DESIGNING WITH LEGO: EXPLORING THE INFLUENCE OF LOW FIDELITY VISUALISATION ON COLLABORATIVE DESIGN ACTIVITIES

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Abstract

Sketches, cardboard mock-ups, and digital modelling software are typical media at a designer's disposal for visualising and evaluating ideas. Recent research indicates the benefits of using such media with a limited level of detail (low fidelity) when representing designer's concepts. Similarly LEGO has gained traction as a visualisation media in co-design and strategy building contexts, where its low fidelity is key to communication across different disciplines. The research in this paper compares LEGO with traditional visualisation media (sketching, cardboard mock-ups and CAD) to understand its influence on collaboration . An experiment was conducted where teams of industrial designers were given a short design task for which to develop solutions using different visualisation media. Results from the study showed that teams using lower fidelity visualisation engaged in more collaborative behaviour than those using traditional media and generated more ideas. This suggests that there are benefits to constraining the level of detail in visualisation media for concept generation during early stages of design process.

Keywords: Design practice, Collaborative design, Industrial design, LEGO, Visualisation media

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1   INTRODUCTION

Collaboration in the form of team design efforts is a widespread feature in engineering and industrial design disciplines. A key component of successful collaborative efforts are the various means to visualize and externalize different design ideas (Goldschmidt, 2007) that allow, synthesizing of multiple viewpoints/ideas via the design process into one final outcome (Kolko 2010). The externalization of ideas via visualisation media (design artefacts) is fundamental to 'sharedness' of collaborative design, allowing a dialogue between the visualized concept, the individual and the team (Goel 1995, Cross 2006, van der Bijl-Brouwer and van der Voort 2014). For the purpose this article collaboration is defined as design activities that embody such a dialogue between members of the design team. Specifically, instances during the design task where designers are designing together, engaging in discussion on the problem at hand, or collectively evaluating ideas.

Typical visualisation media used during the design process consists of hand sketching, physical modelling or prototyping and CAD. Each of these media tends to embody different degrees of fidelity defined as the degree to which the visualisation resembles the process. Physical prototyping/modelling are traditionally used toward the end of the design as a representation (approximation) of a product with respect to particular perspectives or purpose, manifested as a 'looks like' or 'works like' depiction to prove function, human factors, assembly, manufacture, or confirm visual shape or form (Ulrich and Eppinger 2008). There has long been emphasis on using prototypes early in the design phase in fields of HCI (Rudd et al. 1996, Sauer et al. 2008), now also investigated in the sphere of engineering and industrial design processes. Recent literature (Sanders and Stappers 2014, Isa et al. 2015) indicates benefits of stimulated communication between stakeholders and generation of more ideas when used alongside or in place of sketching and CAD.

Similar to early design phase prototyping is LEGO Serious Play (LSP) (GARDE AND VAN DER VOORT 2016). LSP has primarily been used as a tool for team and strategy building. In particular, the tool is used where teams need to explore a wide range of options or solutions with a range of backgrounds and expertise. One of the factors that makes the LEGO serious play successful is the way the simplicity of the blocks removes the need for reliance on domain specific skills or practices (e.g. CAD etc.) as well as the ease of combining models during design discussions. LEGO has not been studied within the engineering design process with the exception of Viswanathan et al. (2014). Here in researching design fixation, LEGO is adopted as an externalization/visualisation media early in the design process. While LEGO is used with positive results in mitigating design fixation, the influence of the medium compared with other design visualisation media is not compared. As such the contribution of the research reported in this paper is to explore the use of LEGO within the engineering design process alongside typical design visualisation media.

2   AIMS

This study aims to investigate the influence of LEGO as a low fidelity visualisation medium on collaboration during early stage design in comparison to other visualisation media. Based on the advantages indicated in the aforementioned literature we hypothesise that LEGO as a low fidelity medium will stimulate a more collaborative design effort due to its physical nature, speed of construction and intuitive mode of interaction. To test this hypothesis we conduct a study where teams are given different visualisation media to complete a design brief and the subsequent collaboration is recorded. The following sections set out the theoretical framework characterizing different media in terms of their fidelity, and the experimental method adopted. Results are presented in section 4. These are discussed in section 5 and conclusions drawn in section 6.

3   METHOD

The research method adopted for this study is now set out.

3.1 Conceptual Framework: Relative fidelity of different visualisation media

We now characterize design and prototyping media in terms of their relative fidelity. The term fidelity

is defined in the same manner as Sauer et al. (2008) as describing the degree of resemblance or accuracy of the medium to be able to embody/represent the designer's mental model or target concept. Importantly this definition is distinct from the notion of precision of the designer's technique when building models. Figure 1 illustrates the framework for the relative fidelity of the media used in this study. It is noted that this framework is derived from generalisations on the way different media are typically used and that there will always be variations on these characterisations depending on factors such as skill and experience of the designer and the nature of the design task at hand. The rationale behind characterisation of each media is now discussed. Potentially influential factors such as skill level and the design task used are discussed in sections 3.3 and 3.4.
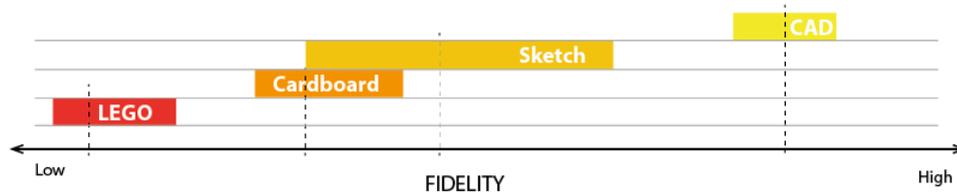

Figure 1 Characterising visualisation media in terms of relative fidelity in representing designs

- LEGO: Lowest fidelity

LEGO is deemed to have the lowest fidelity firstly due to the limit on the number of pieces available in a given set. The fidelity is also said to be low in that the blocks are limited to the minimum size of one block i.e. the stud interval of LEGO bricks is limited to a fixed distance of 8mm. Furthermore the majority of blocks can only be arranged in an orthogonal fashion constraining possible placement of pieces. Hence unless the designer has a LEGO-like structure in mind, the media is unlikely to be able to accurately portray the designer's mental picture of the resulting design.

- Cardboard: Low fidelity

Cardboard modelling is also deemed to be low fidelity, but higher fidelity than LEGO. This is because the medium allows for a wider range of shapes, for example 2D curved surfaces or curved profiles. Equally cardboard affords a higher fidelity in that models are not constrained by a minimum block size/stud interval. However, while some curved surfaces and profiles are possible, the sheet-like/2D nature of the raw material makes accurate representation of 3d forms/volumes challenging.

- Sketch: Low-Medium fidelity

Here sketching is deemed to be low-medium fidelity. The rationale behind this characterisation relates to the typical use of sketches in early stages of design where they tend to be created quickly and describe broad concepts. Here fidelity is rated higher than cardboard as designers have greater freedom (are less constrained) with lines sketched to represent more complex profiles (lines) and 3d forms compared with the accuracy that is possible with cardboard or LEGO. The authors acknowledge that sketches can become very high fidelity however this would be an atypical use of sketching early in the design process.

- CAD: High fidelity

CAD gives the opportunity for the highest level of fidelity in that it supports a high level of accuracy in constructing and modifying geometry and crucially represents a 3d space with a high level of accuracy. Similar to sketching the authors acknowledge that different CAD software can provide different degree of freedom in design representation. The authors however contend that common to all CAD is the factual/realism exactness in the representation of inputted geometry.

3.2 Visualisation media provided

The specific details of the visualisation media provided include:

- Sketching team: A4 sketch pads, a selection of Copic markers and fine-liner pens.

- Cardboard team: 1 and 2 ply cardboard, elastic bands, a hot glue-gun and adhesive tape.

- CAD team: Solidworks 2016 3d modelling software with one work station per team member

- LEGO team: 1x Classic Large Creative Brick box consisting of 790 assorted LEGO pieces.

3.3 Design Team Participants

Design teams were made up of 2 x classes of 2nd year Industrial design students, 27 students in total. Teams of 3 and 4 members were designated by the medium they were to use. Team members were selected at random from the overall cohort.

This demographic was selected as all students had received training in Sketching, CAD and cardboard prototyping, providing some control for the influence of prior training/skill level of each designer. LEGO remains uncontrolled, however, because of its simplistic/intuitive nature (why it is ideal in LEGO Serious Play) the required experience to use it is contended to be of less influence than in the other media. The relationship between skill/experience with different media and design team collaboration is of interest, however, it is outside the scope of the research reported in this paper.

3.4 Design Task

The designers in this study were asked to design a novel disruptive approach to personal transportation for 15-20 years time. This brief is specified because it is suitably broad to reflect an early design stage task and facilitate a wide range of solutions. Furthermore, breadth was considered desirable, as it does not prescribe any form or function that would make one media more suited to producing/representing a particular type of design, schema or interaction. For example designing a handheld device is easier with the representation medium that is easiest to create 1:1 hand-grips. Designs which prescribe an archetypal shape e.g. a cylinder or sphere will be easier to represent using CAD, but require some skill to sketch and present a clear problem for LEGO. Furthermore the brief does not prescribe a specific level of detail or complexity required in the design outcome. This is because level of detail is considered to be another factor that would make some tools more suitable in executing the task. For example using cardboard would be difficult to visualise a high level of detail versus using CAD. Finally, the experience of transportation/mobility is ubiquitous meaning that participants will not need to be briefed of the current issues with personal transportation nor need to do any basic research to understand the problem presented.

3.5 Design Timeline

Due to the time constraints of the experiments, a schedule for the design process was prescribed to the teams, summarized in Figure 2.
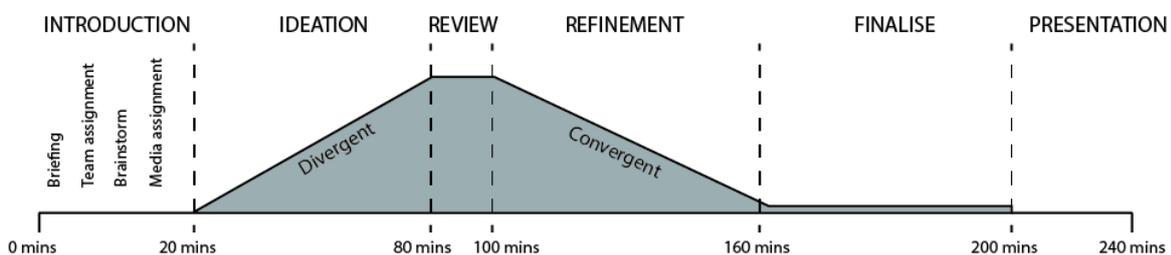

Figure 2 Timeline representing the sequence of design activities followed by teams during the study

The experiment was run and then repeated over two 4hr sessions (morning and afternoon sessions denoted as AM and PM). The designers were briefed on the task and provided with the media that they should use. Teams were given a 1-hour period to focus on ideation, generating a wide range of possible solutions. After 1 hour the teams were asked to spend time rating their concepts in order to select one design direction to pursue over the course of a second 1-hour period. Here teams were encouraged to work together to produce a single concept for a solution. Finally the teams had approximately 30mins

to finalize their design by creating 2 presentation panels to represent their outcome. Here, photographs were taken of the physical models (LEGO and Cardboard), sketches were scanned and screenshots/renders of digital models were produced as the primary content for panels (examples of panels are included in Figure 3). The 4hr session then concluded with teams briefly presenting their designs to the others in the class/session.
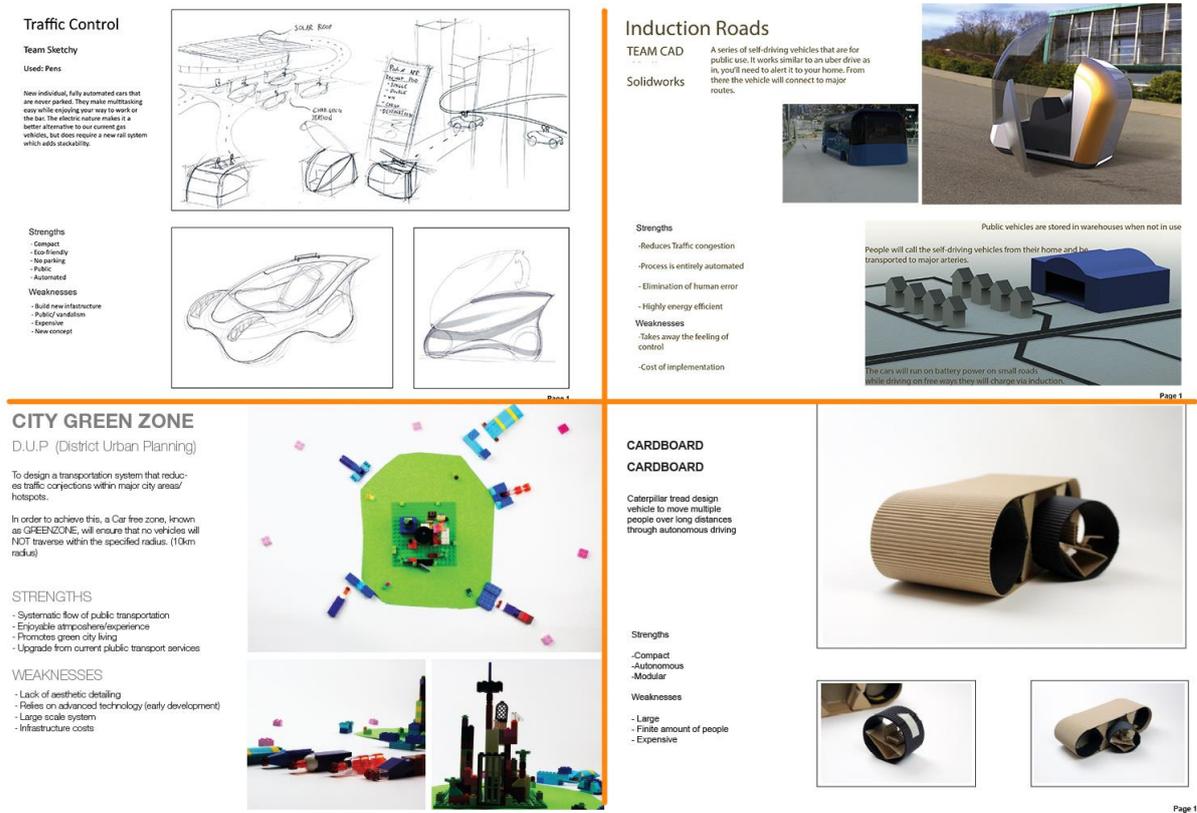

Figure 3 Examples of presentation pages produced by teams. Clockwise from the top left; Sketching, CAD, Cardboard and LEGO

3.6 Data collection: What activities constitute collaboration?

Data on the level of collaboration was gathered using a self-reporting approach based on the methodology used in Jonson (2005) researching ideation with digital tools. At 10 min intervals throughout the design task teams were asked to categorise the extent to which the team collectively had engaged with different design activities. As stated above, collaboration is defined as instances where designers are designing together, engaging in discussion on the problem at hand or collectively evaluating ideas. The rationale is that at the heart of these activities there is a dialogue between designers due to the need to generate a shared understanding of any given idea (van der Bijl-Brouwer and van der Voort 2014). In order to capture the breadth of these collaborative activities three possible categories are provided to the design teams, Collaboration as a broad category (self explanatory), Problem Structuring to capture collaboration relating to problem framing and understanding, and Evaluation. The complete list of categories for describing different design activities is shown in Table 1.

Table 1: Example self-assessment teams were asked to complete at 10 min intervals. Note, Ideating and Refining are not studied in this paper

	None (0 mins)	Some (1-3 mins)	A Lot (5-10 mins)
Problem understanding/structuring			
Ideating/ Generating New Ideas			
Refining/Developing ideas			
Evaluating/Critiquing ideas			
Collaborative work			
Other - define			

Instructions were provided to teams at the outset of the process defining the categories of activities set out in Table 1 and an approximate proportion of the 10 min interval that translates to 'None', 'Some' and 'A Lot'. Importantly teams were told that activities were not mutually exclusive, hence they were able to choose 'A Lot' for more than one activity if they felt this reflected their team's activities over a given 10min interval. This categorising approach was taken as it was deemed simplistic enough not to interfere with the design process itself. Equally attempting to record more precisely the nature and time spent in each of the activities would be challenging, require significant resources and man power, potentially disruptive to the team's process and even then, not necessarily accurate. Reporting was supplemented with observations by the two facilitators of comments made by team members and design behaviours witnessed during the task. The number of ideas/concepts generated was also recorded during the evaluation phase. At the end of the task designer's reflections on the media used was also recorded in the form of a short reflective survey.

4 RESULTS

Results from the study are now presented firstly from the self reporting, followed by observations made by facilitators.

4.1 Self reporting

The extent to which teams engaged in collaboration (collaborative activities) is gauged primarily from self reporting data on approximate time spent in collaborative work, evaluation, and problem structuring (see Table 1). In order to give an overview Figure 4 plots the total instances that team recorded 'None', 'Some' and 'A Lot' categories of engagement summed over the three collaborative activities for each of the media.
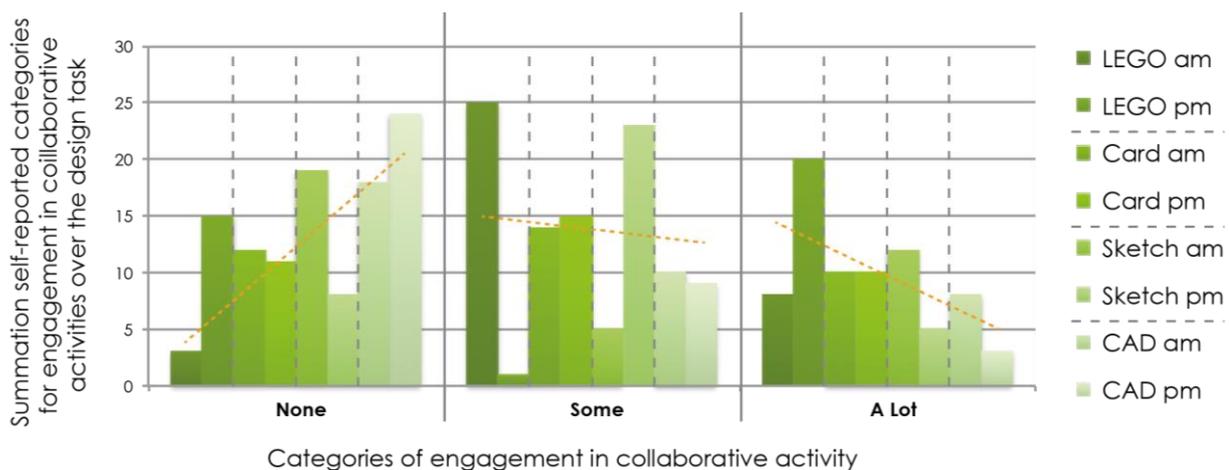

Figure 4 Summarising total instances that teams recorded 'None', 'Some' and 'A Lot' summed over the three collaborative activities for each of the media. Note the trend for CAD and sketching to record 'None' most frequently while LEGO and Card record 'A Lot' and 'Some' more frequently.

From Figure 4 it is possible to identify overall trends between media for engagement in collaborative activities. LEGO teams engaged in the most collaboration, (all of the collaborative activities Collaboration, Evaluation and Problem Structuring) as seen by the higher frequency of recording 'Some' and 'A Lot'. Inspecting this data further, the results show that much of this is due to activities being sustained over the total design task. Cardboard teams do engage in these activities, but to a lesser extent than LEGO. Notably for the cardboard medium engagement in these activities was observed to be skewed towards the end of the design task (60mins onwards). See Figure 5.

CAD teams spend a surprising amount of time collaborating and very little time in problem structuring and comparatively less time in evaluation than other media. Cumulatively the sketching teams spend a greater amount of time collaborating than the CAD teams, however, less than LEGO and Cardboard teams.
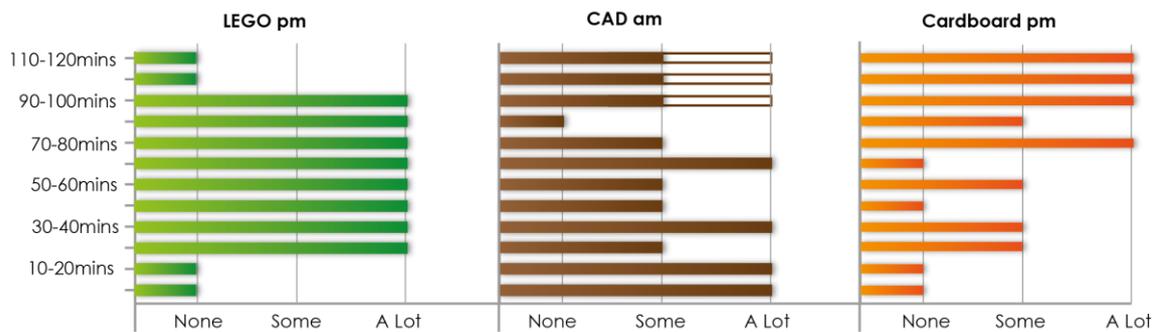
Figure 5 Examples of level of engagement in the 'Collaborative Work' activity category for LEGO, CAD and Card media shown over the course of the design task. Note consistent engagement in collaboration for LEGO and collaboration skewed toward the end of the task for Card.

The Sketching teams show the greatest inconsistency between the two experiments. The first team indicate they collaborated heavily evaluating less and spending little time on problem structuring. The second team were opposite spending the least time collaborating but more time evaluating and structuring.

4.2 Observations

Observations by facilitators during the study were generally consistent with self-reporting data. A key observation with respect to the data gathered for the CAD AM team was that toward the end of the task the first team spent significant time (30mins, out of the 120mins of the allotted design time) collaborating on creating renders of their 3d model (see Figure 3 for examples of their outcome). Thus arguably the collaboration (with respect to designing) score seen in Figure 4 is artificially high as this collaboration was concerned with finalising/representing their design rather than evolving/resolving design characteristics. Figure 5 shows an adjusted score for collaborative work to reflect this.

Supplementary to self-reporting data, facilitators observed a number of comments/reflections on difficulty in using the media. Both LEGO teams stated that they were limited by the number of pieces available and found the medium restrictive in being able to represent their design intent. Consequently both teams indicated they had to rely on verbal communication to support what they could represent physically. Similar observations were made of the Card team. However, in the second experiment the card team indicated that they did not need additional communication as the model "spoke for itself". The AM CAD team also indicated some difficulty in representing their design and required verbal support in the early phase of the task. Both sketching teams also indicated in reflections at the end of the task that they had some difficulty with the media when it came to make changes/evolving designs that they had sketched. Similarly both teams indicated that they had difficulties in adding detail to their designs when it came to the end of the task.

Another area of interest with respect to collaborative efforts was in the way team members became physically engaged with one another's models. Both LEGO and cardboard teams were jointly constructing models towards the end of the design task. The CAD team was not actively adding to a single model however this is not surprising given the nature of the interface. CAD teams appeared to follow more of a delegate, work individually, then synthesise approach. The sketch teams were observed to work very much independently in terms of creating the sketches. The Sketching AM team, having decided on a final direction, nominated the strongest sketcher do the designing while others directed and to some extent lost interest/disengaged. The Sketch PM sketch team took the approach of the CAD teams delegating different aspects/features of the concept to develop. In terms of the media used, both sketching teams indicated that the media was difficult to make changes to designs during the design task and also to add detail toward the end of the task. The Sketch AM team add to this that they would have preferred access to CAD toward the end of the session where details became more refined.

4.3 Number of Concepts generated

Table 2 lists the number of concepts generated by each of the teams. It can be seen that LEGO teams generated the most concepts, followed by sketching and then Cardboard and CAD respectively.

Table 2 Total concepts generated during the first hour of the design task by each team

Media	LEGO		Card		Sketch		CAD	
	AM	PM	AM	PM	AM	PM	AM	PM
No. Concepts	8	7	4	4	7	5	3	1

5 DISCUSSION

Key trends in the results and observations are now discussed considering possible reasons for the differing levels of collaboration.

The overall trend in results supports the hypothesis that lower fidelity media stimulate the greatest levels of collaboration. This is also consistent with literature on the use of low fidelity models early in the design phase (Blackler 2008). Considering the conceptual framework, the relatively higher level of collaboration in LEGO teams compared with cardboard teams goes further suggesting that the lower the fidelity, the greater the level of collaboration. Based on the observations on the "difficulty" in using LEGO and cardboard for representing ideas, we contend the way lower fidelity media constrain the extent to which designers can add detail to their representation has the effect of forcing the designers to augment the representation with verbal description. This in turn requires a greater level of engagement between team members in the form of discussion in order to achieve the shared understanding mental/model necessary to design as a team.

While these results give an indication of the trend that lower fidelity media can lead to greater collaboration, the instances of fidelity are distinct meaning this relationship is only exhibited in specific examples. In other words there is a need for more comparable and continuous versions of media to truly prove this relationship (in addition to the need for further study with larger participant teams). Furthermore it is expected that there must be some limit at which point fidelity becomes so low and representations so ambiguous that shared understanding is only achieved through discussion. Regardless, this preliminary study provides evidence that there are potential benefits to using lower fidelity media early in the design process and hence there is a place for LSP/LEGO to have a role in early design phase collaboration.

The result that LEGO as a low fidelity media resulted in a larger number of concepts generated during the first hour of the task concurs with those of Isa et al. (2015) that the lower fidelity media limit the level of detail and hence the time and effort invested in creating visualisations/representations. As such there is less "sunk cost" (Viswanathan et al. 2014) associated with a given idea and the designer is more willing to move on and iterate. Another perspective is that the designer is not able to move on given the limit of the detail they are able to design. The sunk cost argument also explains the relative lack of concepts generated by cardboard teams. Similar to the cardboard teams, the low number of ideas generated by CAD teams is consistent with the literature (Robertson and Radcliffe 2009) suggesting that use of CAD early in the design process can curb creativity.

Finally, the level of collaboration seen in sketching teams was somewhat surprising. One reason for this might relate to the designers in this study having a benchmark/expectation of sketch quality. This was highlighted in observations of students being dissatisfied with sketches, and reflections indicating that this media was challenging to represent detail and also to modify ideas. We contend that the designers were more concerned with creating a sketch at a certain level of skill/accuracy (in essence expecting that a sketch should be of higher fidelity/accuracy), and less on creative collaborative problem solving. This attitude toward trying to achieve a standard was likely related to the wariness to sketch together (add to one-another's sketches) for fear of spoiling a teammate's work. In turn this raises the need to

educate designers in differentiating the use of representation media as thinking tools versus embodiment tools, and the emphasis on each should fall at different stages of the design process.

6 CONCLUSIONS AND FURTHER WORK

This study set out to explore the influence of low fidelity design media in early stages of the design process. An experiment was carried out where teams using either LEGO, cardboard, sketching or CAD to complete a short conceptual design task. Findings from the study confirmed the hypothesis that low fidelity media result in greater collaboration between the team and a greater number of ideas. It is contended that the low fidelity nature of media forces designers to engage their team augmenting the design embodied in the media with verbal explanation. Furthermore, it is surmised that the physical nature of the media facilitates easier collaborative building/designing. Sketching was seen to be less collaborative as a consequence of students focusing efforts on creating higher quality sketches rather than doing design. Thus we contribute by demonstrating that the benefits of low-fidelity media highlighted in LEGO/LSP are relevant to early stages of the design process. Namely providing a levelling medium that removes skill barriers and enables all members to participate in doing design and stimulating discussion.

In this paper we present initial findings using student designers from the industrial design discipline. Hence further work is needed to expand the study to professional industrial designers with greater experience, and also to engineering designers with differing strengths and design. In particular, it will be interesting to assess the findings on collaboration where skill in both sketching and CAD are higher through greater experience. Similarly this study focuses on a broad conceptual design brief. It would be equally interesting to explore the collaborative nature of media in the context of a more technically constrained, design challenge. A further aspect that has not been explored in this paper is the relative quality of the designs produced by each of the teams. This further work is anticipated to require a more extensive design outcome/presentation to facilitate reliable expert judgement on the quality of ideas, as well as a longer experiment duration more similar to design practice. This could also allow teams to use any media of their choosing following a certain amount of time ideating using only the prescribed media.

Finally the study uncovered an example of a misconception between tools that assist and facilitate in problem solving versus tools that facilitate detailed representation. CAD software has advanced immensely over the last decades making it easier to create detailed designs. Equally there is a broad range of CAD software available with different strengths in resolution and flexibility for editing. In light of our findings on the positive influence of low fidelity early in the design process, there is a need to research alternate media and/or CAD software/tools that provide less fidelity but with the benefit of stimulating creativity and collaboration, saving media capable of high fidelity representation until later in the design process.

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