# EXPERIMENTS WITH AUGMENTED REALITY FOR SUPPORTING EDUCATION IN DISTRIBUTED PRODUCT DESIGN SOLUTION EVALUATION

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**Abstract:** This paper presents results of an experiment set up to exploit the impact of using Augmented Reality (AR) whilst groups of engineering design students from Malta, Scotland, London and Hungary were collaborating on designing different parts making up a car seat belt mechanism. In particular, the experiment focuses on the distributed, real-time evaluation of the emerging design solution. The results achieved are encouraging and the paper contributes insights of the suitability of using AR in distributed and collaborative design evaluation scenarios.

**KEYWORDS**: Distributed Augmented Reality, Collaborative Design, Solution Evaluation

## 1. INTRODUCTION

The University of Malta (UoM), the University of Strathclyde (UoS), the City University of London (CUL) and the Budapest University of Technology & Economics (BUTE) have been cooperating in the teaching of real-time distributed collaborative design. Based on six years experience running this exercise, it emerged that solution evaluation is a challenging activitiy to achieve. This is because a student design team located in site 'A' will not be necessarily interpreting correctly the intended solution conceived in site 'B'. As a consequence, solution evalution in different sites is performed differently, resulting indeed in different solution assesments. Based on this challenging experience, the four Universities have embarked on carring out experiments involving *Augmented Reality (AR)* to establish if this helps improve the *evaluation* activity taking place during a basic design cycle. To help address this issue, this paper is structured as follows. Section 2 will provide an overview with the state-of-the-art in collaborative design education, followed by Section 3 that will introduce the experiment setup to investigate the exploitation of AR in solution evaluation. Section 4 will present the results achieved whilst section 5 will discuss their significance and make some conclusions on future research directions.

## 2. STATE-OF-THE ART IN COLLABORATIVE DESIGN EDUCATION

Due to a shift towards the involvement of world-wide organisations in the development of a single product, there has been an increasing trend concerning the training of engineers to allow them to be able to engage in real-time collaborative design activities using a range of IT tools. A number of studies were carried out related to collaborative design education. For instance, Mamo *et al.* [1] investigated the patterns employed by students in using different design tools using a range of on-line media. Wodehouse *et al.* [2] and Schembri *et al.* [3] focused on the role that different types of sketches play in a students' distributed design set-up.

Using Roozenburg's [4] basic design cycle model as a reference and previous studies, it can be established that a host of different collaborative tools have been used for a range of design activities, these being outined in Table 1. The literature reviewed indicates that whilst video conferencing, text chatting (e.g. using social media), and email communications are used for different design activities. Cloud computing is mainly used in solution synthesis, analysis and evaluation activities. Furthermore as Table 1 reflects, the use of AR technology has so far been sparingly used for actual evaluation activities directly involving clients. Combined with this, research efforts were so far focused on how AR technology

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can be exploited to enhance collaborative learning [5]. The research reported in [6] concerns design principles to implement AR for the classroom. The study conducted by Matcha *et al.* [7] investigates students' behaviour while interacting with an AR based system in group learning environment. Therefore, a research gap currently exists in specifically assessing the suitability of AR in evaluating product engineering design solutions in a distributed set-up.

**Table 1 Indicative Use of Tools for Collaborative Product Design**

| | Design Problem Analysis | Solution Synthesis | Solution Analysis | Solution Evaluation | Decision |
|---|---|---|---|---|---|
| Video conference | ✓ | ✓ | ✓ | ✓ | ✓ |
| Cloud computing | | ✓ | ✓ | ✓ | |
| Email exchanges | ✓ | ✓ | ✓ | ✓ | |
| Text chatting using social media | ✓ | ✓ | ✓ | ✓ | |
| Augmented Reality | | | ✓ | | |

## 3. COLLABORATIVE DESIGN PROJECT

The aim of the project is to train students in collaborating during the design and development of a product involving organisations in different physical locations. It is nowadays very common to have an organisation in Location 'A' with its own design team 'A' responsible for designing a complex product required by a client organisation. Due to certain complexities and sub-systems, the organisation in location 'A' will subcontract the design of certain parts to other organisations located in different locations (B, C and D) as schematically illustrated in Figure 1. The different teams in the different organisations will be working on generating solutions for the parts assigned to them, with the Team 'A' at Location 'A' responsible for integrating the different sub-solutions into one complete product that needs to satisfy the client. Indeed during the design process, the different team members exchange information on their design solution to enable an overal design solution to be generated. It is typical for the client to thus be involved by Team 'A' in evaluating the emerging solution before it is approved for production.

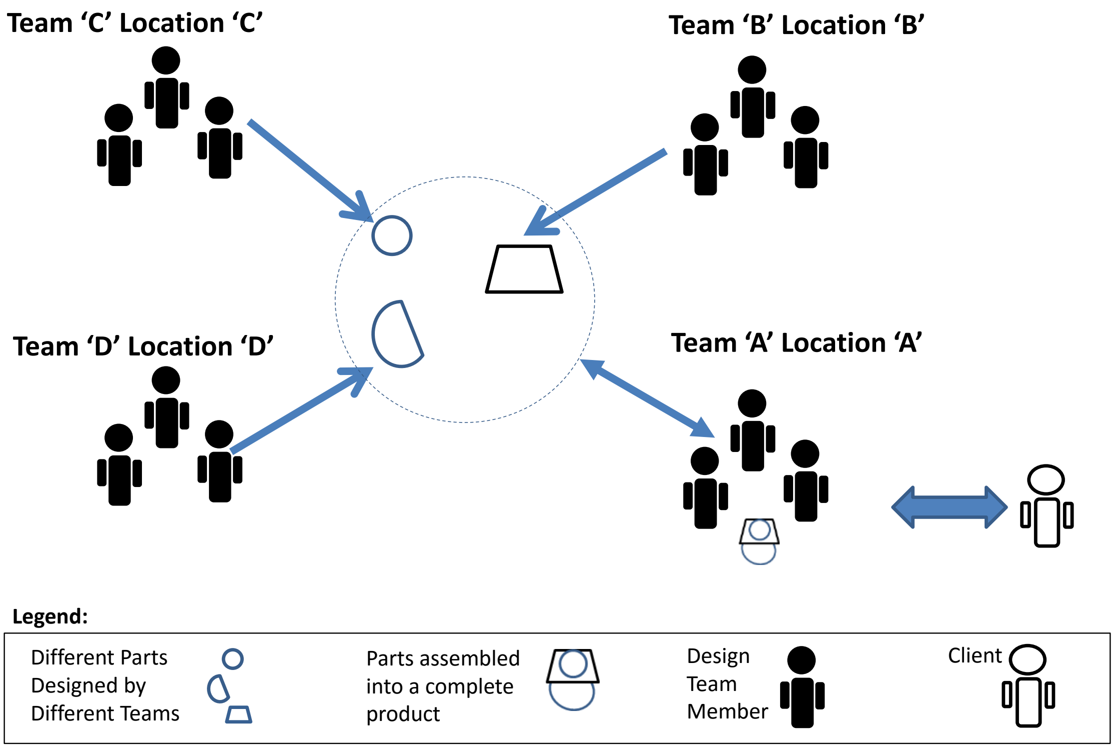



*Fig. 1. Collaborative Design Case-Study Scenario*

The scenario illusrtrated in Figure 1 is precisely the one emulated in the collaborative design education exercise involving student teams in Malta, Scotland, London and Hungary. The design problem provided for this collaborative design scenario is the design of a more effective aeroplane seat belt.

The exercise was spread over a period of eight weeks during which students had to go through the different design stages – from concept to detailed engeering drawings. In the first week students had to introduce each other, agree on communication tools, meeting schedules and project planning. In the second week they had to create a mind map to define problem. In the following two weeks they had to generate concepts and select the most suitable. Weeks five and six focused on prototyping and detailed development. In week seven they had to finalise the design including manufacturing drawings, bill of materials and renderings. In the last week each tema was asked to deliver a presentation on the project.

As the four universities have engineering design modules taught in different years in their degree structure, this meant that some students were more academically prepared than others. However this mix was considred useful from an experimental perspective as it helped emulate the different level of expertise involved in real, collaborative design projects. Table 1 summarises the mix of students involved in the globalproject. A total of sixty students participated in the exercise. The students were divided into six teams having between nine to eleven members and where possible coming from each of the four universities.

**Table 1 Mix of Students Involved in Collaborative Design Project**

| University | No. of Male Students | No. of Female Students | Course | Year of Degree /Duration of Degree |
|---|---|---|---|---|
| University of Malta | 16 | 2 | Bachelor in Mechnical Engineering – Industrial Stream | 3/4 |
| University of Strathclyde | 7 | 5 | Master in Product Design Engineering | 5/5 |
| | 10 | 7 | Master in Global Innovation Management | 1/2 |
| City University London | 3 | 0 | Bachelor in Mechnical Engineering | 2/3 |
| | 2 | 1 | Bachelor in Electrical Engineering | 2/3 |
| | 1 | 0 | Bachelor in Aereospace Engineering | 2/3 |
| Budapest University of Technology & Economics | 5 | 1 | Bachelor in Mechnical Engineering | 2/3 |

To faciliate the experiment with AR, the students at the University of Malta were specifically trained in generating AR models as from the second week of the exercise. For this training, they made use of on-line training material developed as part of the EU funded project *JoyAR* [8]. The conceptual seat belt models were developed using *Trimble SketchUP* and the *ARmedia* plugin. Other plug-ins available for advanced Computer-Aided Design (CAD) modelling systems (e.g. *Autodesk Inventor*) were also employed. Students were encouraged to test the plug-ins in the early stages of the exercise for two reasons – firstly to familiarise themselves with AR models and secondly to avoid technical problems when they actually use AR technology towards week 6.

## 4. DISTRIBUTED & EVALUATION EXPERIMENTAL RESULTS

To assess the impact of AR in evaluating the candidate solution developed by each distributed design team, students had to first adopt the normal practice, i.e. visualise the 3D model by using just a CAD package and then share their views via collaboration tools (e.g. *Skype*). After this step, each team in Malta had to augment, an assembly of 3D virtual components consituting 3D the seat-belt, on one of the team members who represented the passenger. Figure 2 illustrates two members of team 6 in Malta showing an augmented 3D model of the seat-belt to one of their team members who is located in Glasgow. Therefore, through collaboration tools, the team members abroad were able to visualise what the seat-belt looked like in reality. At the end of this exercise, the members of the distributed teams were asked to participate in a short questionnaire in order to assess the impact of AR technology on the evaluation stage of the global design exercise. To measure the respondents' attitude, a 6-point Lickert scale was employed, where in most questions a rating of 0 implied a negative attitutde whereas a rating of 5 implied a strong attitude. Respondents were encouraged to provide reasons for the rating given, so as to collect qualitative data.

***Fig. 2. Members of team 6 using AR to help the distributed team members visualise one of the concepts of the seat-belt***

The objectives of the evaluation exercise were to investigate:

1. to what extent AR was perceived useful to communicate ideas with co-located and distributed team members;
2. to what extent AR was perceived useful to visualise the final design solution;
3. the suitability of different approaches (e.g. CAD models only, physical prototypes only, CAD models and physical prototypes, CAD models used with AR etc.) to visualise and hence evaluate the final design solution in a distributed design environment;
4. whether any difficulties in using AR were encountered with co-located and distributed team members;
5. to what extent AR was perceived useful in improving the solution outcome in the exercise.

Sixteen students, coming from different design teams at UoM (six students), CUL (one student), UoS (four students) and BUTE (five students), volunteered in the questionnaire. Following are the key quantitative and qualitative results obtained in the survey. The results of each question were analysed both analytically as well as statistically (where relevant) by performing a number of tests (a significance level of 0.05 was taken), using Microsoft Excel data analysis tool. As illustrated in Table 2, a mean (M) rating of 3.06 with variance of 2.2 was attained as regard to the usefulness of AR to communicate ideas with co-located team members. This indicates that participants were hesitant whether AR is useful in this respect. A possible reason for this result could be attributed to the fact that three out of six groups either did not use AR or else experienced difficulties in installing AR plug-ins. For this reason, some of the results obtained are actually based on the students' perception of using AR in collaborative design. Note that due to the low turnout of students in the survey, it was unfeasible to segregate results otained by students who managed to actually use AR from those who did not. It must also be mentioned that terms *'between groups'* and *'within groups'* in the one-way Anova results tables are standard terms used in the statistical analysis and by no means refer to co-located and distributed design teams respectively.

A slightly more positive result was attained vis-a-vis the usefulness of AR to communicate ideas with distributed team members (M = 3.81, variance = 1.63). As reflected in the F (2.35) and p values (0.14) obtained, there was no significant difference in the these two mean average scores. One of the participants, whose group managed to use AR, reported that this technology *''was useful for sharing with members with no CAD access, also for showing the scale of a CAD model in real life which can be difficult to determine from the computer screen''*. Another participant pointed out that AR is more useful when working with people abroad as sometimes it is difficult to explain some concepts.

A similar result was obtained concerning the usefulness of AR to visualise the final design solution (M = 3.88, variance = 0.92). From the qualitiative results analysed, it was evident that participants who did not use AR in the exercise opted for a neutral opinion.

**Table 2 *One-way Anova* on results related to usefulness of AR in communicating ideas**

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| usefulness of AR to communicate ideas with co-located team members | 16 | 49 | 3.0625 | 2.195833 |
| usefulness of AR to communicate ideas with distributed team members | 16 | 61 | 3.8125 | 1.629167 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 4.5 | 1 | 4.5 | 2.352941 | 0.135527 | 4.170877 |
| Within Groups | 57.375 | 30 | 1.9125 | | | |
| | | | | | | |
| Total | 61.875 | 31 | | | | |

Figure 3 depicts the results of the mean rankings attained as regard to the suitability of different approaches to visualise and hence evaluate the final design solution in a distributed design environment. Note that a rank of 1 indicates the most suitable approach. As clearly demonstrated in Figure 3, participants preferred CAD models used with AR, together with physical prototypes (mean ranking of 1.25, variance = 0.45), followed by CAD models and physical prototypes (mean ranking of 2.19, variance = 0.56) and CAD models used with AR (mean ranking of 2.75, variance = 0.47). As illustrated in Table 3, the One-way Anova test revealed a significant difference in the mean ranking obtained ($F = 53.51 » F_{\_crit} = 2.59$, p-value $< 0.05$). The least ranked were those approaches which consisted of just one type of model. Therefore, participants preferred a multi-media approach, as also reflected in the mix of models they employed during the exercise. Figure 4 shows exempler CAD and physical models generated by teams 1 and 5. One participant remarked that CAD models with detailed documentation should be another approach considered.

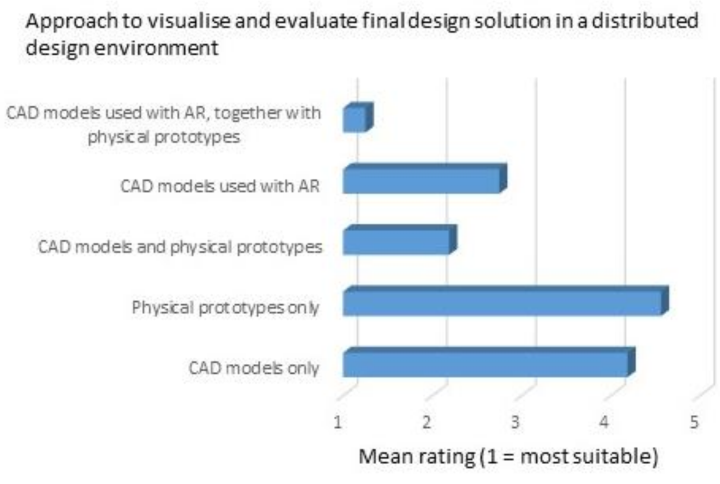



***Fig. 3. Mean rankings***

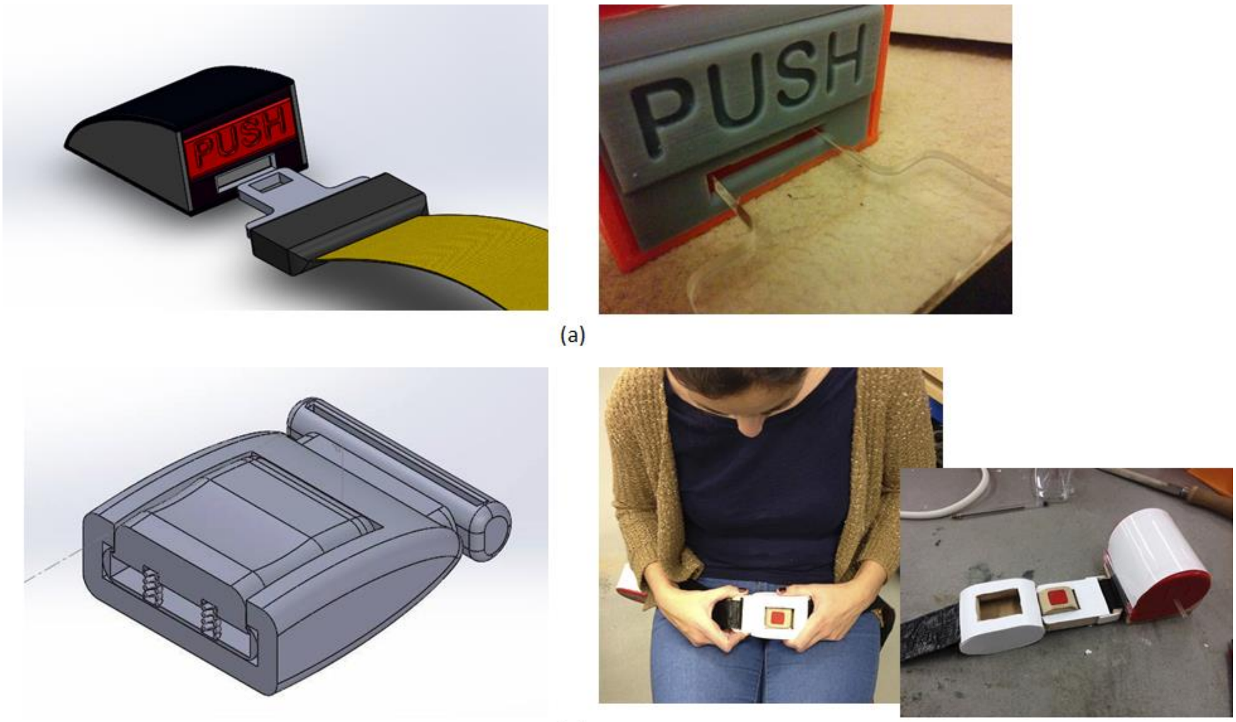
**Table 3.** ***One-way Anova*** **on mean scores obtained in ranking different approaches to visualize and evaluate design solutions in a distributed design environment.**

SUMMARY

| *Groups* | *Count* | *Sum* | *Average* | *Variance* |
|---|---|---|---|---|
| CAD models only | 16 | 67 | 4.1875 | 0.695833 |
| Physical prototypes only | 16 | 73 | 4.5625 | 0.6625 |
| CAD models and physical prototypes | 16 | 35 | 2.1875 | 0.5625 |
| CAD models used with AR | 16 | 44 | 2.75 | 0.466667 |
| CAD models used with AR, together with physical prototypes | 16 | 20 | 1.25 | 0.466667 |

ANOVA

| *Source of Variation* | *SS* | *df* | *MS* | *F* | *P-value* | *F crit* |
|---|---|---|---|---|---|---|
| Between Groups | 122.175 | 4 | 30.54375 | 53.5073 | 3.08E-21 | 2.493696 |
| Within Groups | 42.8125 | 75 | 0.570833 | | | |
| | | | | | | |
| Total | 164.9875 | 79 | | | | |




(a)

(b)

***Fig. 4. Exempler 3D CAD and physical models obtained by (a) team 1 and (b) team 5***

Results show that in general participants found less difificulties in using AR with their co-located team members compared to when using it with distributed team members. However the difference resulted to be only marginal (M = 2.19, variance = 3.76, M= 2.19, variance = 2.56 respectively, where a rating of 0 implied no difficulties were encountered). As mentioned earlier, the main difficulty was that in some cases the AR plug-ins found were not working.

With regard to the last evaluation objective, results indicate that participants tend to agree that AR was useful to improve the solution outcome in this exercise (M = 4.13, variance = 1.45, where a rating of 5 implied a positive attitude). Interesting, although those participants who found difficulties in using AR, they nonetheless were of the opinion that using such technology would enhance their design solution. In particular, the qualitative analysis indicate the following perceived benefits:

- by having AR models prior to 3D printed physical models could save a lot of printing costs and time, hence improving the performance metrices of the product. One particular member in team 6 remarked that a total of nine hours were spent in producing 3D printed prototypes;
- by having assembly of virtual models augmented in reality, the design teams can better decipher whether the concept generated looks appealing and practical, compared to when just using CAD models;

## 5. DISCUSSION & CONCLUSION

The research reported in this paper sheds light on the suitability of using AR technology in distributed design environments. The validity of the research results has to be taken in the context that firstly only 27% of the global design exercise students volunteered in the questionnaire, and secondly on the difficulties encountered by three teams to install AR plug-ins. Another factor which could influenced the results lies in the fact that this was the first time that AR was introduced in the global project, so the learning curve to implement it was challenging from the tutors' perspective.

As future work it is planned that a framework which would serve as a roadmap for design tutors to deploy AR in distributed design environments will be developed and evaluated in practice.

In conclusion, this paper has contributed a step in addressing the research gap outlined in section 2. Results provide a degree of evidence that AR technology in distributed design set-ups is useful as it eliminates unnecessary 3D printing and helps the teams to visualise and evaluate better the assembly of the evolving design solution, compared to just 3D CAD models. This indicates that AR has an impact on design solution evaluation. Having said that, it is concluded that more research work is required to assess the suitability of AR in collaborative working environments in both an academic and industrial set-ups.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