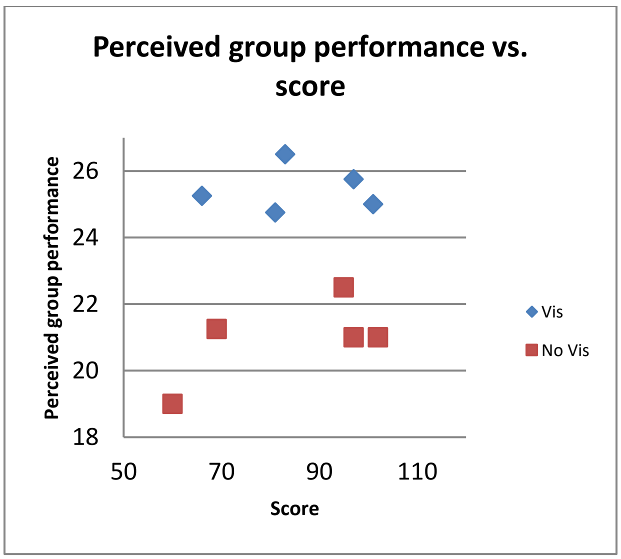


Figure 19: Scatter plot demonstrating the significant difference in perceived group performance for groups with and without visualization.

7.0 Discussion

The project suffered heavily from the protracted construction process. The trial and error in finding a sufficient illumination setup, coupled with the long wait for illuminators to be delivered (three weeks), set the project back significantly. Had the table been completed in mid-June, we may have had sufficient time to collect enough data and complete a thorough analysis.

7.1 Table Discussion

Although multi-touch tables are not a new idea, and our table could not be called a 'prototype' in the strictest of senses, it was the first experience we had had in building both the necessary hardware and software. As such, there were aspects in the design and construction that we overlooked.

Perhaps the most significant problem with our table is with false touches. As the surface is not a 'touch' surface in the strictest of senses (in that it does not require pressure to activate), false touches are common. The magnitude of the problem was not discovered until the first pre-experiment user testing sessions.

Almost without thinking, as the table's creators (with intimate knowledge) we interacted with the surface in such a way that gave the tracking the best chance of accuracy. Although there is some learning curve, many times new users during pre-experiment testing suggested we had a 'master's touch' – the table responded much better to us than to novices. The problem was compounded further by the fact that James is tall and reaches down to the table surface rather than across. Further still, the initial demo application (a fluid dynamic simulation that generates coloured trails on touch) that was run on the table before the development of the Carcassonne software did not care whether false touches were registered. Precision selection and dragging were unnecessary and false touches were masked in the swathes of colour.

Participants who held their fingers level with their palms generated many false touches. Initially, hand-position based bounding boxes were not included but the amount of false touches made it necessary to include (especially for false-touches on the timeline). Early Carcassonne software versions did not robustly deal with multiple touches on tiles/meeple. This problem was discovered in pre-experiment user testing and corrected. Still, even after introducing these measures false touches were still occasionally a problem. The most common manifestation was in tiles/meeple jumping between fingers (false or otherwise) if the real dragging finger momentarily lost contact (or was misattributed by the finger tracker).

We took to educating our experiment participants before the scenario on how best to interact with the table. The familiarization period allowed us to ensure that each participant knew how interact with the table to give them the best chance of accuracy. Whether the participants did this or not is another matter. Frankly, any interaction style should be acceptable; any hand position should be acceptable. Although our polycarbonate CAVE wall surface is diffuse on one side, it is perhaps not sufficiently diffuse to correctly distinguish touches and near-touches. If the table were built again, a different surface should be used (or a second diffusing layer added) to correct this problem.

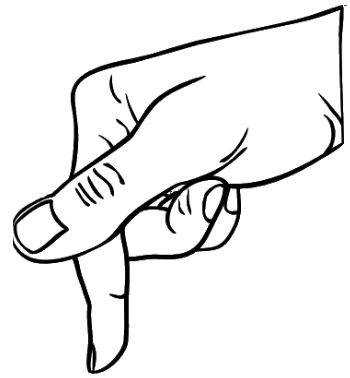


Figure 20: Hand position taught to participants for best table accuracy. This allowed the finger to be distinguished whilst keeping the rest of the hand distant from the table. It also allowed the marker on the back of the hand to be seen by the camera above.

The table is not robust to different lighting conditions. We use a total of 144 IR LED lights; however, this is not enough for the size of the table. In many different situations, the ambient infrared light in a room will overpower the table's internal light. This situation is compounded by our choice of illuminator placement (which was unfortunately necessary to provide sufficient coverage with a limited number of illuminators). Were the illuminators pointed up at the surface, the light would be much brighter.

Only recently did we learn that the Reactable uses 400 IR LED lights. Given the large area of our table's surface, it would not surprise me if 800 IR LEDs were needed to achieve the same level of robustness.

The problem of creating an even distribution of light will always remain. Material choices can help or hinder this process. Plastic signage surfaces such as Plexiglass Endlighten could aid table developers as they aim to provide consistent illumination across their surface when illuminated inconsistently from their edges.

7.2 Experiment Discussion

We did not collect sufficient data for our results to be reliable. With only 10 groups, we needed at least another 4-6 groups to cope with the expected experimental variance.

We did not have time to perform any qualitative analysis on our data; specifically, using the pre-test questionnaire. We do not provide any evidence about the participants as individuals and as such our data may be biased.

We failed to ask all desirable questions in the post-test questionnaire. Specifically, it would have been extremely interesting to gather the reaction of participants to the visualization: whether they paid attention to the visualization, whether they felt it affected their interactions, whether they felt it affected their ratings of other participants in the post-test questionnaire itself.

Anecdotally, only one group ever discussed the visualization during the game (that is, not during the tutorial when its function was explained). This group were aware of each other's participation levels and verbalized their levels at the end of the game.

8.0 Conclusion

Our analysis provides some evidence that visualization feedback does not result in greater equality of participation. Whilst the opposite was in fact observed, this was not a significant result. Even though the speaking time was not presented as a participation visualization element, both the speaking time and table interaction metrics followed the same trend.

The score as an objective measurement of the group's performance did not correlate to either the speaking time or the table interaction metrics.

The individual perceived performance did not vary significantly in the presence of visualization. However, the same was not true for the perceived group performance. The visualization groups rated their group performance significantly higher than the non-visualization groups. We cannot explain this result with any confidence. Although it is possible to suggest reasons why this situation came about, we do not have sufficient data to fully understand what is occurring.

Visualization should not be examined alone, but in relation to many other factors. This is especially important for small group research.

9.0 Future Work

Whilst not an extension of existing works, more experiments should be performed. Our study could be a pilot for a larger study, which corrects many of the mistakes in ours (such as not asking sufficient questions to the participants).

The table and game both acted as barriers to participants. In effect, participants had to cope with two learning curves: one for the table interaction, and another for the rules of the game. It would be interesting to repeat the experiment with the same groups under the same conditions to see whether their appreciation of the visualization changed.

Our analysis from hypothesis 1 and 2, whilst not statistically significant, was at odds with results from the literature. It seems that there is some variable affecting participation that neither experiment has identified and isolated. A better model needs to be devised and tested such that this variance can be explained with confidence. However, this is a large and complicated task. Through use of a pre-test questionnaire, controlled conditions must be created. By forming groups according to the data received from the pre-test questionnaire, different factors (such as age, sex and decision-making experience) may be studied. This situation allows for easier identification of relevant factors and allows for correlation of group and participant internal factors to external factors (such as the visualization).

Appendix 1 – ***Multi-touch Table production documentation***

A1.1 Table Construction Images

Figure 21: This polycarbonate sheet was originally a spare wall from an old CAVE system at UCL. For this reason, it is an excellent projection surface and happens to be suitably diffuse on one side.

Figure 22: Testing the polycarbonate's suitability for a multi-touch table, bearing in mind the polycarbonate is 10mm thick. Due to the large size of the table, the surface needs to be structurally self-supportive.

Figure 23: The steel frame was welded by the Bartlett workshop staff.

Figure 24: The table base was constructed from MDF. It was first glued and then later strengthened with corner brackets.

Figure 25: Completed base, steel structure, and (not final sized) polycarbonate surface.

Figure 26: Inside the table, now with the projector mounted. The mirror is hinged and raised at an angle. Note the aluminum foil on the inside of one side panel. This picture was taken during our investigation into reflective/diffusive finishes.

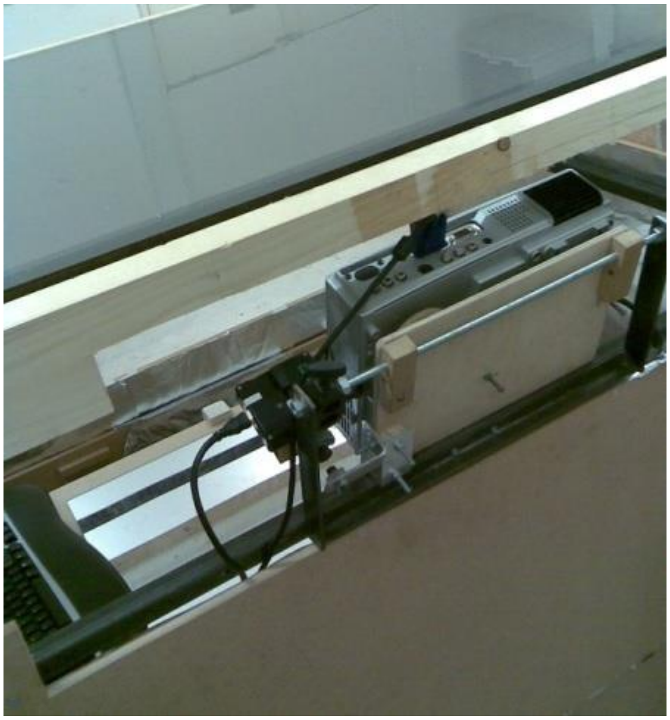


Figure 27: The projector in its metal frame sits inside the table and is invisible from the outside once covered with the lid. The projector's metal frame was designed and constructed to be adjustable and accommodate a variety of models and specifications.

Figure 28: The table before painting. Notice the wooden support beams screwed to the metal frame. The table's lid needs to take the weight of four people leaning on it.

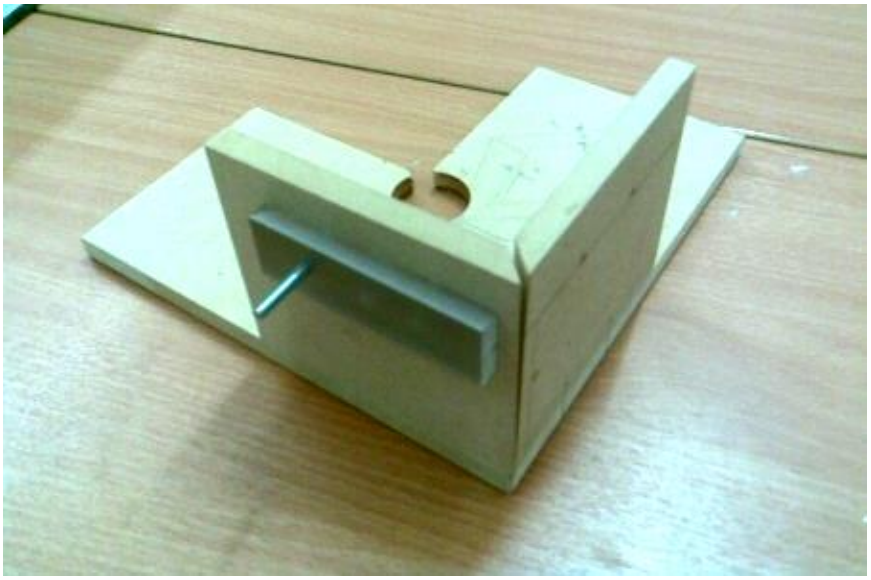


Figure 29: Mock ups are fundamental for deciding the right strategy for a detail. In this case, the lid of the table was mocked up to help decide how more expensive finishes would be applied.

Figure 30: MDF primer allows a smooth finish by sealing the surface and stopping moisture absorption.

Figure 31: A satin-based top coat provides colour. A clear varnish was applied to aid durability.

Figure 32: A small switch box was laser cut and assembled. It is situated between the Perspex and sides in a discrete location. The buttons face the floor so that people cannot accidentally reset the system with their knees.

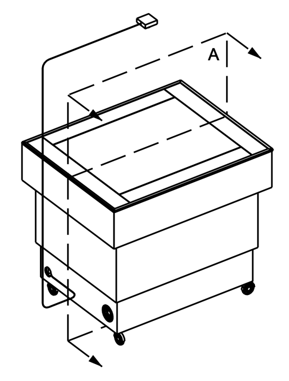
Figure 33: The table lid is constructed from glossy black Perspex. The lid is trimmed with black rubber L-section.

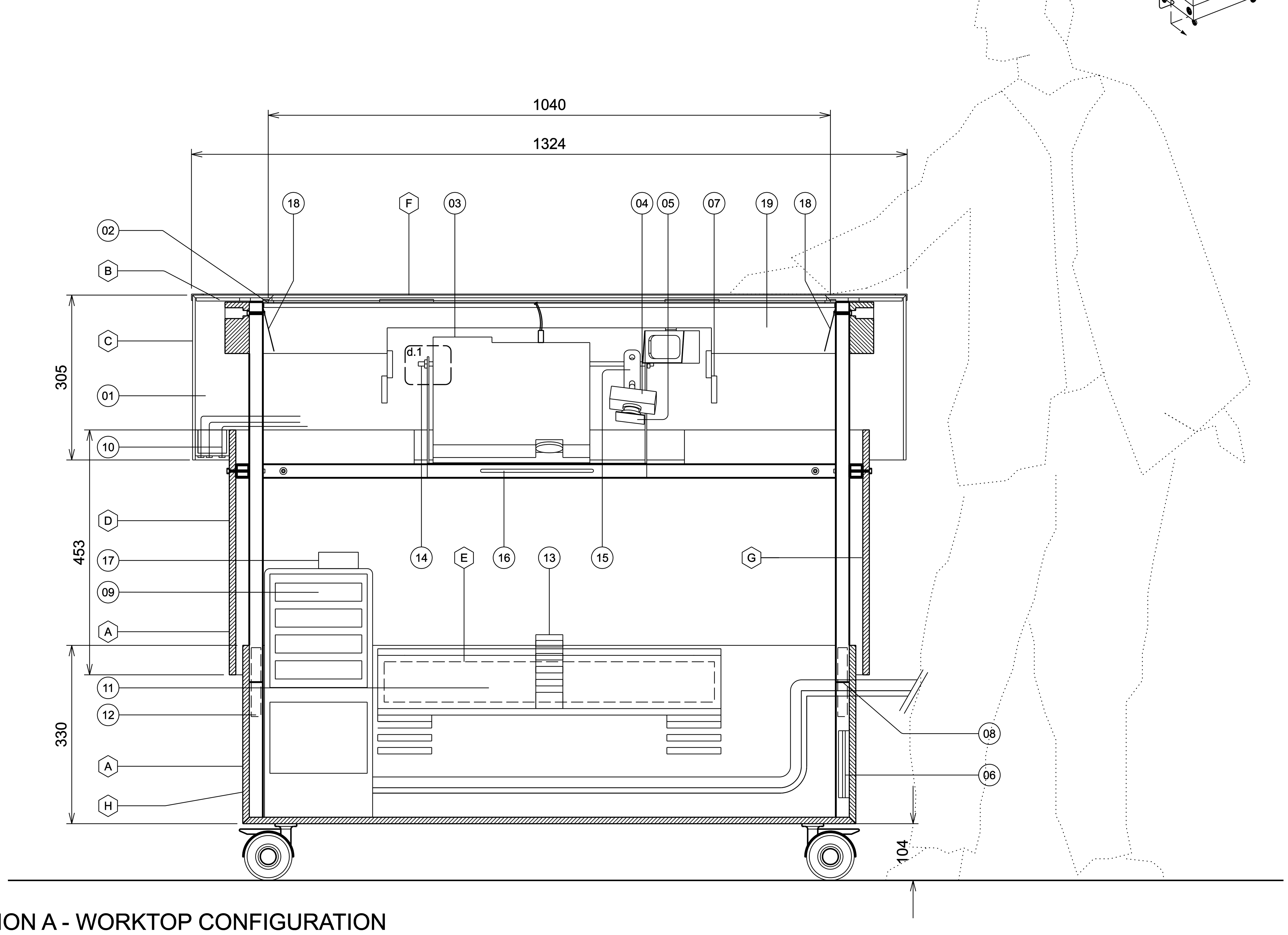
Figure 34: A photograph demonstrating the size of the bezel compared to the base.

LEGEND

- 01 VENTILATION GAP
- 02 L-SECTION BEAM STRUCTURE
- 03 PROJECTOR
- 04 CAMERA
- 05 INFRARED FILTER
- 06 LOWER FAN
- 07 UPPER LATERAL FAN
- 08 OPENING FOR CABLING
- 09 PC TOWER CASE
- 10 CONTROL BOX
- 11 PROJECTED IMAGE MIRROR
- 12 LEG EXTENSION FOR WORK TOP HEIGHT
- 13 MIRROR ANGLE ADJUSTMENT
- 14 ADJUSTMENT FOR PROJECTOR
- 15 ADJUSTMENT FOR INTERNAL TRACKING CAMERA
- 16 LATERAL MECHANISM FOR PROJECTOR
- 17 WIRELESS RADIO MOUSE/KEYBOARD TRANSCEIVER
- 18 WHITE CARD REFLECTOR
- 19 TABLE TOP SUPORT
- 20 INFRARED LED ILLUMINATOR
- 21 PROJECTION SURFACE FRAMING
- 22 PROJECTION SURFACE HEIGHT ADJUSTMENT
- 23 SAFETY/ IMPACT TRIM
- 24 TOP LID INTERNAL SUPPORT
- 25 PROJECTION SURFACE
- 26 HAND TRACKING CAMERA
- 27 MIRROR HEIGHT ADJUSTMENT - INTERNAL WALL MOUNTED
- 28 CASTERS - 500KG SHARED TOLERANCE

DRAWING KEY

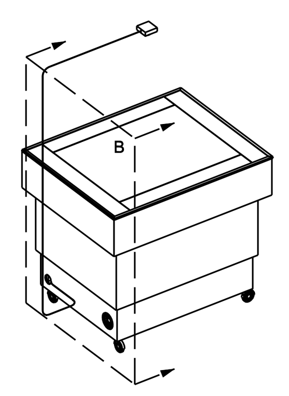


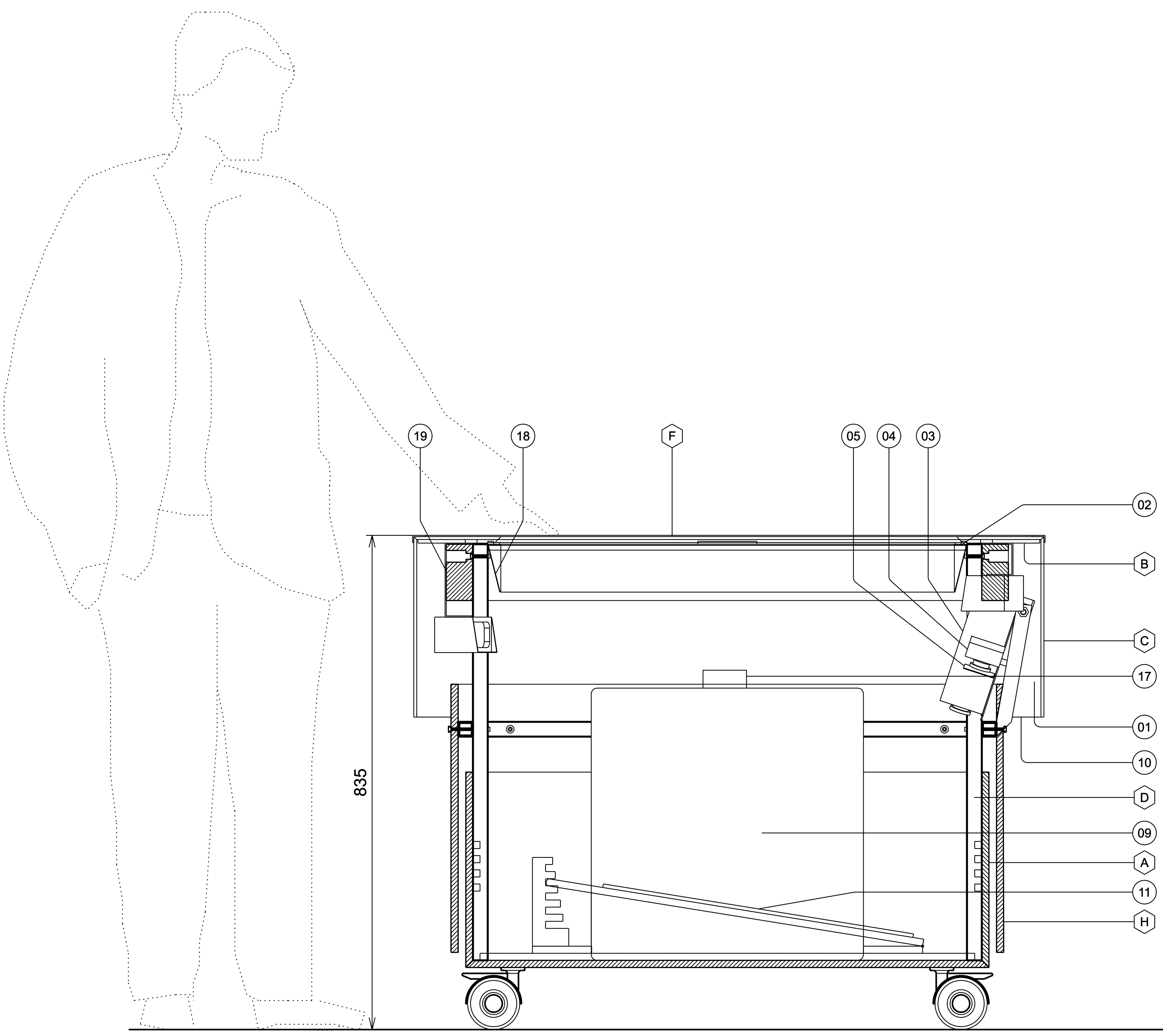


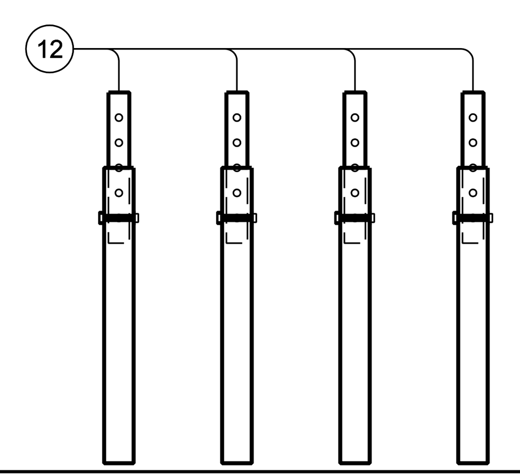
SECTION A - WORKTOP CONFIGURATION

- A MDF 12MM
- B MDF 6MM
- C OPAQUE PERSPEX (Black 9T30)
- D STEEL
- E PERSPEX - MIRROR
- F LIGHT TRANSMITTING POLYCHROMATIC 10MM
- G WATER BASED ACRYLIC - SATIN WHITE
- H WATER BASED ACRYLIC - GRAY
- J RUBBER L-SECTION
- K RUBBER SHEET - 2MM

DRAWING KEY







SECTION B - DESKTOP CONFIGURATION

MULTITOUCH TABLE

GENERAL ARRANGEMENT - AS BUILT

Engineering Doctorate Group Project 2008

Section & Elevation - General Arrangement

50mm 100mm 200mm 500mm

Abel Maciel a.maciel@ucl.ac.uk

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UCL

LEGEND

01 VENTILATION GAP
02 L-SECTION BEAM STRUCTURE
03 PROJECTOR
04 CAMERA
05 INFRARED FILTER
06 LOWER FAN
07 UPPER LATERAL FAN
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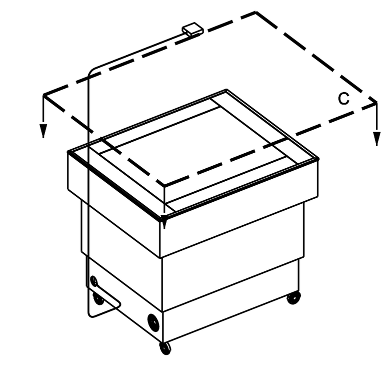
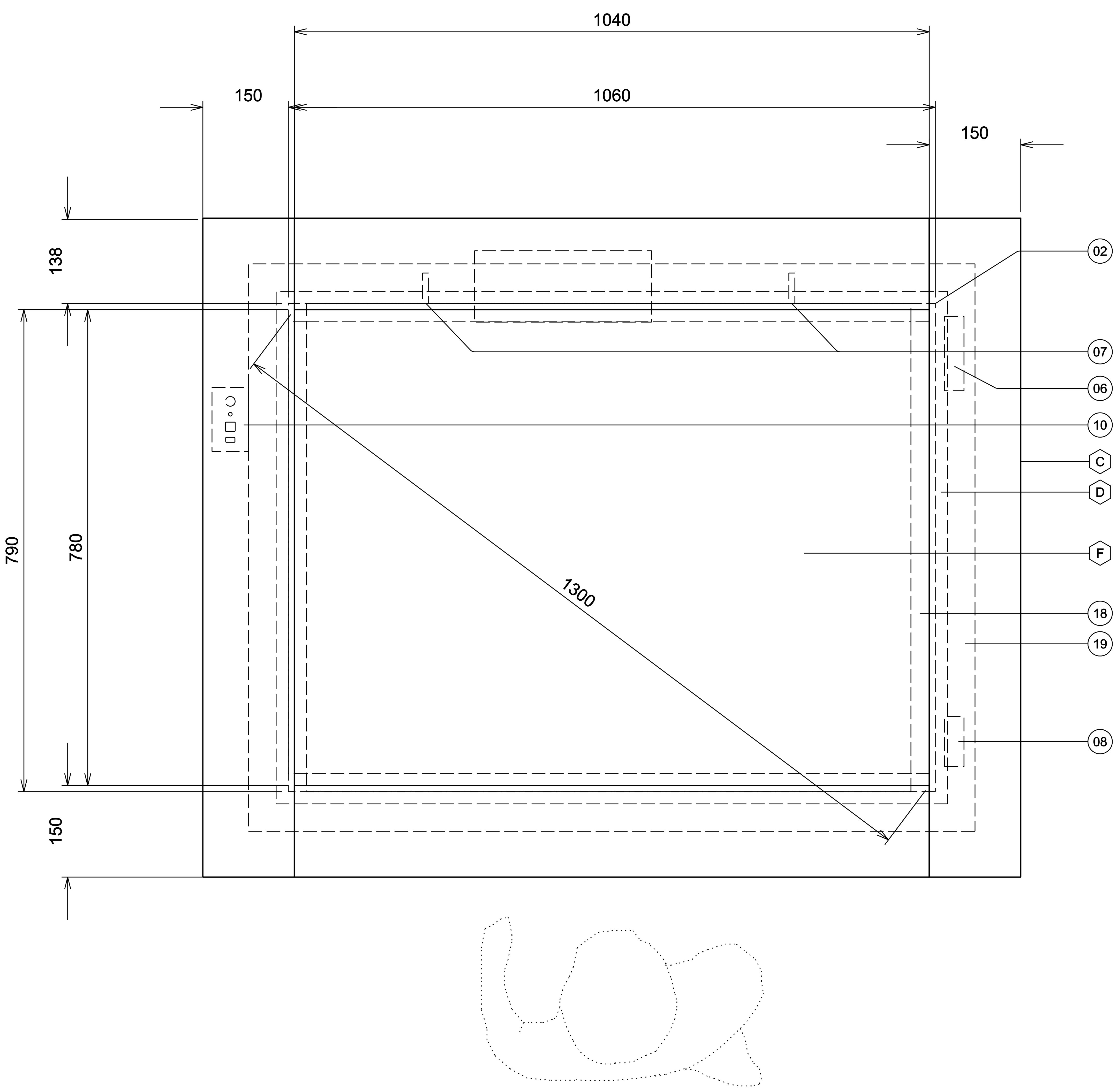
24 TOP LID INTERNAL SUPPORT
25 PROJECTION SURFACE
26 HAND TRACKING CAMERA
27 MIRROR HEIGHT ADJUSTMENT - INTERNAL WALL MOUNTED
28 CASTERS - 500KG SHARED TOLERANCE

DRAWING KEY

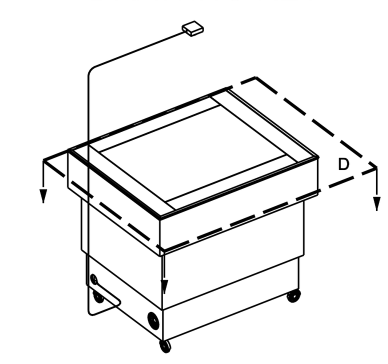


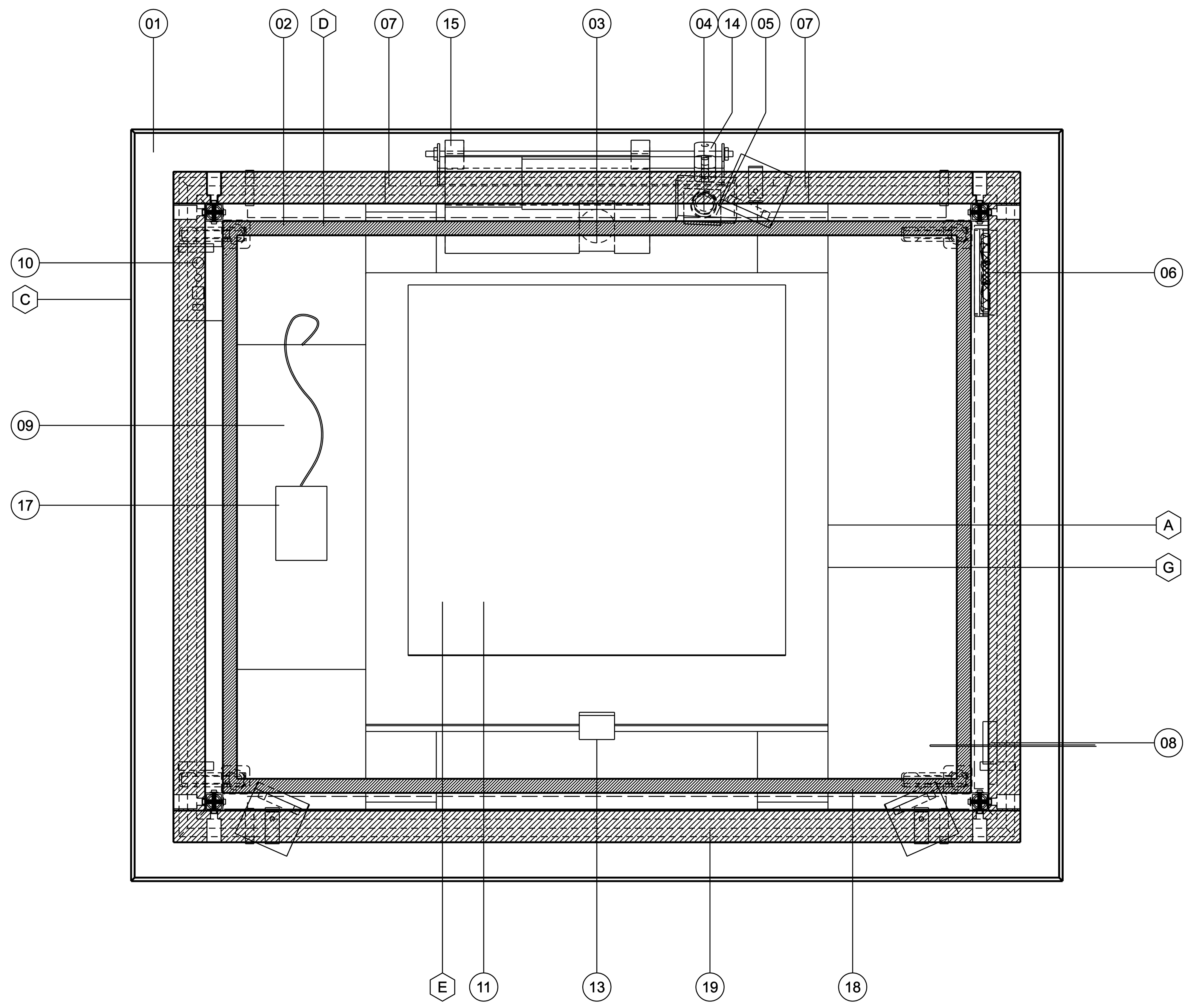


PLAN C - WORKTOP CONFIGURATION

A MDF 12MM
B MDF 6MM
C OPAQUE PERSPEX (Black 9T30)
D STEEL
E PERSPEX - MIRROR
F LIGHT TRANSMITTING POLYCHROMATIC 10MM
G WATER BASED ACRYLIC - SATIN WHITE
H WATER BASED ACRYLIC - GRAY
J RUBBER L-SECTION
K RUBBER SHEET - 2MM

DRAWING KEY





SECTIONAL PLAN D - DESKTOP CONFIGURATION

MULTITOUCH TABLE
AS BUILT
Engineering Doctorate Group Project 2008

Plans - General Arrangement

50mm 100mm 200mm 500mm

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UCL

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LEGEND

- 01 VENTILATION GAP
- 02 L-SECTION BEAM STRUCTURE
- 03 PROJECTOR
- 04 CAMERA
- 05 INFRARED FILTER
- 06 LOWER FAN
- 07 UPPER LATERAL FAN
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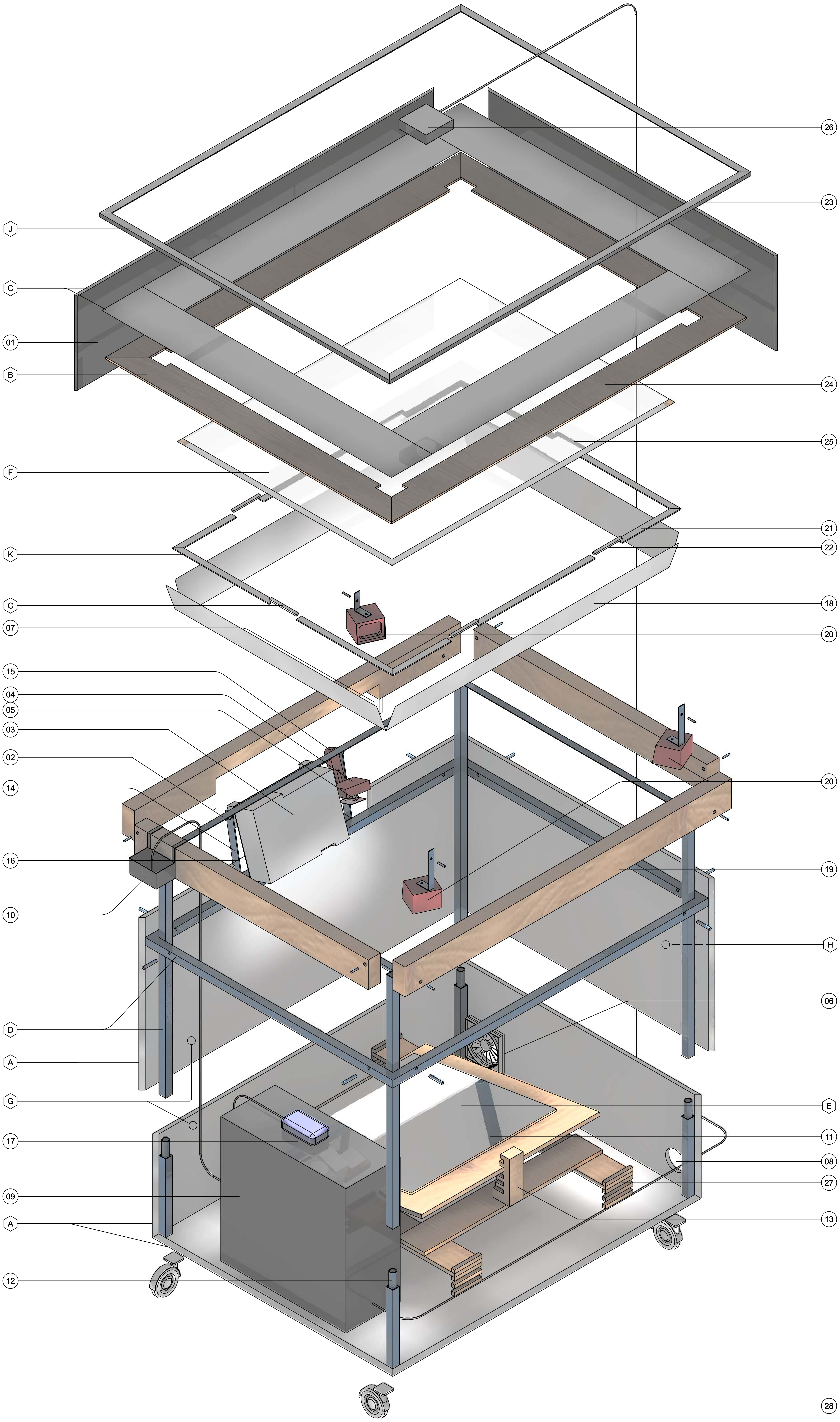
- 25 PROJECTION SURFACE
- 26 HAND TRACKING CAMERA
- 27 MIRROR HEIGHT ADJUSTMENT - INTERNAL WALL MOUNTED
- 28 CASTERS - 500KG SHARED TOLERANCE

- A MDF 12MM
- B MDF 6MM
- C OPAQUE PERSPEX (Black 9T30)
- D STEEL
- E PERSPEX - MIRROR
- F LIGHT TRANSMITTING POLYCHROMATIC 10MM
- G WATER BASED ACRYLIC - SATIN WHITE
- H WATER BASED ACRYLIC - GRAY
- J RUBBER L-SECTION
- K RUBBER SHEET - 2MM



MULTITOUCH TABLE AS BUILT *Engineering Doctorate Group Project 2008*	Isometric 50mm 100mm 200mm 500mm	Abel Maciel a.maciel@ucl.ac.uk University College London 2008 ©

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Appendix 2 - ***Questionnaires***

A2.1 Pre-test questionnaire:

EngD Group Project 2008

Abel Maciel, Artemis Skarlatidou, James Tompkin, Patrick Weber

We would like to welcome and thank you for participating in our study. Before start playing the game, please complete the following questionnaire.

Please note that this questionnaire is completely confidential. The information gathered herein will only be used by our team. Identifying information will never be distributed to parties outside this experiment.

1. **Please indicate your job title.**

....

2. **If you are a student, please specify the subject of your studies.**

....

3. **Please, indicate your age group.**

(Please tick one of the following boxes)

☐ 18-24

☐ 25-34

☐ 35-44

☐ 45-54

☐ 55+

4. **Please specify your gender.**

(Please tick one of the following boxes)

☐ Male ☐ Female

5. **How often do you participate in meetings with colleagues or classmates?**

(Please tick one of the following boxes)

☐ Never

☐ Less Often (1 meeting per month or less)

☐ Often (1 meeting per week)

☐ Very Often (Almost every day)

A2.2 Post-test Questionnaire:

EngD Group Project 2008

Abel Maciel, Artemis Skarlatidou, James Tompkin, Patrick Weber

Thank you for participating in our study. Please answer the following questions.

This questionnaire is completely confidential. The information gathered herein will only be used by our team. Identifying information will never be distributed to parties outside this experiment.

---

1. Please indicate your member ID.

(Please tick only **one** box)

☐ Participant A

☐ Participant B

☐ Participant C

☐ Participant D

---

2. Have you ever played Carcassonne before?

(Please tick only **one** box)

☐ Yes

☐ No

3. How familiar are you with the game?

(Please tick only **one** box**)**

5. Very Familiar (Played the game more than 10 times)	4.Somewhat Familiar (Played the game 5-10 times)	3. Slightly Familiar (Played the game less than 5 times, but I hardly remember the rules)	2. A Little Familiar (I know the rules, but never played the game before)	1. Not Familiar (It is the first time I play the game)
☐	☐	☐	☐	☐

---

4. How helpful was the tutorial in explaining the rules?

(Please tick only **one** box**)**

5. Very Easy (Straight Forward)	4. Slightly Helpful (Asked other team members to further confirm/ explain the rules)	3. Helpful (The rules became clear only while playing the game)	2. A little Helpful (Everything became clear at the end of the game)	1. Not Helpful (Still do not feel confident)
☐	☐	☐	☐	☐

5. To help us understand how you perceive your group's performance, please indicate how much you agree with the following statements.

(Please tick **one** box per row)

	5. Strongly Agree	4. Agree	3. Neither Agree Nor Disagree	2. Disa-gree	1. Strongly Disagree
My team employed the best way to play the game.	☐	☐	☐	☐	☐
My team had a good understand-ing of the game process.	☐	☐	☐	☐	☐
Communication be-tween group mem-bers was necessary in order to play the game.	☐	☐	☐	☐	☐
Our communica-tion helped to bet-ter play the game.	☐	☐	☐	☐	☐
I feel satisfied from the process (strat-egy) followed.	☐	☐	☐	☐	☐
Communication was smooth.	☐	☐	☐	☐	☐

6. To help us understand how you perceive your individual performance, please in-dicate how much you agree with the following statements.

(Please tick one box per row)

	5. Strongly Agree	4. Agree	3. Neither Agree Nor Disagree	2. Disagree	1. Strongly Disagree
I played an essential role as an individual.	☐	☐	☐	☐	☐
I contributed to the discussions.	☐	☐	☐	☐	☐
There were circumstances that I was consulted by the other members.	☐	☐	☐	☐	☐
There were circumstances that I was rewarded by the other members.	☐	☐	☐	☐	☐

---

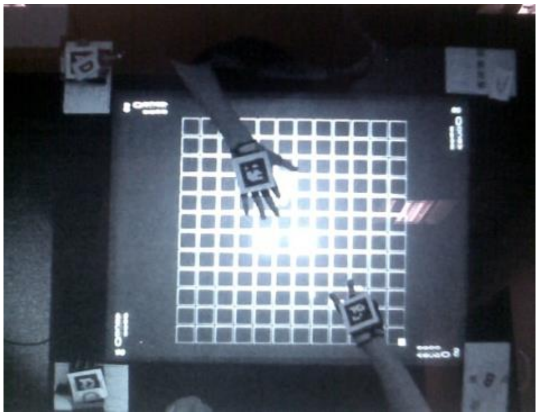
7. Please rate the contribution of each member in the game process.

'5' is high. If you believe that participation was equal, please tick the box of the last option.

	5	4	3	2	1
Participant A	☐	☐	☐	☐	☐
Participant B	☐	☐	☐	☐	☐
Participant C	☐	☐	☐	☐	☐
Participant D	☐	☐	☐	☐	☐
Participation was equal by all group members.	☐				

Appendix 3 ***– Data Collection***

A3.1 Camera above table, grayscale, no audio.



A3.2 Room camera, colour, audio.

Figure 35: Explaining the experiment.

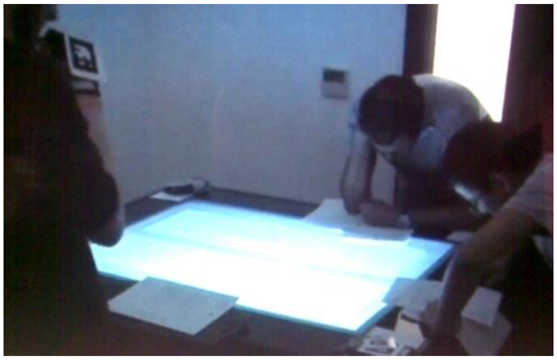


Figure 36: Completing the pre-test questionnaire.

Figure 37: Playing the game. In this case, without feedback.

Figure 38: Completing the post-test questionnaire.

A3.3 Game data output

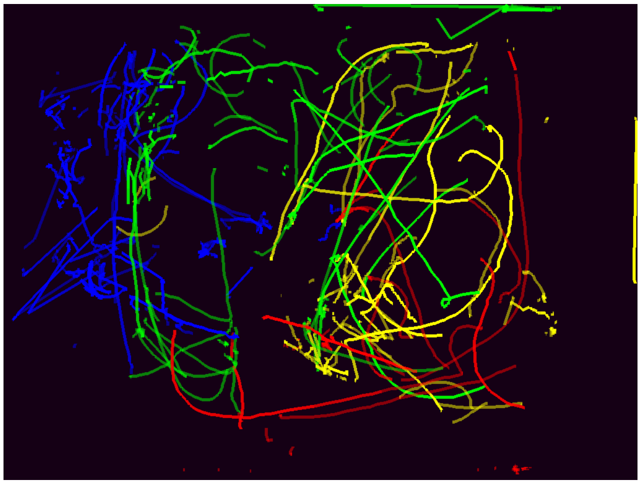


Figure 39: All finger interaction is tracked. Here we see a simple visualization of one group's interaction across the 30-minute scenario session.

Appendix 4 – ***Data Tables***

A4.1 Pre-test questionnaire data

Session	Vis?	Participant	Job Title	Know Game?	Age	Sex	Meetings?	Score	Speaking Time (mm:ss)	Time Touching Table (mm:ss)
2008-06-26 18-28-08	Vis	A	Student	No	18-24	M	4	101	01:10	03:47
2008-06-26 18-28-08	Vis	B	Student	No	25-34	F	4	101	00:43	02:48
2008-06-26 18-28-08	Vis	C	Student	No	18-24	M	4	101	00:56	06:04
2008-06-26 18-28-08	Vis	D	Student	No	25-34	M	4	101	00:09	02:21
2008-06-27 16-58-34	Vis	A	Student	No	25-34	F	2	83	08:59	09:32
2008-06-27 16-58-34	Vis	B	Student	No	25-34	F	2	83	01:24	04:49
2008-06-27 16-58-34	Vis	C	Student	No	25-34	F	3	83	01:13	04:52
2008-06-27 16-58-34	Vis	D	MSc Student	No	25-35	M	4	83	01:41	02:09
2008-07-01 18-00-00	Vis	A	Intern	Yes	18-24	M	2	97	04:16	01:13
2008-07-01 18-00-01	Vis	B	Research Assistant	No	25-34	F	4	97	00:53	03:09
2008-07-01 18-00-02	Vis	C	Student	No	18-24	M	3	97	02:03	02:19
2008-07-01 18-00-03	Vis	D	Student	No	18-25	M	3	97	02:31	02:35
2008-07-03 13-00-00	Vis	A	IS Applications Developer	No	35-44	M	4	81	04:59	01:13
2008-07-03 13-00-01	Vis	B	Student	No	25-34	M	2	81	02:30	04:49
2008-07-03 13-00-02	Vis	C	Reseracher	No	35-44	F	2	81	01:38	06:56
2008-07-03 13-00-03	Vis	D	PhD Student	No	25-34	M	3	81	02:40	05:42
2008-07-04 14-00-00	Vis	A	Architecuret & Computation	No	18-24	M	3	66	02:52	01:32
2008-07-04 14-00-01	Vis	B	Teaching Assistant	No	35-44	F	3	66	03:07	02:55
2008-07-04 14-00-02	Vis	C	Student	No	18-24	F	3	66	01:58	04:41
2008-07-04 14-00-03	Vis	D	Architect Engineer	No	25-34	F	3	66	02:59	10:39
2008-06-26 16-35-13	NoVis	A	PhD Student	No	25-34	M	2	95	00:05	02:45
2008-06-26 16-35-13	NoVis	B	PhD Researcher	No	25-34	M	3	95	00:47	02:18
2008-06-26 16-35-13	NoVis	C	Project Systems Admin	No	25-34	M	2	95	00:20	02:54
2008-06-26 16-35-13	NoVis	D	PhD Student	No	25-34	M	3	95	00:50	08:55
2008-06-27 15-48-14	NoVis	A	Student	No	25-34	F	1	60	01:13	09:38
2008-06-27 15-48-14	NoVis	B	Research Fellow	No	25-34	F	4	60	03:02	09:17
2008-06-27 15-48-14	NoVis	C	Spatial Analysis Researcher	No	25-34	F	4	60	02:01	08:02
2008-06-27 15-48-14	NoVis	D	Student	No	35-44	F	2	60	01:50	03:30
2008-06-30 16-00-00	NoVis	A	Researcher	No	25-34	M	3	69	03:13	04:01
2008-06-30 16-00-01	NoVis	B	Research Engineer	No	25-35	F	3	69	01:18	06:07
2008-06-30 16-00-02	NoVis	C	IT Consultant	No	25-34	M	4	69	04:26	03:58
2008-06-30 16-00-03	NoVis	D	PhD Student	No	25-34	F	3	69	02:25	02:01
2008-07-02 14-00-00	NoVis	A	Software Engineer	Yes	25-34	M	3	102	04:13	04:12
2008-07-02 14-00-01	NoVis	B	Student	No	18-24	M	3	102	02:35	03:32
2008-07-02 14-00-02	NoVis	C	Student	No	25-34	F	3	102	01:27	01:36
2008-07-02 14-00-03	NoVis	D	Student	No	18-24	F	3	102	02:42	03:12
2008-07-03 19-00-00	NoVis	A	Assistant	No	25-34	M	1	97	00:44	01:34
2008-07-03 19-00-01	NoVis	B	IT Risk Management Consultant	No	18-24	M	4	97	02:45	05:02
2008-07-03 19-00-02	NoVis	C	Student	Yes	18-24	M	3	97	05:34	04:57
2008-07-03 19-00-03	NoVis	D	Technical Analyst	Yes	18-24	M	4	97	02:37	01:52

A4.2 Time Touching the Table --Data

Visualization Group - Time Touching Table (in seconds)						
Group	**Participant A**	**Participant B**	**Participant C**	**Participant D**	**Average**	**STD**
Group 1	49	108	83	116	89	26.10555
Group 2	65	223	373	285	236.5	112.4489
Group 3	72	63	115	338	147	112.0112
Group 4	126	88	258	92	141	69.14478
Group 5	295	187	146	98	181.5	72.7066

No-Visualization Group - Time Touching Table (in seconds)						
Group	**Participant A**	**Participant B**	**Participant C**	**Participant D**	**Average**	**STD**
Group 1	192	157	86	118	138.25	39.9398
Group 2	86	221	116	95	129.5	53.93746
Group 3	84	67	73	276	125	87.39279
Group 4	201	130	244	50	156.25	73.62192
Group 5	93	134	128	68	105.75	26.83631

A 4.3 Tiles Picked Up --Data

Visualization Group - Tiles picked Up						
Group	**Participant A**	**Participant B**	**Participant C**	**Participant D**	**Average**	**STD**
Group 1	8	5	19	26	14.5	8.440972
Group 2	18	37	112	63	57.5	35.2881
Group 3	2	8	21	102	33.25	40.2826
Group 4	23	12	58	32	31.25	16.99081
Group 5	50	9	43	16	29.5	17.35655

No-Visualization Group - Tiles Picked Up						
Group	**Participant A**	**Participant B**	**Participant C**	**Participant D**	**Average**	**STD**
Group 1	44	13	23	29	27.25	11.23332
Group 2	44	13	23	29	27.25	11.23332
Group 3	14	14	43	78	37.25	26.33795
Group 4	40	25	42	14	30.25	11.45371
Group 5	16	4	24	50	23.5	16.87454

A 4.4 Tiles successfully placed --Data

Visualization Group - Tiles Successfully Placed						
Group	**Participant A**	**Participant B**	**Participant C**	**Participant D**	**Average**	**STD**
Group 1	3	1	4	6	3.5	1.802776
Group 2	4	4	4	2	3.5	0.866025
Group 3	0	1	3	7	2.75	2.680951
Group 4	6	4	2	2	3.5	1.658312
Group 5	5	2	5	2	3.5	1.5

No-Visualization Group - Tiles Successfully Placed						
Group	**Participant A**	**Participant B**	**Participant C**	**Participant D**	**Average**	**STD**
Group 1	8	3	1	2	3.5	2.692582
Group 2	2	4	4	4	3.5	0.866025
Group 3	2	4	3	5	3.5	1.118034
Group 4	3	2	4	0	2.25	1.47902
Group 5	4	2	3	4	3.25	0.829156

A 4.5 T-test result for Tiles Picked Up

Tiles Picked Up by Group	n	Mean	SE	STD
No-Visualization Group	20	29.1	3.93	17.6
Visualization Group	20	33.2	6.87	30.7

Mean Difference	-4.1
95% CI	-20.1 to 11.9
SE	7.92
T statistic	-0.52
DF	38.0
2-tailed p	0.6076

A 4.6 T-test result for Tiles Successfully Placed

Tiles Successfully Placed by Group	n	Mean	SE	STD
No-Visualization Group	20	3.2	0.37	1.7
Visualization Group	20	3.4	0.42	1.9

Mean Difference	-0.2
95% CI	-1.3 to 1.0
SE	0.56
T statistic	-0.27
DF	38.0
2-tailed p	0.7908

A 4.7 Time Speaking Data

Visualization Group - Speaking Time (in seconds)						
Group	**Participant A**	**Participant B**	**Participant C**	**Participant D**	**Average**	**STD**
Group 1	255.92	52.92	122.88	151.2	145.73	72.98557
Group 2	299.4	150.12	97.56	159.84	176.73	74.68129
Group 3	172.48	187.12	117.64	178.6	163.96	27.24357
Group 4	69.72	42.72	56.12	8.88	44.36	22.59949
Group 5	538.96	84.24	73.44	101.28	199.48	196.25

No-Visualization Group - Speaking Time (in seconds)						
Group	**Participant A**	**Participant B**	**Participant C**	**Participant D**	**Average**	**STD**
Group 1	253.48	154.8	87.48	162.16	164.48	59.05312
Group 2	44.36	164.56	333.6	157.04	174.89	103.2621
Group 3	4.84	46.96	19.84	49.6	30.31	18.75945
Group 4	72.88	181.52	121.36	109.56	121.33	39.07932
Group 5	193.48	77.68	265.64	144.96	170.44	68.64315

A 4.8 Perceived Individual Performance and Ratings for visualisation groups

Group	Individual Perceived Perfor-mance	Ratings
Visualiza-tion	2.8	3.75
Visualiza-tion	2.8	4
Visualiza-tion	2.8	4
Visualiza-tion	2.8	4
Visualiza-tion	3	3.5
Visualiza-tion	2.6	3.5
Visualiza-tion	2.4	3.5
Visualiza-tion	2.8	3.5
Visualiza-tion	2.8	3.75
Visualiza-tion	1.8	3.25
Visualiza-tion	2.2	3.75
Visualiza-tion	3	3.25
Visualiza-tion	3	4.5
Visualiza-tion	2.4	4.25
Visualiza-tion	2	3
Visualiza-tion	3.8	3.25
Visualiza-tion	3.2	2.5

Visualiza-tion	2.2	3.75
Visualiza-tion	2.8	4.25
Visualiza-tion	3	3.75

A 4.8 Perceived Individual Performance and Ratings for non-visualization groups

Group	Individual Perceived Performance	Ratings
No-Visualization	2.4	3.75
No-Visualization	2.8	3.25
No-Visualization	2.4	3.5
No-Visualization	2.8	3
No-Visualization	3.2	4.75
No-Visualization	2.8	3.5
No-Visualization	3.2	3.75
No-Visualization	4	3.25
No-Visualization	2.8	4.5
No-Visualization	3.2	2.75
No-Visualization	2.8	3.75
No-Visualization	2.4	2.75
No-Visualization	2.8	3
No-Visualization	2.8	3
No-Visualization	1.8	3
No-Visualization	2.6	3.25
No-Visualization	1.8	3
No-Visualization	3.4	3
No-Visualization	3.4	3
No-Visualization	2.6	3.25

A 4.9 Perceived Individual Performance – T-test results for visualisation and non-visualisation groups. This is a statistically significant result and demonstrates that individuals perceived better group performance in the presence of visualisation.

Totals by Group	n	Mean	SE	SD
Non-Visualization	20	25.5	0.57	2.6
Visualization	20	21	0.73	3.3
Mean Difference	4.5			
95% CI	2.6 to 6.4			
SE	0.93			
T - statistic	4.84			
DF	38			
2-tailed p	<0.0001			

A 4.10 Perceived Group Performance and Score Comparison

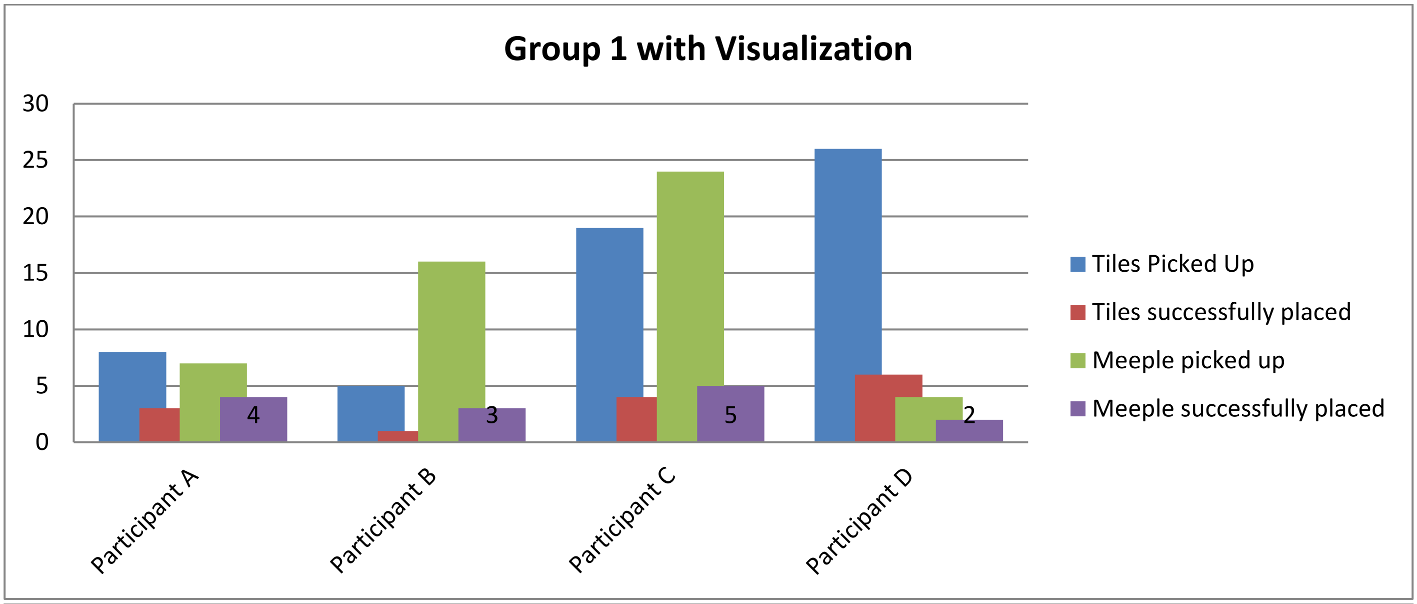
	PGP/Group	Score
Visualization	25.75	97
Visualization	24.75	81
Visualization	25.25	66
Visualization	25	101
Visualization	26.5	83
No-Visualization	21	102
No-Visualization	21	97
No-Visualization	22.5	95
No-Visualization	19	60
No-Visualization	21.25	69

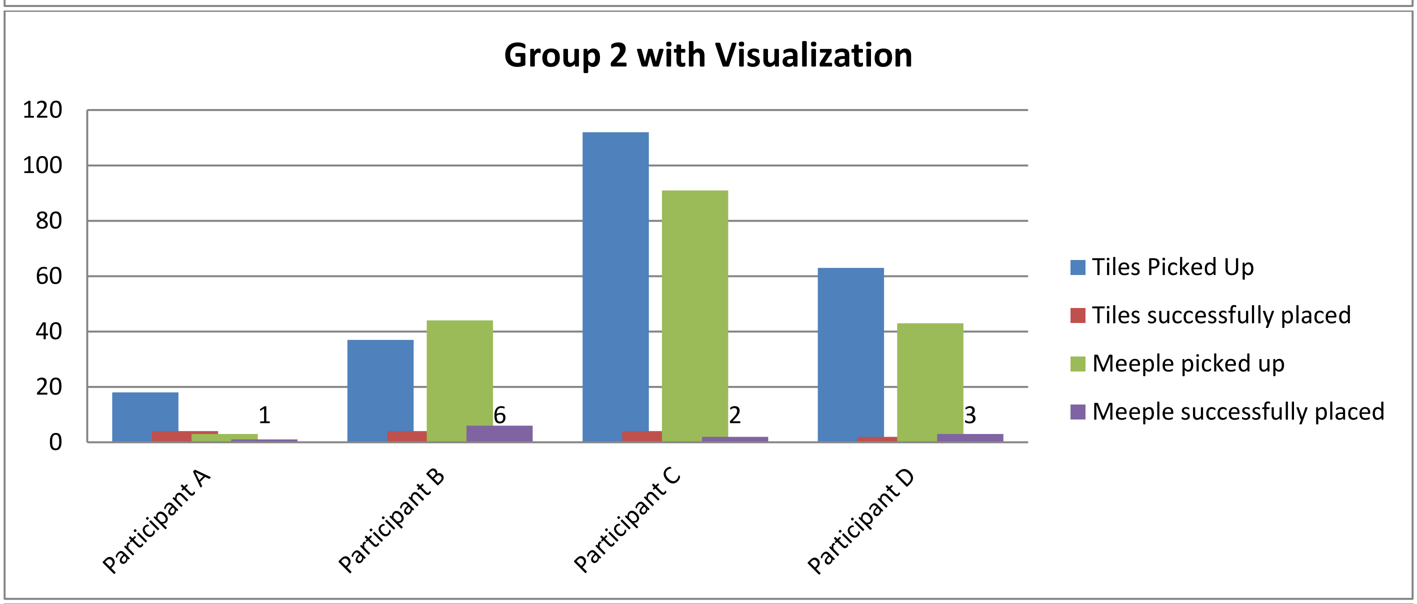
A 4.11 Perceived Group Performance – T-test results for visualization and no visualization groups. This is a statistically significant result and demonstrates that groups as a whole perceived better group performance in the presence of visualization.

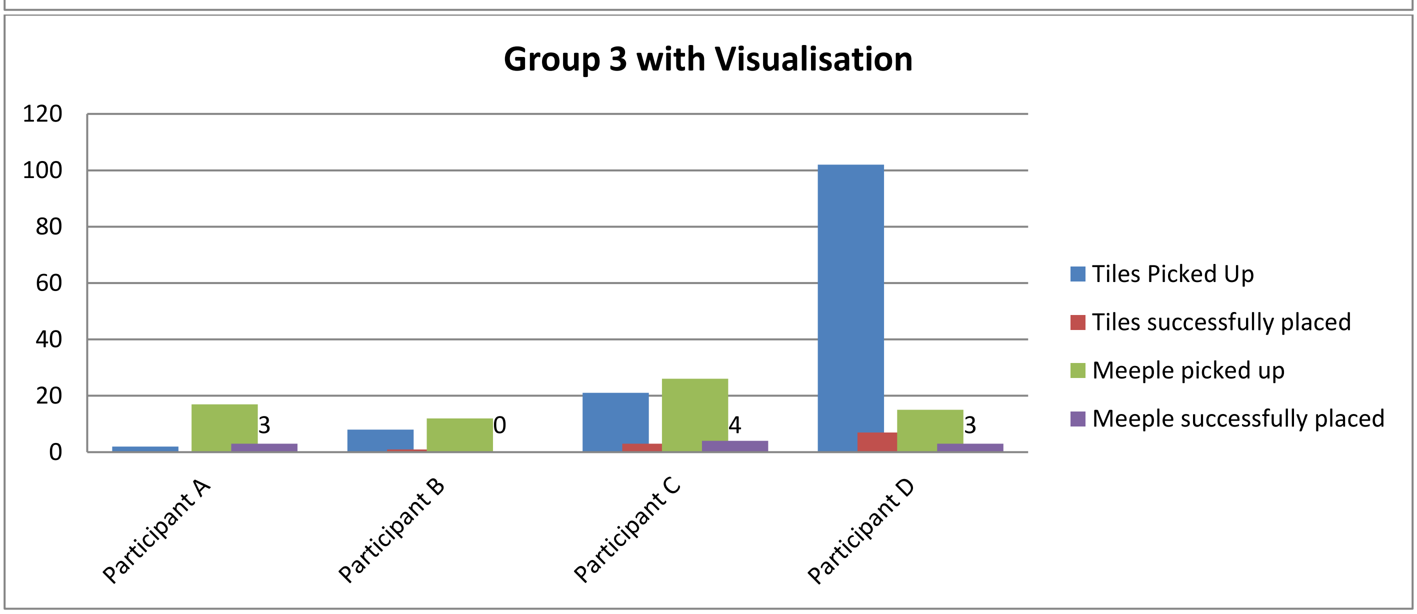
PGP/ Group	n	Mean	SE	SD
Non-Visualization	5	20.950	0.5612	1.255
Visualization	5	25.450	0.3102	0.694

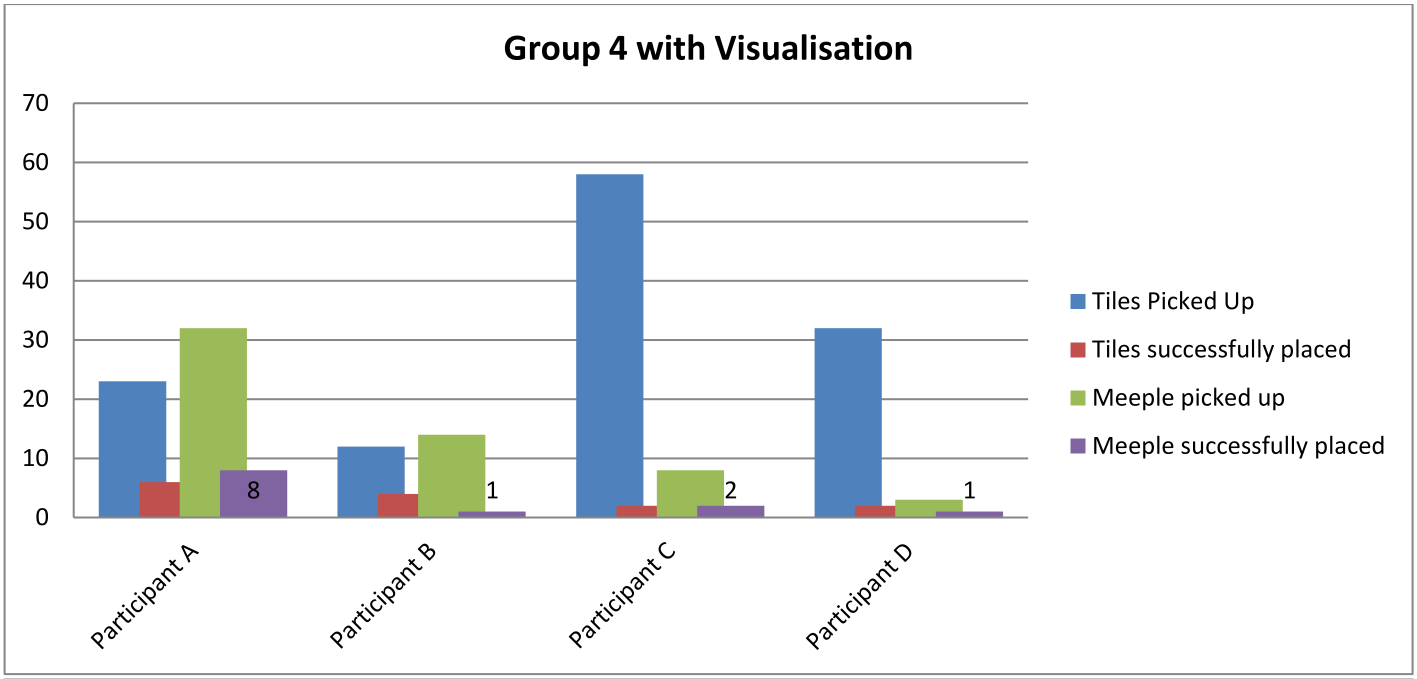
Mean Difference	-4.500
95% CI	-5.979 to -3.021
SE	0.6413
T - statistic	-7.02
DF	8.0
2-tailed p	0.0001

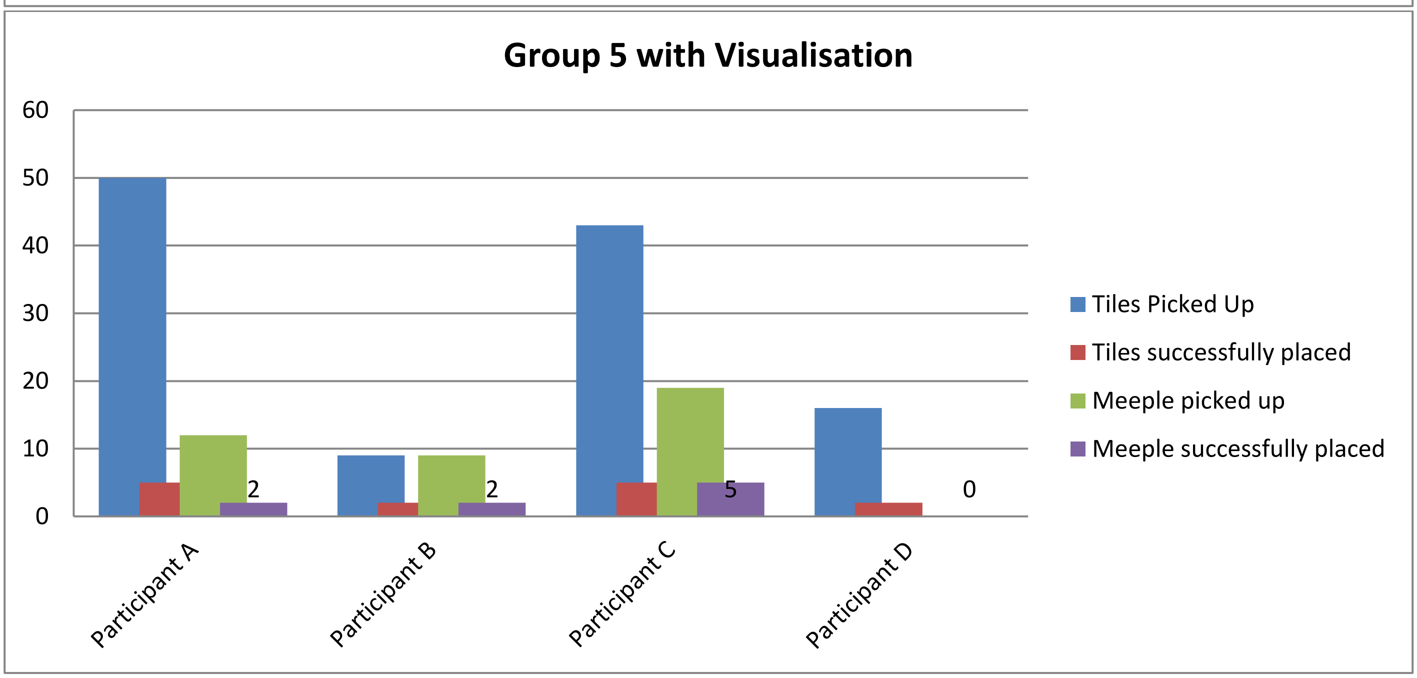
Appendix 5 - Metrics for groups with visualization

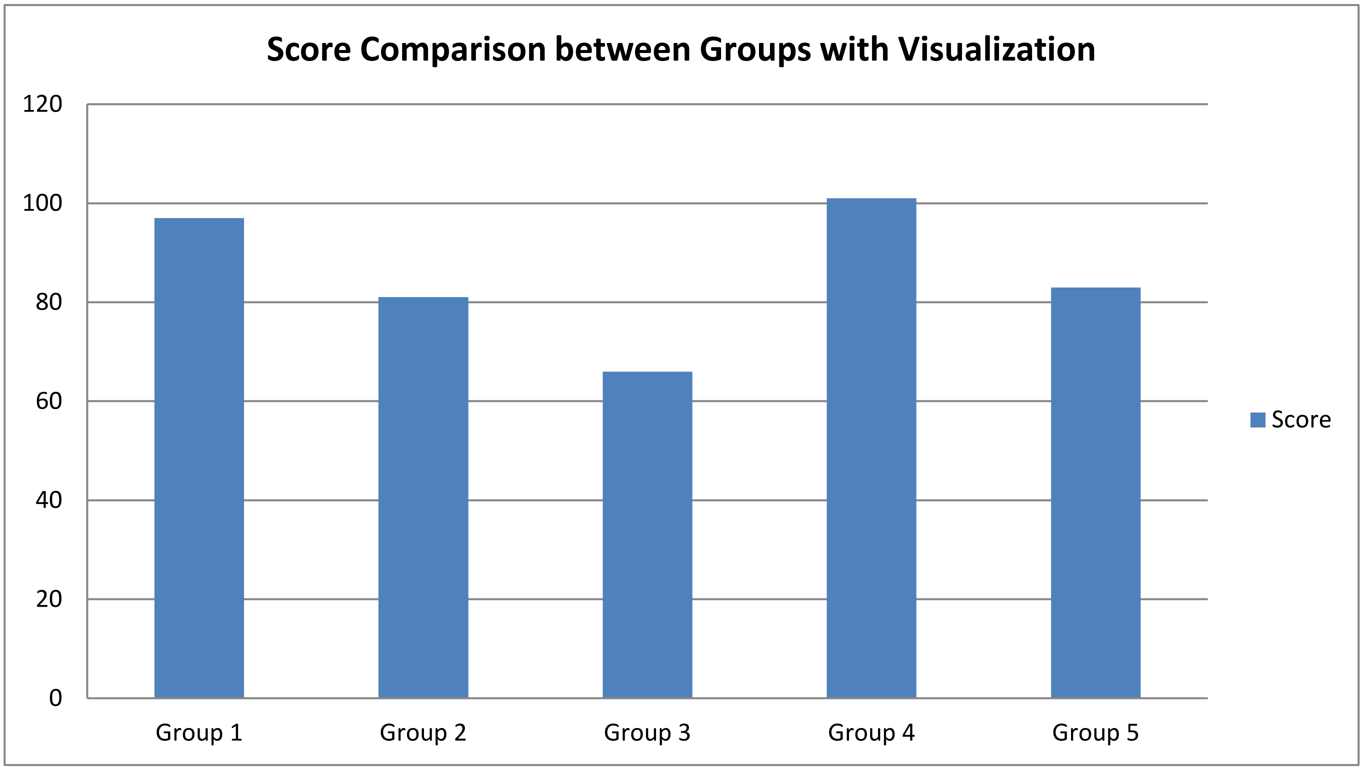


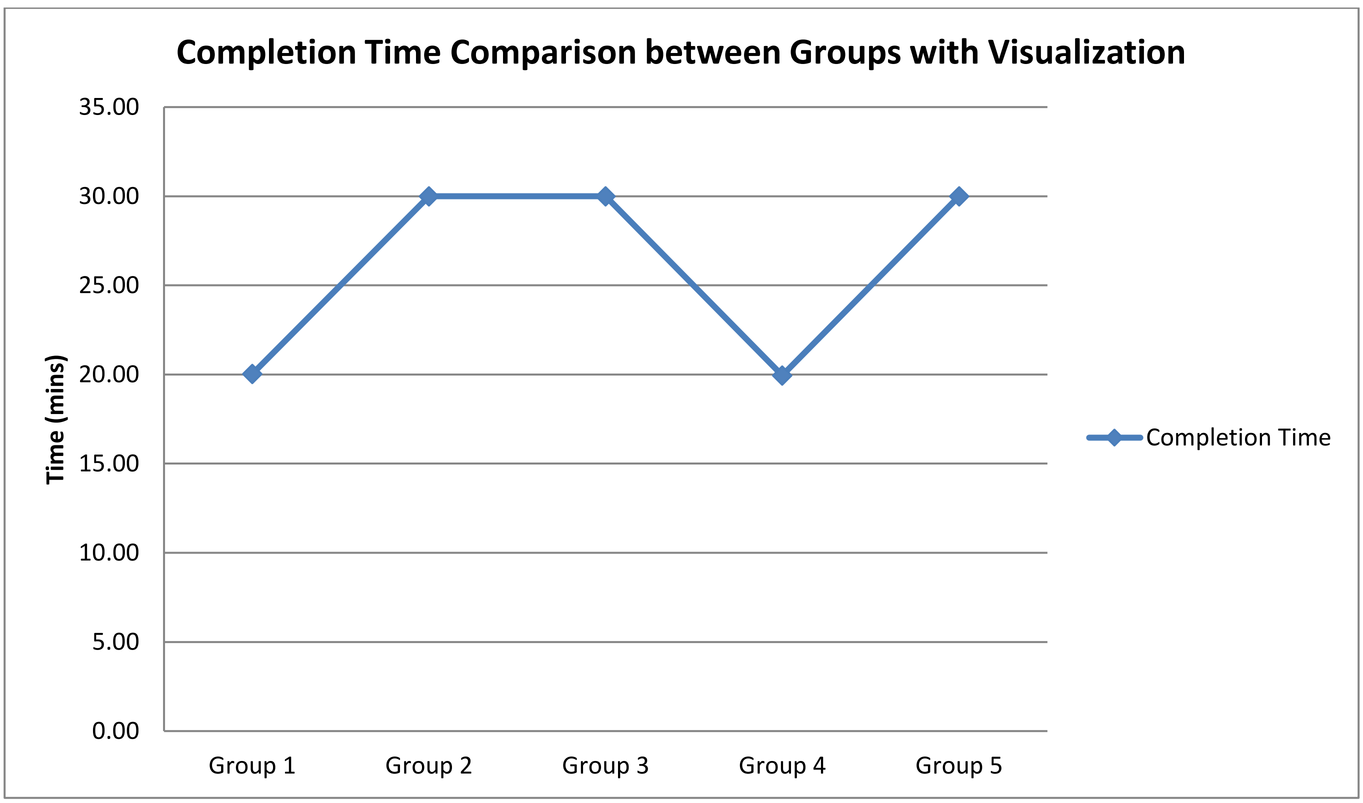




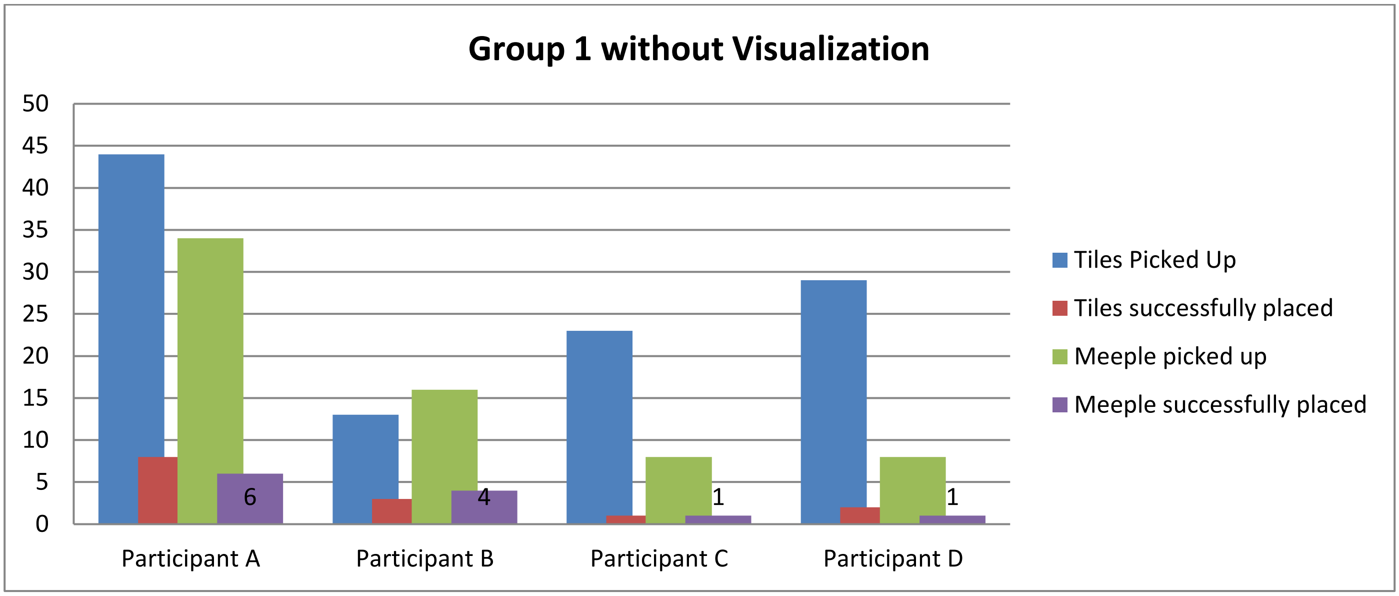

Group 4 with Visualisation
70
60
50
40
30
20
10
0
8
1
2
1
Participant A
Participant B
Participant C
Participant D
Tiles Picked Up
Tiles successfully placed
Meeple picked up
Meeple successfully placed

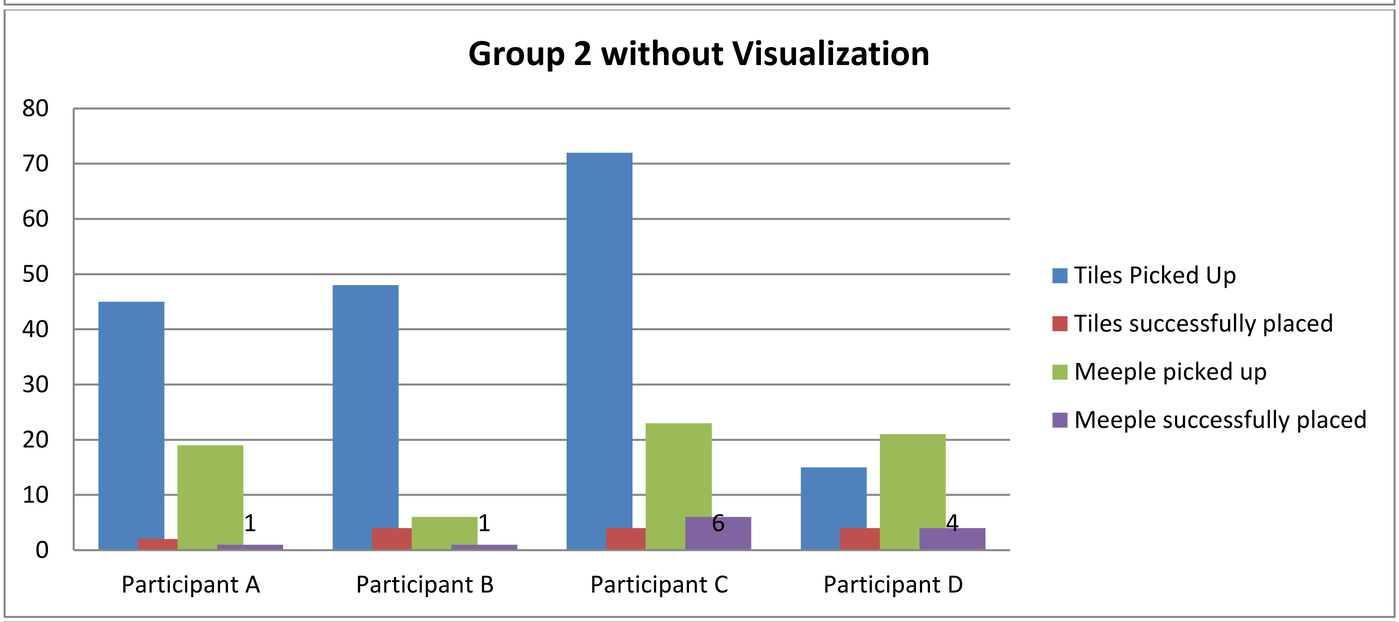

Group 5 with Visualisation
60
50
40
30
20
10
0
2
2
5
0
Participant A
Participant B
Participant C
Participant D
Tiles Picked Up
Tiles successfully placed
Meeple picked up
Meeple successfully placed

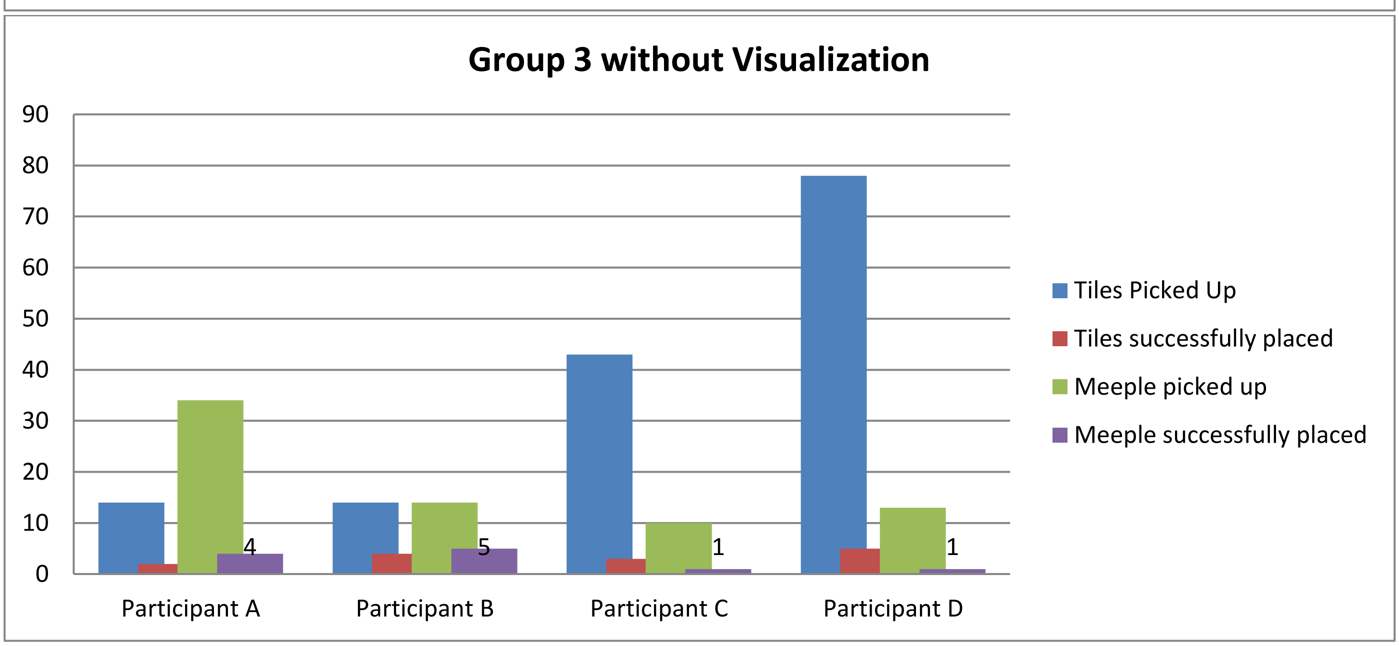

Score Comparison between Groups with Visualization
120
100
80
60
40
20
0
Score
Group 1
Group 2
Group 3
Group 4
Group 5

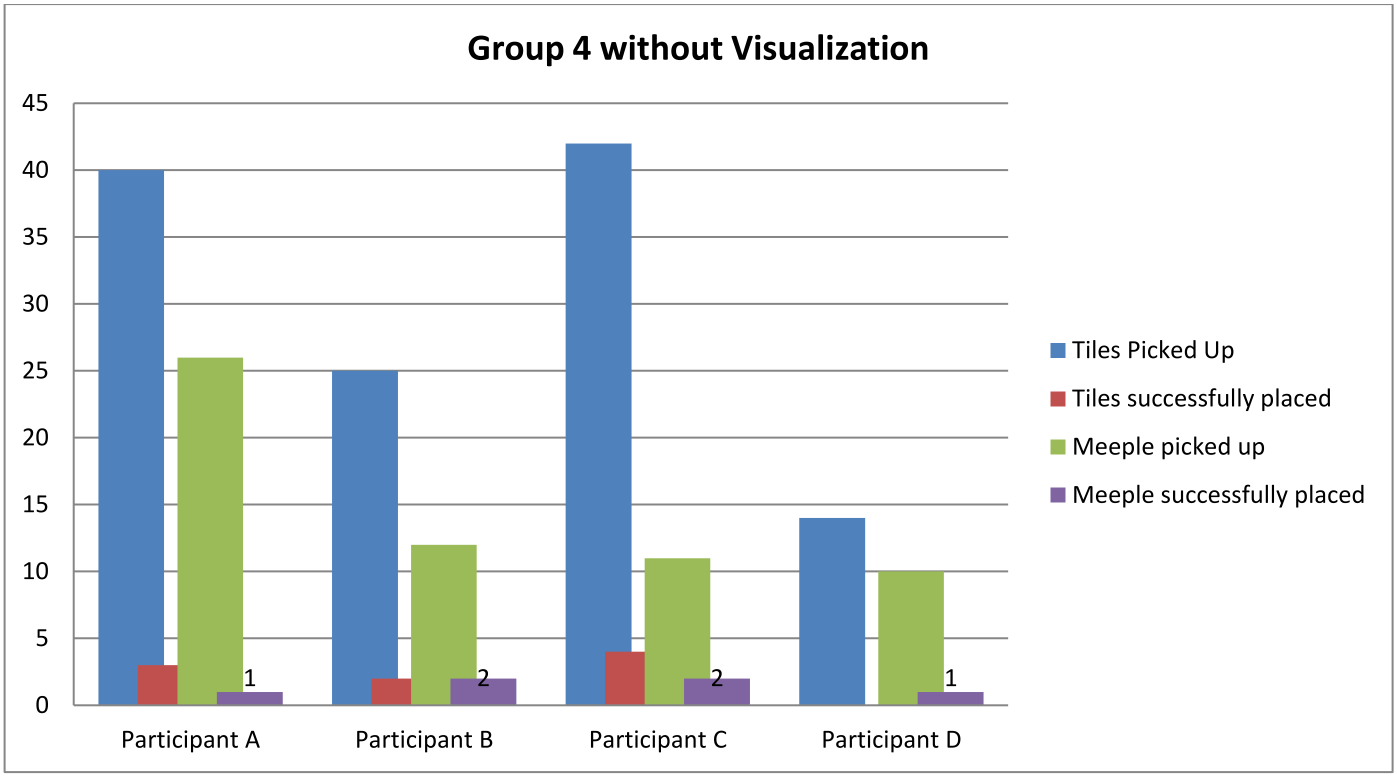

Completion Time Comparison between Groups with Visualization
Time (mins)
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Completion Time
Group 1
Group 2
Group 3
Group 4
Group 5

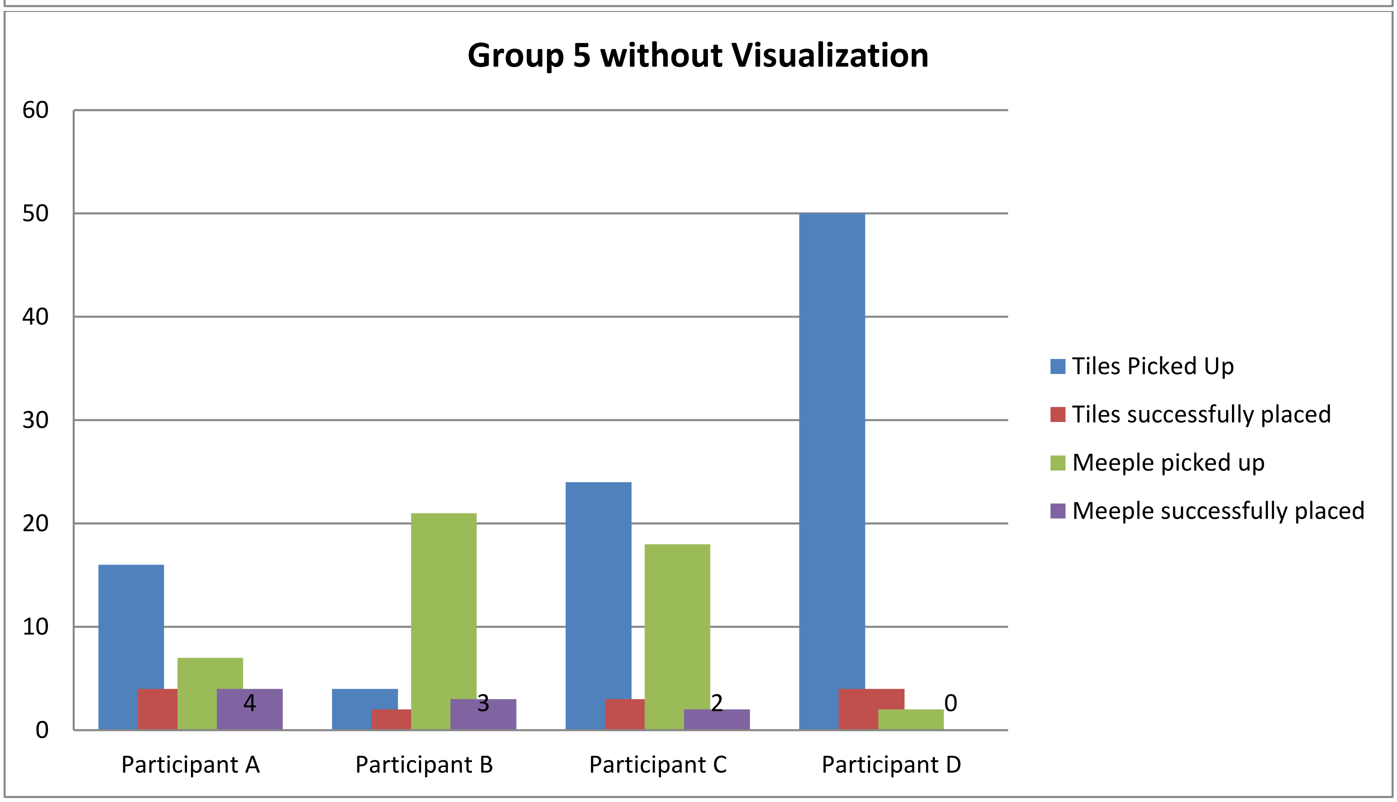
A5.1 Metrics for Non-Visualization Groups

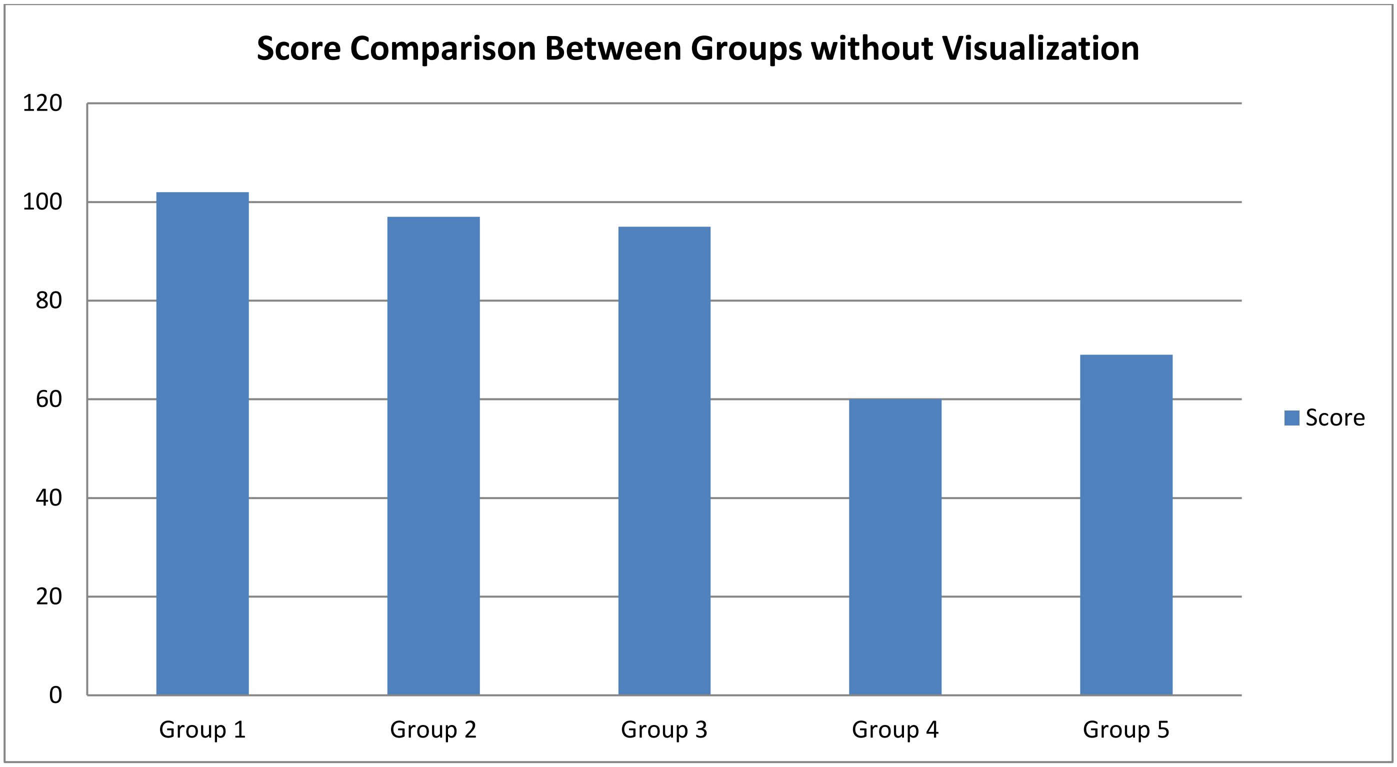


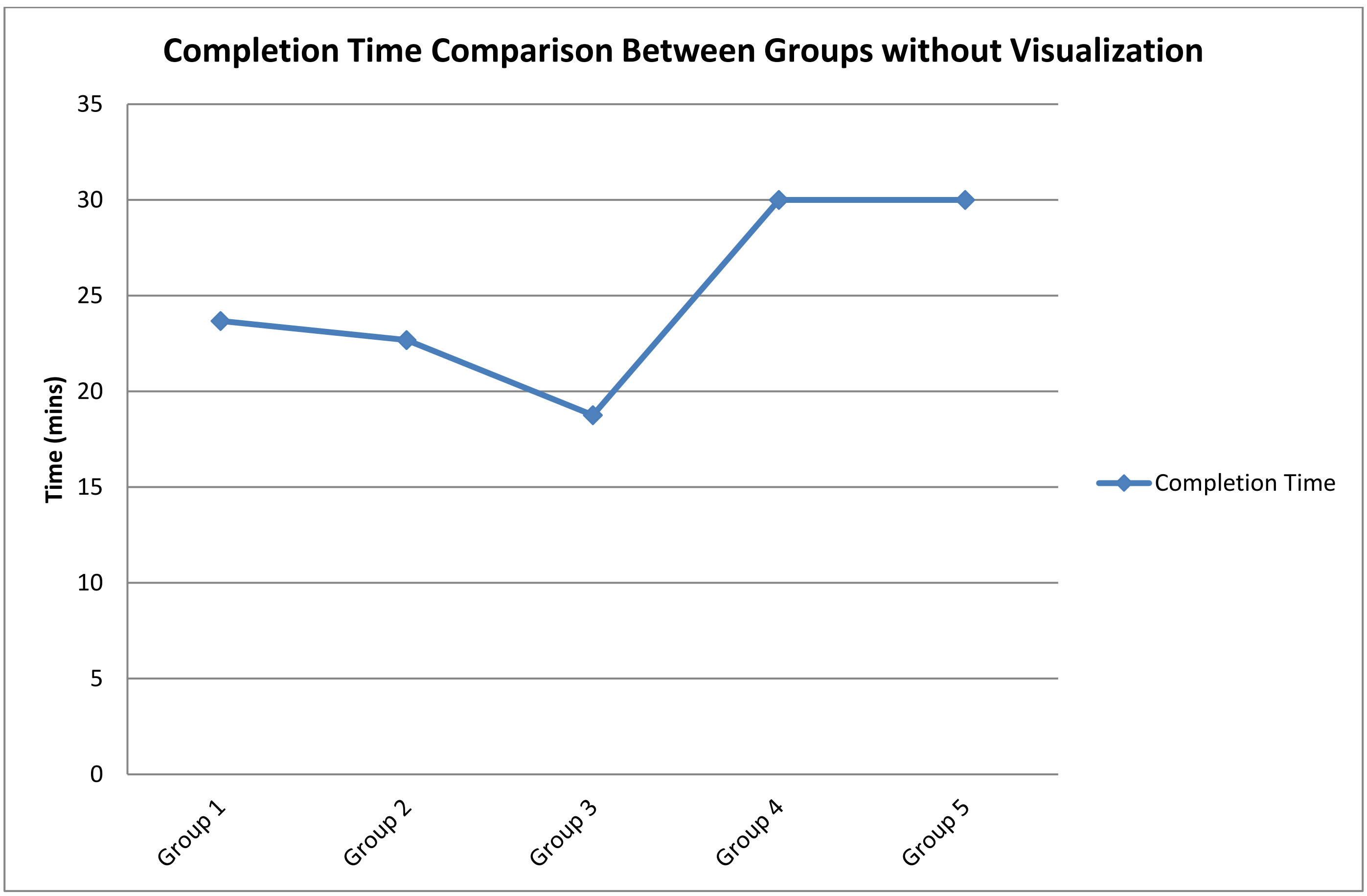





Group 4 without Visualization
45
40
35
30
25
20
15
10
5
0
1
2
2
1
Participant A
Participant B
Participant C
Participant D
Tiles Picked Up
Tiles successfully placed
Meeple picked up
Meeple successfully placed

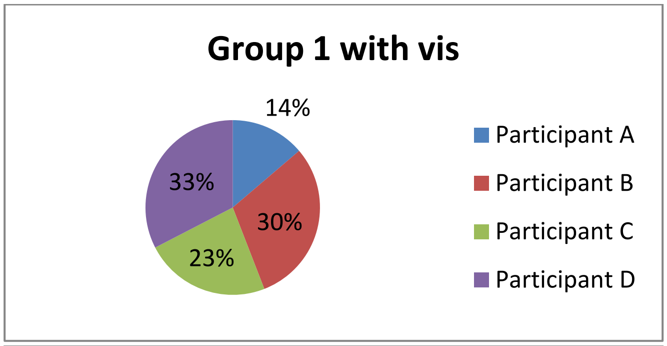

Group 5 without Visualization
60
50
40
30
20
10
0
4
3
2
0
Participant A
Participant B
Participant C
Participant D
Tiles Picked Up
Tiles successfully placed
Meeple picked up
Meeple successfully placed

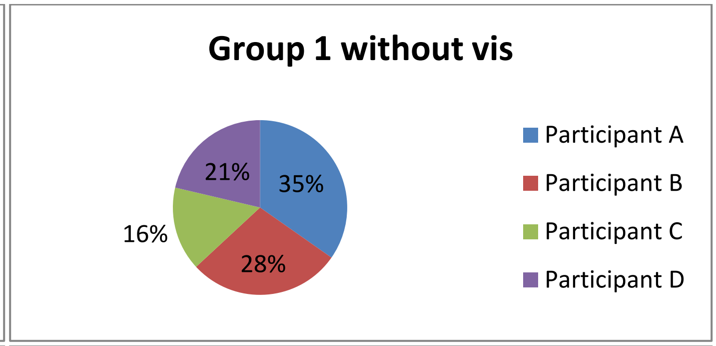

Score Comparison Between Groups without Visualization
120
100
80
60
40
20
0
Group 1
Group 2
Group 3
Group 4
Group 5
Score

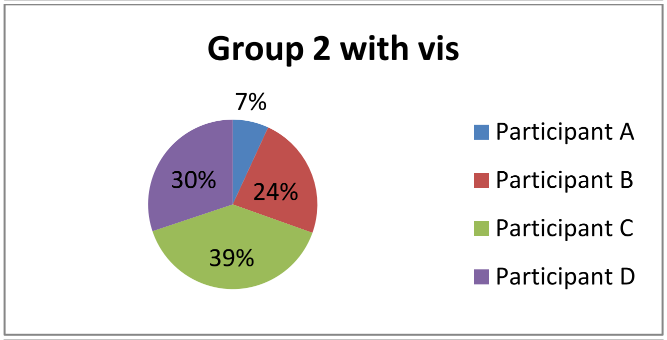

Completion Time Comparison Between Groups without Visualization
Time (mins)
35
30
25
20
15
10
5
0
Group 1
Group 2
Group 3
Group 4
Group 5
Completion Time

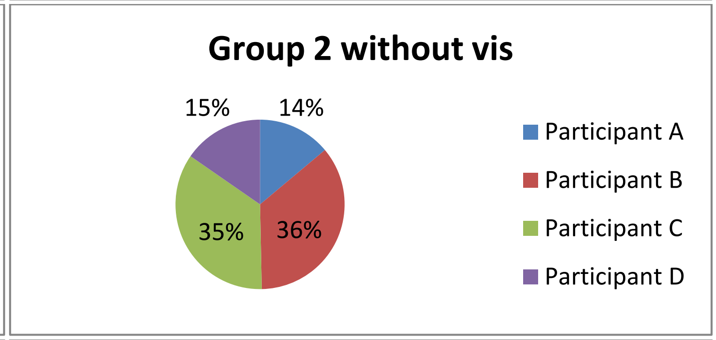
Appendix 6 - Comparative Graphs for Visualization and Non-Visualization Groups

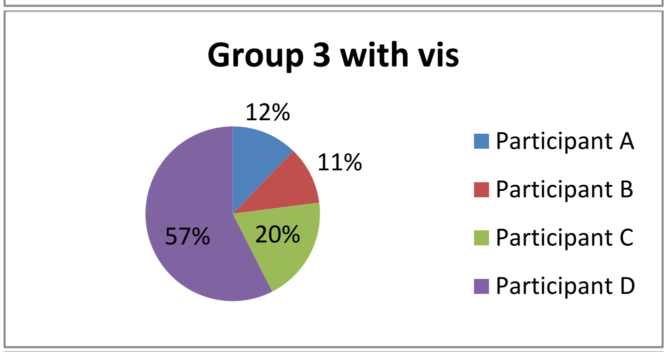
6.1 Time touching table

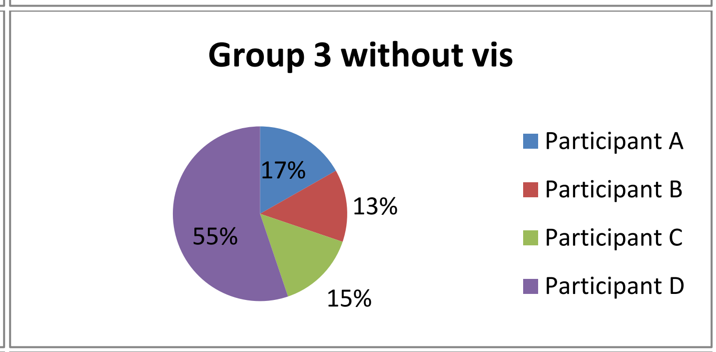


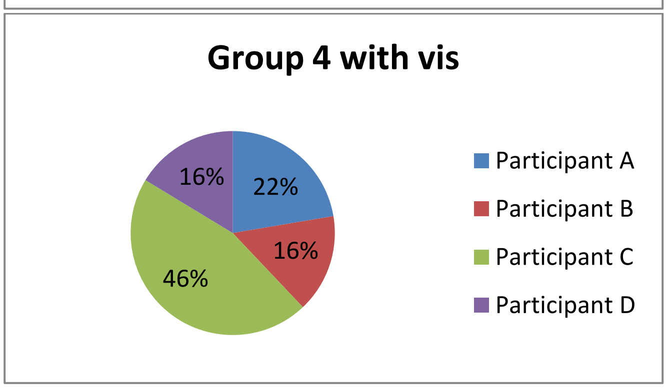


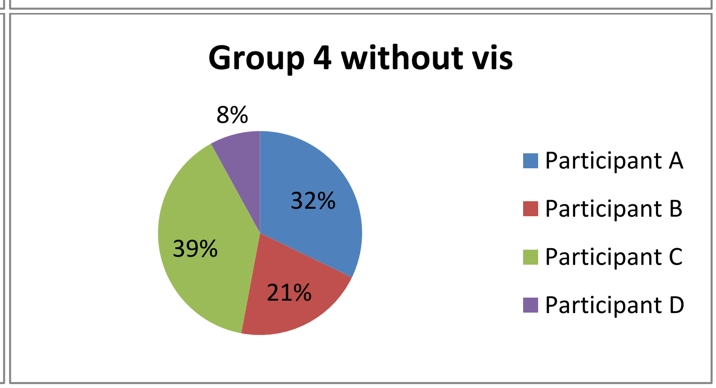


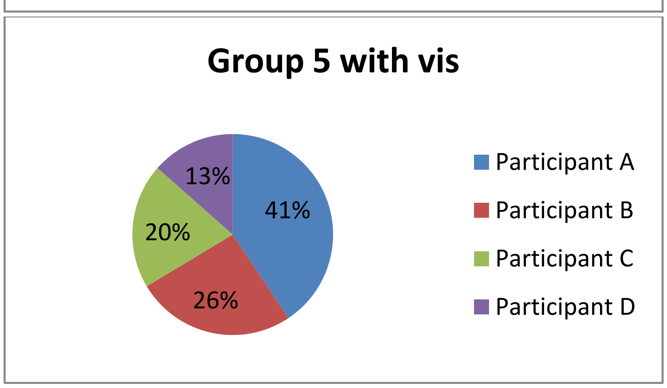


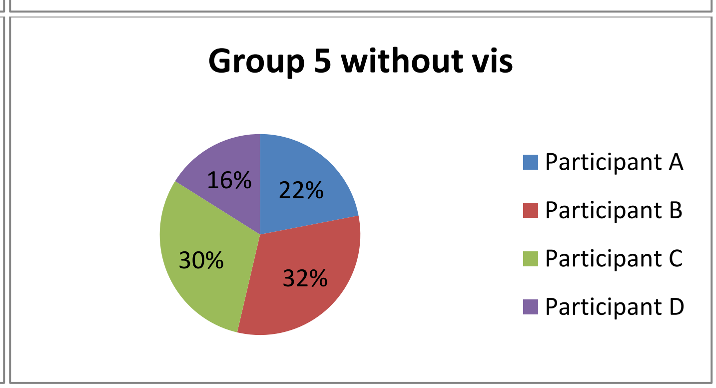




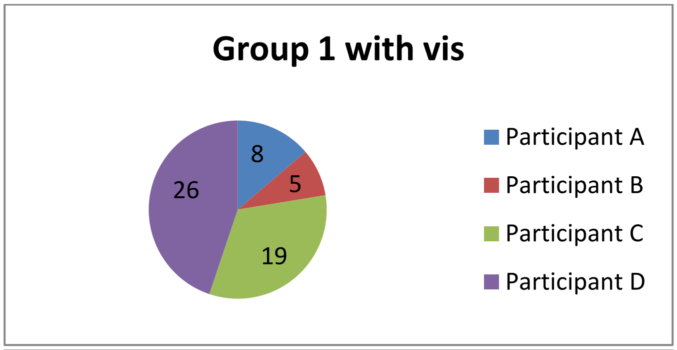


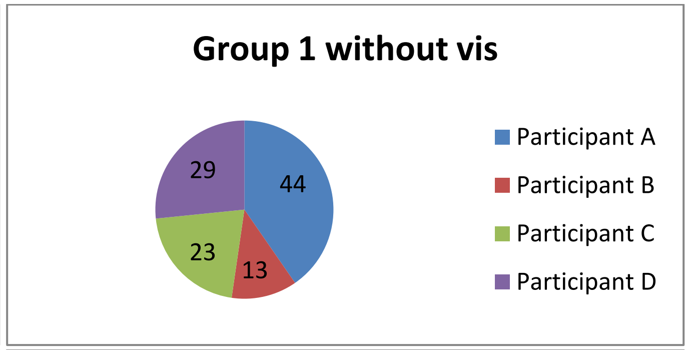


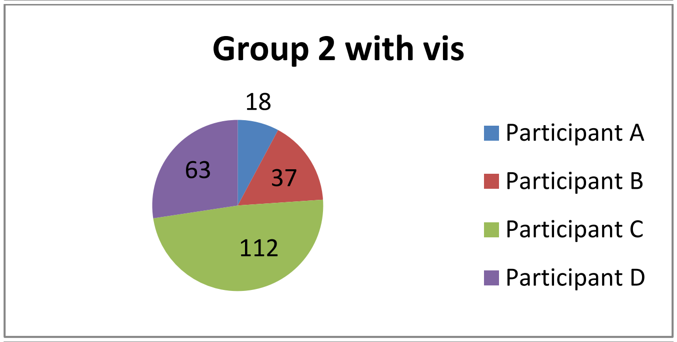


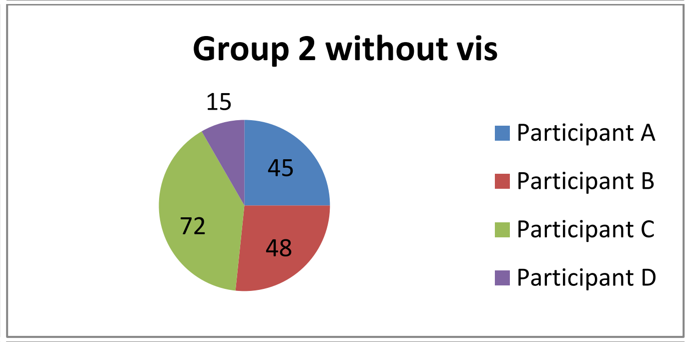


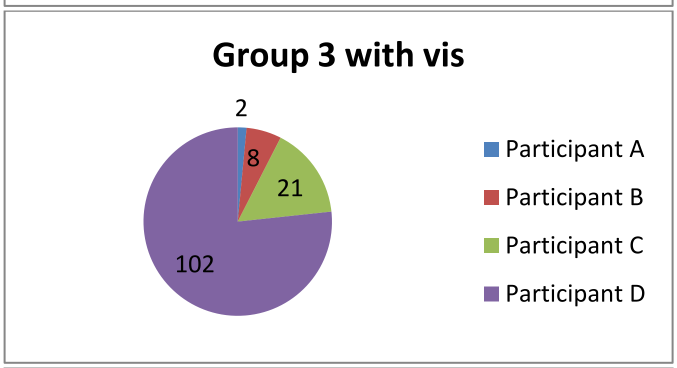
6.2 Tiles Picked Up

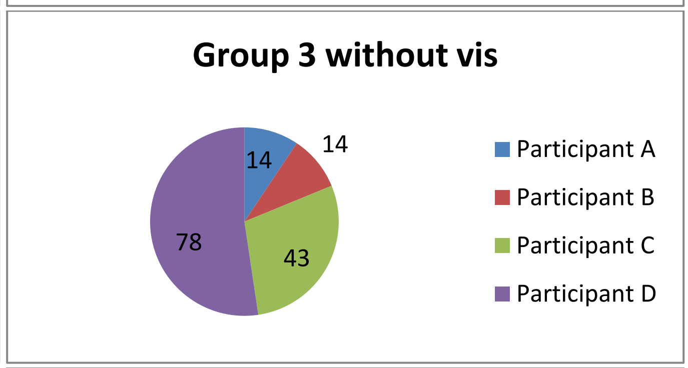


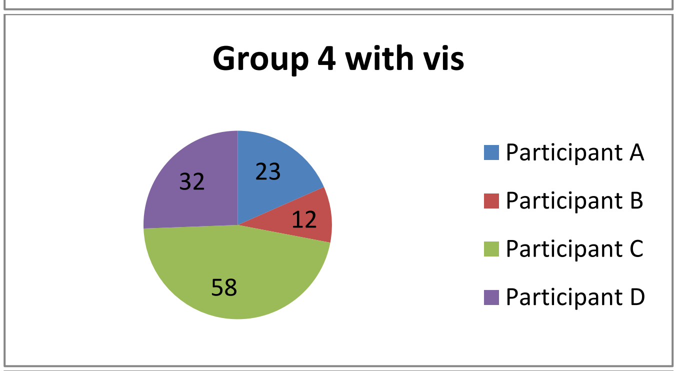


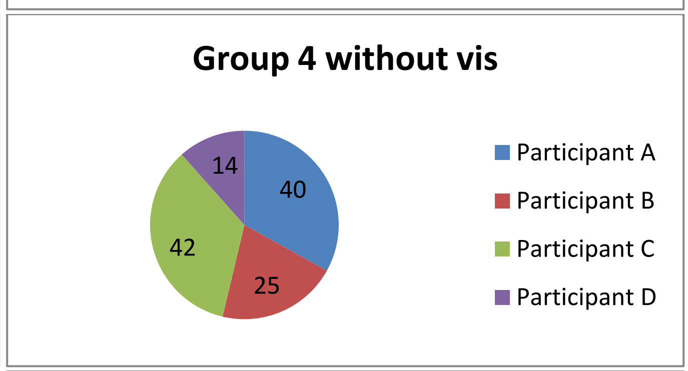


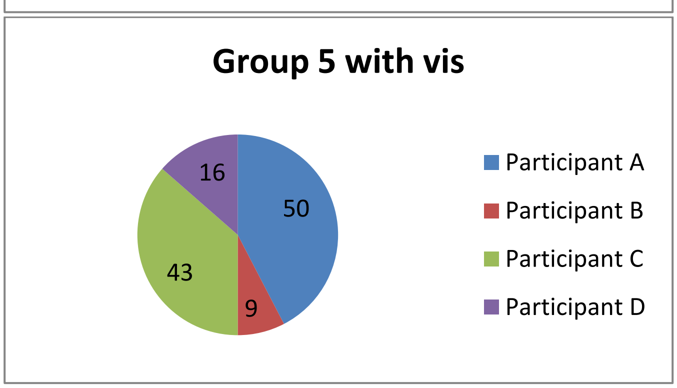


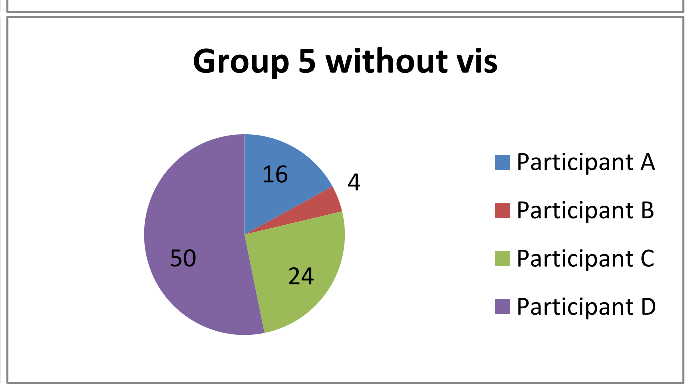




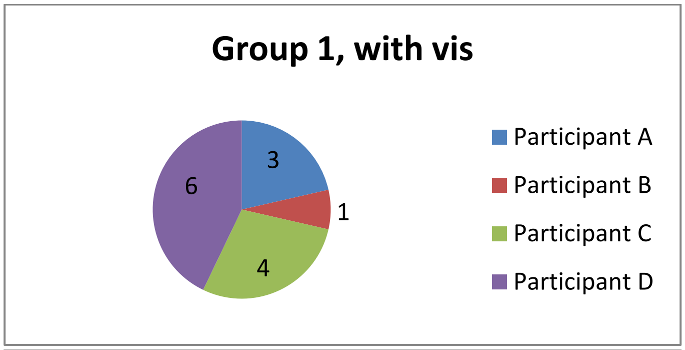


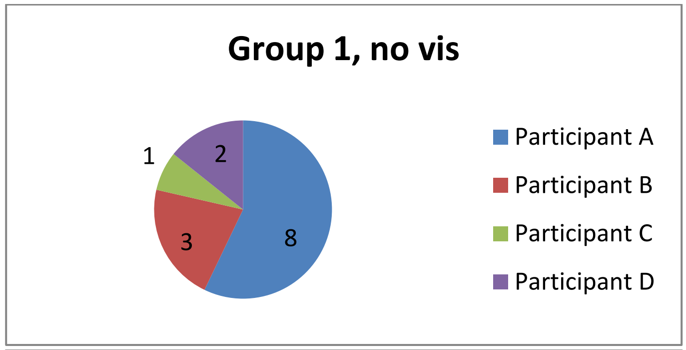


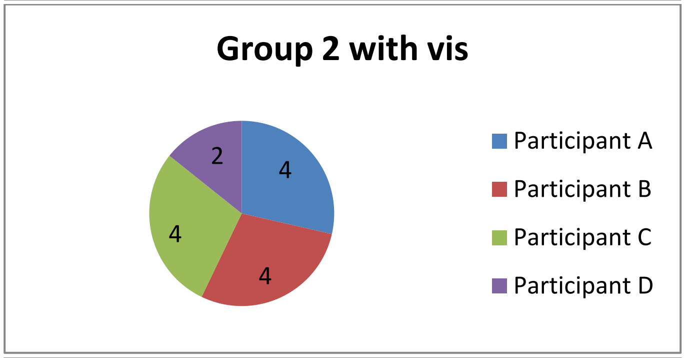


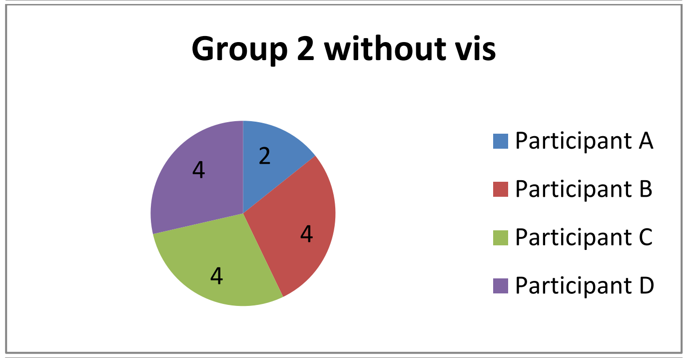


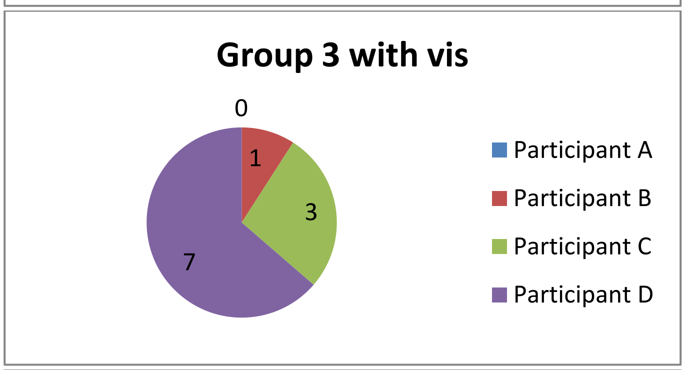
6.3 Tiles Successfully Placed

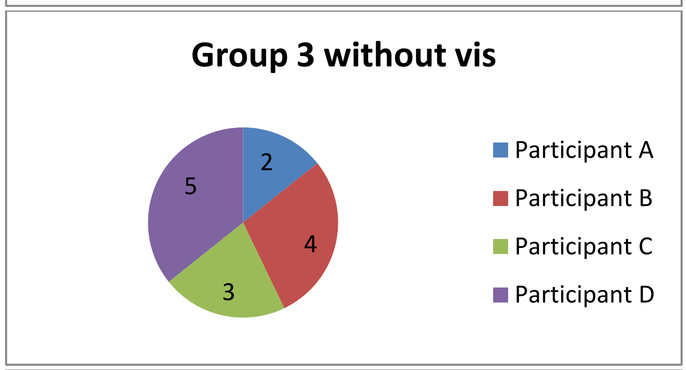


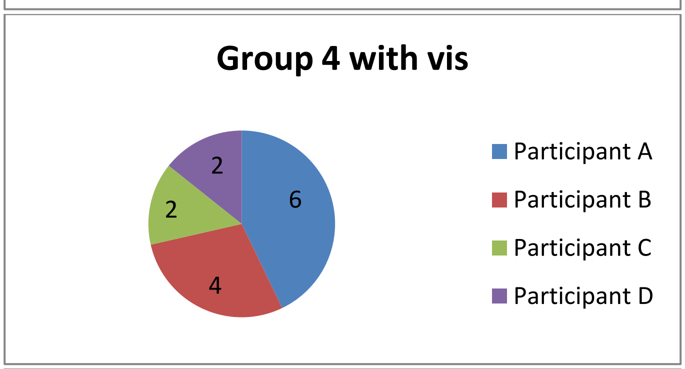


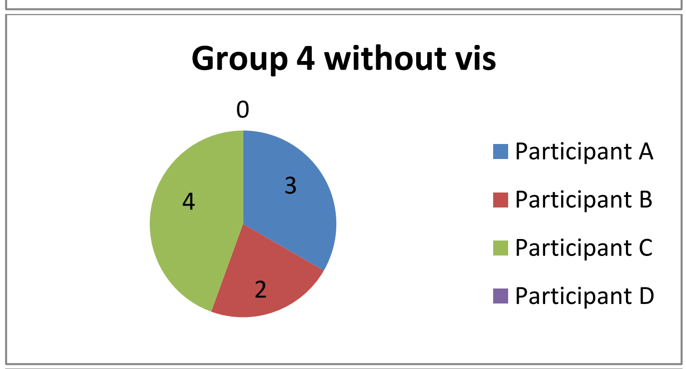


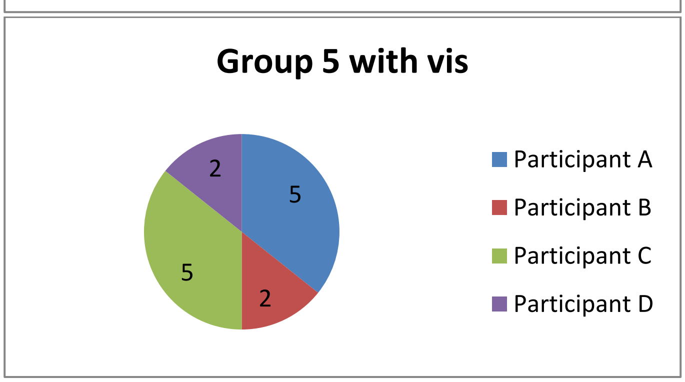


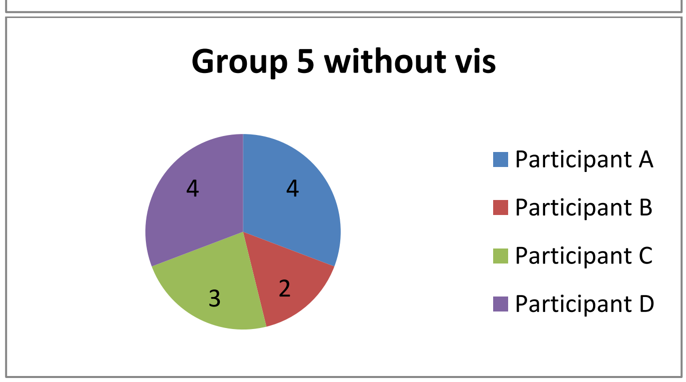












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