INTERNATIONAL CONFERENCE ON ENGINEERING AND PRODUCT DESIGN EDUCATION
8–9 SEPTEMBER 2022, LONDON SOUTH BANK UNIVERSITY, LONDON, UK

THE APPLICATION OF A DIGITAL PROTOTYPING SUPPORT TOOL IN A GLOBAL DESIGN STUDENT PROJECT

Konstantinos PETRAKIS[1], Andrew WODEHOUSE[1], Hilary GRIERSON[1], Euan COUTTS[2], Jussi LIIKKANEN[3] and Hannu PARKKAMÄKI[3]
[1]Department of Design, Manufacturing and Engineering Management, University of Strathclyde, Glasgow, United Kingdom
[2]School of Product Design, University of Canterbury, Christchurch, New Zealand
[3]Unit of Engineering and Business, Turku University of Applied Sciences, Turku, Finland

ABSTRACT
Prototyping is an inseparable part of product development in industrial and academic settings and a major theme of design education. However, it is still regarded as a design activity which is poorly implemented by students due to their limited prototyping scope; a challenge that is raising the need for the development of structured guidelines. Since distributed design projects are becoming popular in design education, research highlights the necessity for digital tools which ensure efficient collaboration and communication between globally dispersed students. The intention of this study is to explore students' usage of the prototyping support tool (PST) which aims to assist with planning, documentation and evaluation of their prototyping activities. Insights show that the tool's digital version (e-PST) enables students to communicate efficiently and present higher competency when documenting their design process, providing justification to their decisions and illustration as to how their outcomes have been informed through design iterations. Suggestions for further improvement of the e-PST are provided through surveys and interviews of participant students.

Keywords: prototyping tool, design education, prototyping purpose, student design projects

1 INTRODUCTION AND LITERATURE REVIEW
Prototyping is one of the most prominent design methods and represents an inseparable aspect of product development processes in both professional and academic settings. Prototypes represent physical or digital manifestations of design concepts and can encompass multiple features according to designers' needs who apply them for exploration or learning purposes, to inform their decision-making and improve communication between project stakeholders [1]. Especially in engineering design university courses, students have to build a wide range of different prototypes in order to support their learning objectives. Relevant research has emphasised prototyping's cognitive benefits to students, i.e., the reasoning and understanding of a design problem during the early stages, as well as the advantages offered through learning by reflection, learning by thinking and learning by making during prototyping-based exercises [2], [3].
Nevertheless, although prototyping constitutes a major theme of design education, it is still regarded as an underexplored activity which is inadequately understood and implemented by students [4], [5]. Our previous work is built on the importance of prototypes having pre-defined purposes, as an explicit purpose to be achieved by a prototype can ensure higher quality outcomes and better inform decision-making. Still, the task of constituting this purpose requires reflective thinking which comes less naturally to inexperienced designers. Investigation of students' prototyping reasoning has shown that their limited prototyping scope prevents them from realising prototyping's maximum benefits and raised the need for strategic guidelines that would improve learning and enhance their academic performance [4].
Relevant research has focused on the development of several tools for assisting students with their prototyping activities. Such means intend to structure prototyping into systematic step-by-step processes and have been introduced in the form of platforms containing photo- or video-based resources [2] or consist of questions which force conscious decision-making and are included in canvases [5] or

planning-based templates [6]. However, the recent shift towards online and blended learning environments due to COVID-19 restrictions and globalisation, has raised the need for additional online design tools that can ensure the successful delivery of distributed design activities [7]. Efficient collaboration in particular, is a key requirement of global design projects as it ensures the sharing of knowledge and expertise between dispersed stakeholders. Collaborative team projects are becoming more popular in the field of design education, as they facilitate the delivery of innovative solutions, enhance design coordination and represent real-world design scenarios found in professional settings [8]. At the same time, distant collaboration includes a number of challenges due to the participation of students of multiple disciplines, diverse cultures and different design practices as well as due to the obstacles in efficiently allocating tasks amongst team members [8]. All these barriers are even more evident in the case of students working in different time-zones, which consequently require asynchronous communication and collaboration for overcoming resource mismanagement which can lead to unsuccessful design outcomes. The evolvement of technology has significantly contributed to tackling these types of challenges by integrating appropriate digital tools which ensure collaboration and communication. They include functionalities such as messaging and video conferencing, collaborative document editing, electronic whiteboards, cloud storage platforms and shared calendars involving task distribution modes [9]. Yet, due to issues related to students' unawareness and inadequate experience, design educators should also ensure their integration into curricula by ensuring their availability and inform students about the appropriate selection of such practices.
Therefore, the aim of this paper is to present a study on students' usage of a digital tool including aspects of the aforementioned functionalities, which supports them during their prototyping activities by providing a shared, dynamic environment for collaboration. In detail, through exploration of students' engagement with the tool, we will examine if it has contributed to the development of prototyping-driven mindsets or if it disrupts the design process in any undesirable way. Followed by surveys and interviews, the students had the opportunity to reflect on their usage and provide valuable suggestions for its future improvement.

2 STUDY DESIGN

2.1 The "Global Design" module

This study has been conducted on design projects of "DM503 Global Design", a postgraduate level module at the University of Strathclyde which aims to provide 5th year students with appropriate understanding of the nature and management of distributed design practices. The team projects run for 7 weeks and involve a collaborative design task between co-located and distributed members of 8 teams, across 3 regions: University of Strathclyde (Scotland), University of Canterbury (New Zealand) and Turku University of Applied Sciences (Finland). Students have to apply necessary tools for producing, sharing and storing design information with the aim of delivering a product solution that prevents COVID-19 transmission in aircraft cabins.

2.2 The requirements and key steps of the Prototyping Support Tool (PST)

The Prototyping Support Tool (PST) aims to guide designers by assisting in the planning, documentation and evaluation of prototyping activities. Previous studies on novice and professional designers' practices [4], [10] have contributed to the elicitation of the underlying foundations of the PST; its essential requirements and the key steps of its structured supporting process. In detail, the PST comprises of a decision-making guide which minimises prototyping risks and encourages prototype assessment and refinement according to the quality of acquired insights. It facilitates efficient communication by encouraging designers to build context around their ideas and effectively articulate them to stakeholders. Given the diverse nature of each design project, PST ensures a modular process, the steps and tasks of which can be re-designed and integrate project risks and critical factors, while sticking to the underlying supporting process. Based on Design Thinking and Human-Centred Design principles, PST aims towards the development of a prototyping-driven mindset and adoption of a holistic design approach as well as the involvement of people across all decisions.
The current, online version of the tool (e-PST) has been created by taking the requirements and learning objectives of the "Global Design" module into consideration. A digital template has been developed on Mural (Mural.co), a digital workspace platform for visual collaboration which enables remote teamwork synchronously or asynchronously through a virtual environment. The project objectives were aligned with Mural's delivery format as all team members were able to input information in the form of text,

post-it notes, visuals and graphs, or even create their own personalised templates to support communication, sharing and management of their design work. As shown in Figures 1 and 2, e-PST comprises of 4 main Sections which include specific tasks, and its core is the provided built-in list of prototyping purposes which has been adapted from previous work and tailored to the project brief. This study is based on prototypes' emerging role as information prompts in supporting learning, communication and decision-making, regardless of their fidelity [1]; therefore, sketches, storyboards, role-playing, physical mock-ups, CAD models and functional models are all considered as prototypes.

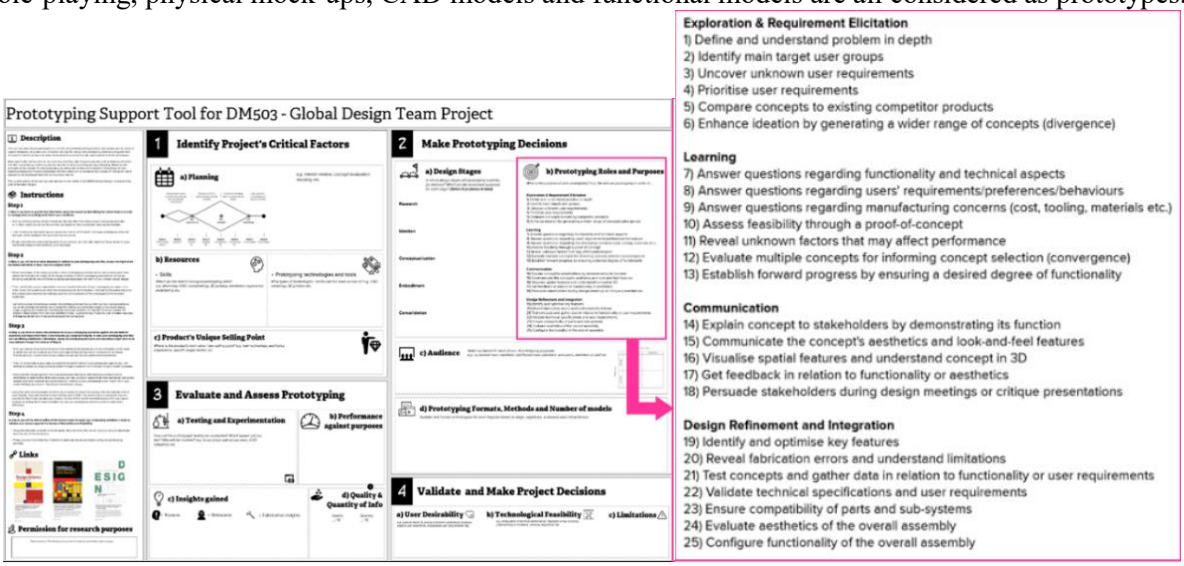

Figure 1. Mural template of e-PST with built-in list of prototyping purposes being highlighted

Section 1 – Identify Project's Critical Factors
• Provide information by defining key project or prototyping milestones • Document resources in terms of members' prototyping skills and access to available prototyping technologies • Describe product's unique selling point
Section 2 – Make Prototyping Decisions
• Recognise when prototyping is needed and associate prototyping purposes from built-in list to the according design stages • For the purpose of this exercise, select up to 8 explicit purposes • Consider types of audiences to which prototypes are communicated • Define prototyping formats, methods and numbers according to above inputs i.e., design stage, purpose, audience
Section 3 – Evaluate and Assess Prototyping
• Document and describe the conducted testing and experimentation methods • List the insights gained from testing and prototyping building process • Assess performance of prototyping outcomes by scoring them against their pre-defined purposes • In case of underperforming prototypes, consider the revision of Section 2 and explore prototype refinement
Section 4 – Validate and Make Project Decisions
• Utilise the total of lessons learnt through prototyping activities and combine with findings acquired through other design tools • Validate product against the factors of user desirability and technical feasibility • Highlight any prototyping challenges or limitations and document your reflection remarks

Figure 2. e-PST Sections and instructions on included tasks

2.3 Methodology

Once the project brief was released, students were introduced to the e-PST. Explicit instructions were provided within the template, and a video demonstration of its usage was presented during the class. Also, researchers were supervising the usage of the e-PST during the project. After the projects' conclusion, students were asked to complete an online survey comprising of 40 multiple choice Likert scale questions in relation to the e-PST's usage, complexity, effectiveness and design. In order to capture a mixture of quantitative and qualitative feedback, semi-structured interviews were also conducted with 3 of the students to get in-depth feedback and suggestions for further development. Lastly, we gathered the completed e-PST Mural templates from all teams, and we tried to relate the levels of their engagement to their marks, prototypes and final design solutions.

3 RESULTS AND DISCUSSION

3.1 Students' usage and degree of engagement with the e-PST

With regards to the teams' usage of the e-PST, we classified their templates according to the degree of engagement as shown in the examples included in Figure 3. Although we can recognise significant relationship patterns between engagement and their associated marks, as highest marked teams showed

higher levels of e-PST usage and templates filled with information, we should also mention that their assessment is based on their overall design work and process management. Nevertheless, although teams with little or no engagement show fair consistency in the quality of prototyping outcomes, a valuable observation has to do with their process documentation. Teams which demonstrated adequate or good usage of the e-PST, managed to justify and document their design process more effectively. They also exhibited higher competency in relation to providing rationale behind their decisions and better illustrate how their outcomes informed iteration and development processes. Furthermore, these teams conveyed a stronger sense of collaboration and interaction across their members and clearer structure in terms of project management. Finally, it is evident that higher engagement with the e-PST facilitated the application of mixed prototyping methods, informed problem definition and considerably enhanced ideation and concept generation in relation to spatial and feature exploration. As a result, these teams were more capable in evaluating their prototypes based on ergonomics and functional aspects, while offering manufacturing considerations and providing realistic conclusions on feasibility and desirability.

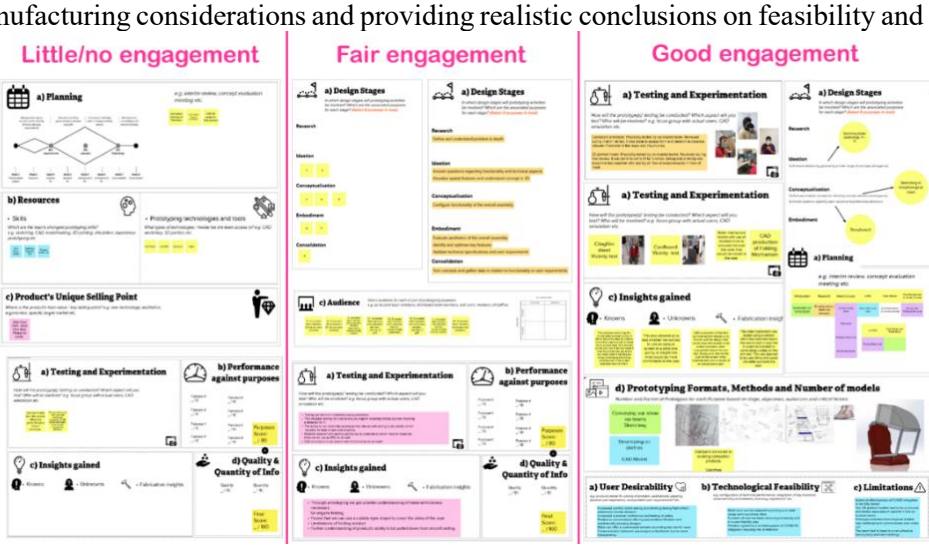

Figure 3. Examples of completed e-PST template Sections, based on level of student engagement

3.2 Feedback on different e-PST aspects through surveys and interviews with students

Initially, a noteworthy finding concerns students' previous exposure to similar prototyping guidelines and tools. In detail, 82% of them had never employed any comparable support, even despite the fact that they are all part of a postgraduate level design course. As far as complexity is concerned, while the majority was satisfied with the provided instructions, students reported that the execution of the e-PST can be moderately (66%) or significantly (11%) challenging. Additional interview insights indicated that instructions were skipped, and e-PST was completed through simply following the natural flow between Sections, and that the provided video demonstration was more useful; results that feed back to students' experience in analogous support tools. e-PST integration was also regarded as fairly (44%) or significantly (11%) time-consuming, a finding that may be related to students' retrospective approaches, i.e., inputting information after they had already completed the related tasks. Nevertheless, disruption of process was insignificant, as the e-PST did not significantly interfere with their actual design or prototyping activities. The e-PST facilitated students to appropriately address the assessment criteria of the project's brief, and consequently achieve the module's learning objectives, an important finding for the modularity and adaptability of the tool. Interestingly, e-PST achieved similar rates of effectiveness in terms of communication of concepts among dispersed and co-located team members, showing that while digital template-based tools can enable efficient distributed design practices, they also ensure successful communication between local design teams in which synchronous or asynchronous collaboration modes may be required. In terms of their overall e-PST experience, 66% of students rated it as very or moderately useful, whereas 11% were extremely satisfied with the value it added to their projects. This novel approach of project management based on prototypes was considered as "new and really interesting" and students were pleased with the breakdown of different prototyping phases.

Students seemed satisfied with the level of support provided in Section 1 (Identify Project's Critical Factors) for planning prototyping activities and managing the project, as the latter was also among the

two highest ranked useful attributes of the e-PST by 56%. Definition of key milestones was also deemed as valuable, along with the focus on the identification of the product's unique selling point, aspects significantly assisting in Section 2 (Make Prototyping Decisions) decision-making. All students acknowledged the e-PST in relation to managing their resources, whereas 73% of them highlighted that it enabled them to realise and appreciate their skills in different prototyping methods. These conclusions are notable due to the relatively little amount of time students had to complete the project, meaning that resource management and risk reduction had to play an important role in successful delivery.

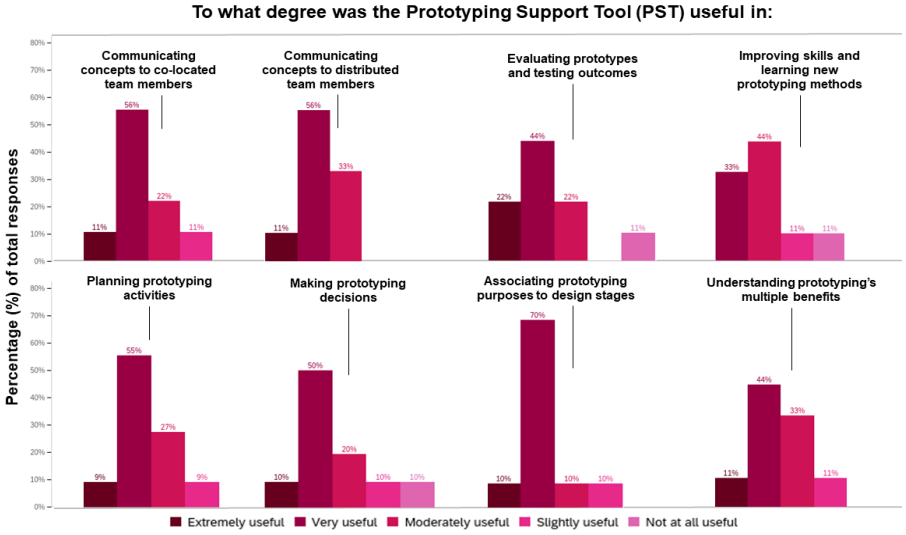

Figure 4. Survey results on different utility aspects of e-PST

Prototyping decisions and assessment of prototyping outcomes, which embody the core of the PST, were also the most acknowledged. Section 2 was really beneficial in recognising when prototyping is needed, as well as associating purpose to the corresponding design stage. The built-in purpose list was rated as the most useful aspect of the e-PST as it regularly acted as a reference and turned out to be more useful than the actual instructions provided for the project's overall goals. Students were generally impressed with the wide variety of roles prototyping can serve, stating that e-PST facilitated the learning of prototyping's multiple capabilities and enhanced their creativity. They specified that past experiences were mainly limited to technical requirements and did not actively involve the task of pre-defining a purpose, a finding that verifies the narrow prototyping scope exhibited. The aforementioned findings are strongly related to exploration and ideation enabling attributes of prototyping, which are not widely used, and massively affect students' adoption of a Design Thinking mindset, one of the key PST aims. The tool's implementation was also useful in correlating prototype purposes and features to the associated type of audience. Ideally, future e-PST versions should be able to provide bespoke prototyping format guidelines according to the inputs in previous Sections; however, students stated that although suggestions and examples would be welcome, they would prefer some degree of freedom.

In relation to Section 3 (Evaluate and Assess Prototyping) and Section 4 (Validate and Make Project Decisions), particular mention was made to the capacity of the e-PST in documenting lessons and assessing testing outcomes, as this practice may not be normally done. This process provided them with reassurance and enabled them to translate insights into user or product requirements. Section 3 in particular facilitated the prototypes' iterative refinement and ensured that they were exploited to their maximum potential, as 89% of students were able to revisit Section 2 and make appropriate prototype alterations, while 55% of them used the e-PST to predict potential prototyping issues. The distinction made between prototyping insights (Section 3) and project decisions (Section 4), enabled students to combine the lessons learnt from prototyping with information acquired through other design tools, to make "bigger picture" decisions in relation to desirability and feasibility such as ergonomics, product lifecycle and manufacturability.

Finally, the template's design was considered as "visually attractive" and a "fun addition" to the module, while the efficient interface and the intuitive flow between Sections were emphasised. The digital e-PST was preferred over a paper sheet version due to its easier access and storage, and the presence of information on a single template; consequently, the majority are willing to apply it to future projects. Highlighting the importance of the user-friendly and modular aesthetics, students were ensured that

bespoke, personalised versions can be developed for their design projects, a fact that also verifies the specifications realised during PST's development.

4 CONCLUSIONS AND FUTURE WORK

This paper documents the development and evaluation of a digital prototyping support tool (e-PST) through its application in an academic, distributed design project. The need for the e-PST was established through literature findings on students limited prototyping competencies as well as the requirements of design projects of global nature which necessitate efficient communication, collaboration and sharing of design information. Exploration of students' tool usage on the web-based platform Mural, showed that it can enhance their prototyping activities, boost their decision reasoning and enable them to justify their design processes effectively while ensuring efficient communication.
Future work includes the ongoing development of the tool to align with design education practices, to ensure that prototypes are exploited to their ultimate capabilities and improve students' skillsets. Since the effortless execution and smooth integration of the tool into the design process is one of its key requirements, findings from this study will be considered towards its future refinement. Such modifications include, ensuring that disruption from actual design and prototyping tasks is kept to a minimum, integration of visual instructions within its template and the more efficient allocation of space, which would allow more detailed documentation and greater number of visual inputs. Also, refined versions of the e-PST tool will be used in future team or individual academic projects for the purpose of validating their use and compare their application with this study's findings.

REFERENCES

[1] Lauff C., Kotys-Schwartz D. and Rentschler M. E. What is a Prototype? What Are the Roles of Prototypes in Companies? *Journal of Mechanical Design 140 (6): 061102. doi:10.1115/1.4039340,* 2018.

[2] Ramos J. D. and Wallace D. R. Designy: a multimedia platform for supporting student prototyping in product design education. *In Proceedings of the ASME 2019 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference (IDETC/CIE2019), Anaheim, CA, USA, August 18–21, ASME,* 2019.

[3] Böhmer A. I., Kayser L., Sheppard S. and Lindemann U. Prototyping as a Thinking Approach in Design: Insights of Problem-Solving Activities While Designing a Product. *International Conference on Engineering, Technology and Innovation (ICE/ITMC), 955–963,* 2017.

[4] Petrakis K., Wodehouse A. and Hird A. Physical Prototyping Rationale in Design Student Projects: An Analysis Based on the Concept of Purposeful Prototyping. *Design Science 7* e7. *doi:10.1017/dsj.2021.6.*, 2021.

[5] Lauff C., Menold J. and Wood K. L. Prototyping Canvas: Design Tool for Planning Purposeful Prototypes. *Proceedings of the Design Society: International Conference on Engineering Design 1, no. 1 1563–72. doi:10.1017/dsi.2019.162,* 2019.

[6] Hansen C. A., Jensen L. S., Özkil A. G. and Martins Pacheco N. M. Fostering Prototyping Mindsets in Novice Designers with the Prototyping Planner. *Proceedings of the Design Society: DESIGN Conference 1, 1725–34. doi:10.1017/dsd.2020.132.,* 2020.

[7] Brisco R., Grierson H. and Lynn A. Lessons learned in the development of an online 6-3-5 digital design tool for distributed idea generation. *DS 110: Proceedings of the 23rd International Conference on Engineering and Product Design Education (E&PDE 2021), VIA Design, VIA University in Herning, Denmark. 9th-10th September* 2021.

[8] Mamo J., Farrugia P., Borg J., Wodehouse A., Grierson H. and Kovacevic A. Using engineering design tools in multidisciplinary distributed student teams. *DS 82: Proceedings of the 17th International Conference on Engineering and Product Design Education (E&PDE15), Loughborough, UK, 03-04.09. (pp. 099-104)*, 2015.

[9] Brisco R., Whitfield R.I., Grierson H. and Bohemia E. Overcoming the challenges of global collaboration through design education. *DS 95: Proceedings of the 21st International Conference on Engineering and Product Design Education (E&PDE 2019), University of Strathclyde, Glasgow. 12th-13th September* 2019.

[10] Petrakis K., Wodehouse A. and Hird A. Prototyping-Driven Entrepreneurship: Towards a Prototyping Support Tool Based on Design Thinking Principles, *The Design Journal, 24:5, 761-781, DOI: 10.1080/14606925.2021.1957531,* 2021.