DESIGN SPRINT: USE OF DESIGN METHODS AND TECHNOLOGIES

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ABSTRACT

This paper analyses the use of design methods and information and communication technology (ICTs) tools in design sprint (DS) activities. Team members, team leaders, and coaches of five international student teams were interviewed (40 interviews in total) regarding their use of design methods and ICT tools during three DS activities: problem definition, conceptual design, and embodiment design. The results show that teams utilise various methods through three approaches: one method for the task, several methods for the task, or adjusting methods. Teams considered several aspects when deciding which method to utilise: the possibility of work distribution, the time needed to execute the method and their prior experience in using the method. The results on using ICT tools suggest that teams mainly use the collaborative whiteboard and Computer-aided design (CAD). In this context, tools that enable continuous sharing of the work in progress (e.g., cloud-based tools) show great potential for DS activities. Finally, the results show a potential to integrate various tools in order to enable easy transition between tasks (e.g., a transition from collaborative whiteboard to CAD modelling).

Keywords: Design education, Design methods, Collaborative design, Design sprint, Information and Communication Technology

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1 INTRODUCTION

Design education is mainly based on project-based courses (Dym *et al.*, 2005) that provide students with the opportunity to solve problems in real-world projects. In this context, working in time-bounded but intense activities is becoming more and more common (Goudswaard *et al.*, 2022), as they help the team stay focused and motivated in a short timeframe (Baraças Figueiredo Correio and Leme Fleury, 2019). Therefore, time-bounded intensive design work is of great importance for project-based courses.
The common approach to time-bounded intensive work is the Design sprint (DS) - a framework encompassing fast-paced design activities (Banfield *et al.*, 2015). These sprints are similar to design iterations, where an output or outcome is expected to be produced within a set timeframe that includes repetitions or cycles (Banfield *et al.*, 2015). While DS is an inevitable approach to answer demands for faster product development, design researchers rarely explored these time-bounded intensive design activities (Flus and Hurst, 2021). Furthermore, most of the developed design methods (e.g., functional decomposition, morphological table) were not developed for such activities, although they can be adapted to various cases (Lawson and Dorst, 2009). Nevertheless, the usage of design methods in time-bounded intensive design activities has rarely been exploited. Hence, it remains unclear to what extent the methods developed for the traditional design process could be utilised in these intense periods, such as DS activities.
In order to help them utilise design methods in project-based courses, students use a wide variety of information and communications technology (ICT) tools (Pacheco *et al.*, 2022). However, students might not always use the optimal ICT tool for the given tasks (Horvat *et al.*, 2021), as they might face a steep learning curve if the tool is unknown to them (Verstegen *et al.*, 2016). Consequently, students might spend a lot of time learning these ICT tools, which might be a decisive factor in the time-bounded intensive design activities. Therefore, understanding how ICT tools students might utilise during the DS activities is of crucial importance in this context.
In order to fill these gaps, the paper aims to explore the use of design methods and ICT tools in DS activities as part of the engineering design project-based course. The following research question guided the study: *"How students utilise design methods and ICT tools in various DS activities?"*

2 BACKGROUND ON DESIGN SPRINT (DS)

DS consists of five time-bounded intensive design activities (Banfield *et al.*, 2015): understand, diverge, converge, prototype, and test. These activities usually last about one day, thus enabling teams to quickly develop and test new versions of their solution. In the understanding activity, teams explore the background of the challenge, focusing primarily on understanding users and markets. This activity gives the product team a sense of empathy for the people they are designing, thus providing a better understanding of a problem to solve. In the diverge activity, teams look at possible solutions and generate as many ideas as possible to explore the range of possibilities that solve the problem. The converge activity is about narrowing the choices to one or two solutions that will be prototyped and tested. The prototype activity aims to create a model that users can interact with - something they can use to test their hypotheses and confirm or disprove assumptions. Finally, testing the prototype is usually conducted with end users. During this activity, the team usually observes user interaction with the prototype and analyses what is effective for them and what is not.
This framework borrows techniques from design thinking and lean startup (Knapp *et al.*, 2016). From the design thinking perspective, it uses the designer's sensibility and methods to match people's needs by alternating between divergent and convergent thinking. From the lean startup perspective, the DS focus on converting technologically feasible solutions and viable business strategies into customer value and market opportunity, advocating cost reduction and lean manufacturing concepts. Based on these various roots, a range of design methods might apply to DS activities.

2.1 Design methods for DS activities

Various design methods have been utilised for DS activities. For example, Goudswaard et al. (2022) do not suggest any design methods and leave a choice to participants to choose whichever methods they would like to utilise. In this context, participants might follow a traditional design process similar to the ones in common design tasks (Flus and Hurst, 2021). Flus and Hurst (2021) suggest that teams might identify problems (first DS activity) from the industry partners, personal experience, or user

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research. For these purposes, teams might use various methods to understand a problem further, such as challenge mapping, user profiling, and stakeholder mapping (Banfield *et al.*, 2015; Flus and Hurst, 2021; Knapp *et al.*, 2016). In addition, teams might also conduct interviews with users (Banfield *et al.*, 2015; Flus and Hurst, 2021) or experts (Knapp *et al.*, 2016). As a support for the diverge (generate) DS activity, researchers often suggest that it is necessary to review existing ideas and sketch their combination or improvements (Knapp *et al.*, 2016). In this context, methods such as the network of problems or the morphological table might be useful. Furthermore, brainstorming and brainwriting are both methods that can support this activity (Banfield *et al.*, 2015). Finally, for the prototyping DS activities, researchers often point out the importance of virtual prototyping, as these types of prototypes can be quickly created at a lower cost than physical prototypes (Camburn *et al.*, 2017) and quickly transfer across the globe - an essential characteristic for distributed teams (Vukašinović and Pavković, 2017). Moreover, they are easy to modify and duplicate (Camburn *et al.*, 2017), thus supporting the iterative nature of the design. For the prototyping activity, Pacheco et al. (2022) suggest the use of computer-aided design (CAD) models. In this context, collaborative CAD modelling provides a unique opportunity as they increase team member communication and awareness of the actions that the team takes to create a prototype (Eves *et al.*, 2018). Therefore, various methods can be utilised for design, but their advantages and disadvantages remain unclear.

2.2 ICT tools for DS activities

Many different tools are used in project-based courses (Horvat *et al.*, 2021). In the context of DS activities, researchers suggest the usage of collaborative tools that enable real-time synchronous working. For example, many researchers suggest that collaborative whiteboards (e.g., Miro, Mural) have a great potential for most tasks (Horvat *et al.*, 2021; Verstegen *et al.*, 2016; Vukašinović and Pavković, 2017). Whiteboards enable structuring acquired information, integrating with the existing information and sharing the information among team members (Verstegen *et al.*, 2016). Therefore, they might be especially useful for early DS activities, as they are characterised by collecting a lot of information in order to define a problem (Banfield *et al.*, 2015; Knapp *et al.*, 2016). Whiteboard ICT tools also support sketching and importing 2D sketches - an inevitable approach while creating concepts (Pacheco *et al.*, 2022). As such, the generation DS activities might also be supported by these tools (Horvat *et al.*, 2021). In creating prototypes, students most often utilise CAD tools (Pacheco *et al.*, 2022). However, student teams, especially if they know different CAD tools, often utilise more than one CAD tool (Horvat *et al.*, 2021). This makes collaboration especially challenging, as problems with exchanging files and editing created models might take too much time. Following the importance of collaborative tools for DS activities, researchers often explored the potential of collaborative CAD tools in this context. While working on the same part might not be the most efficient as their modelling takes more person-hours than individual work (Phadnis *et al.*, 2021), having an up-to-date version of all models might be especially useful for the time-bounded intensive design activities. Although previous research reported ICT tools that might support DS, none of them provides comprehensive information on using ICT tools for methods used during DS activities.

3 CASE STUDY: PROJECT-BASED DESIGN COURSE

In order to better understand the methods and tools used in a DS context, the study follows a case study research design of student teams developing a product within an international project-based course. The course is organised as a collaboration of four universities (University of Zagreb, Politecnico di Milano, University of Ljubljana, and TU Wien), in which five mechanical engineering student teams work on a product design problem. Students worked mainly virtually on a problem proposed by an industrial partner. Four female and 35 male students on both undergraduate and graduate levels participated in the course. Four teams consisted of eight members, two from each institution, while one team had seven members. Two aspects were considered when deciding on the size of the team. The first is the international aspect that should be covered by two members from each country. The second is related to previous experiences with previous course editions that indicated an eight-member team size as suitable. During the course, each team had one or two academic coaches who worked as the team's facilitators. The coach advised, helped communicate with the company, and explained the basic objective of the course and the work methodology.

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3.1 Course description

The course was divided into an initial workshop, followed by three phases (problem definition, conceptual design, and embodiment design). Each phase finished with a design sprint activity (Figure 1). The entire course was conducted online, except for the third DS activity, which was conducted as an event in a physical environment (Figure 2 - right). The initial workshop delivered a design problem and introduced ICT tools that might support teams throughout the course. The design problem was to improve passenger experience in metros and create added value for the operator. The suggested ICT tools were video conferencing (e.g., Microsoft Teams) and instant messaging (e.g., WhatsApp) for communication, and a collaborative whiteboard (e.g., Miro) for task execution. At the beginning of each phase, teams received an information package that included the required outputs of the DS activity and suggested methods that can help to deliver these outputs. The required outputs and suggested methods were based on the previous experience in conducting similar courses, as they were shown to be appropriate for the given context (e.g., course assignment, team size, ease of learning).

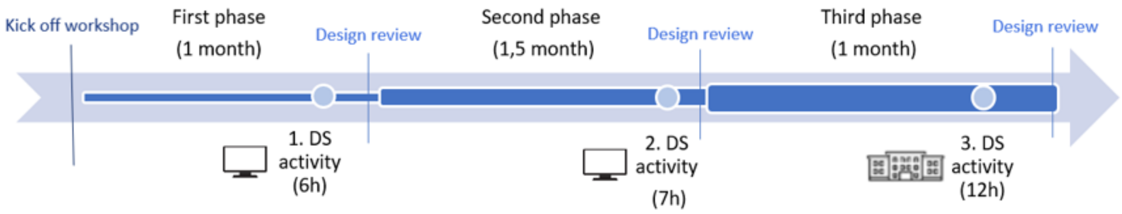

Figure 1. Timeline of the project

In the first phase, teams got to know each other, created a team logo, and had to generate three product visions. Students were introduced to methods related to market and user research (e.g., user persona, political-economic-social-technology-environmental-legal (PESTEL) analysis, activities-environment-interaction-objects-users (AEIOU) framework) and idea generation (e.g., brainstorming). At the end of the phase, the first DS activity was held online in Microsoft Teams (Figure 2 - left). In the first DS activity, which lasted 6 hours (split into two days), students conducted market and user research and generated three product visions. At the end of the first phase, students had to define functional requirements and present the visions to the company representatives. The representatives have chosen one vision per team to work on in the next phase.

At the beginning of the second phase, a presentation was given explaining design methods for problem framing (e.g., a network of problems, functional decomposition) and concept generation (e.g., brainstorming, brainwriting, and morphological table). The aim of this phase was to generate three concepts for the chosen vision. Considering all the information gathered from the coaches, in the second DS activity (duration: 7 hours, split into two days), students had to create several product concepts and write solutions for product functions. At the end of the conceptual design phase, students had to present the concepts to the company representatives. The representatives have chosen one concept per team to work on in the next phase.

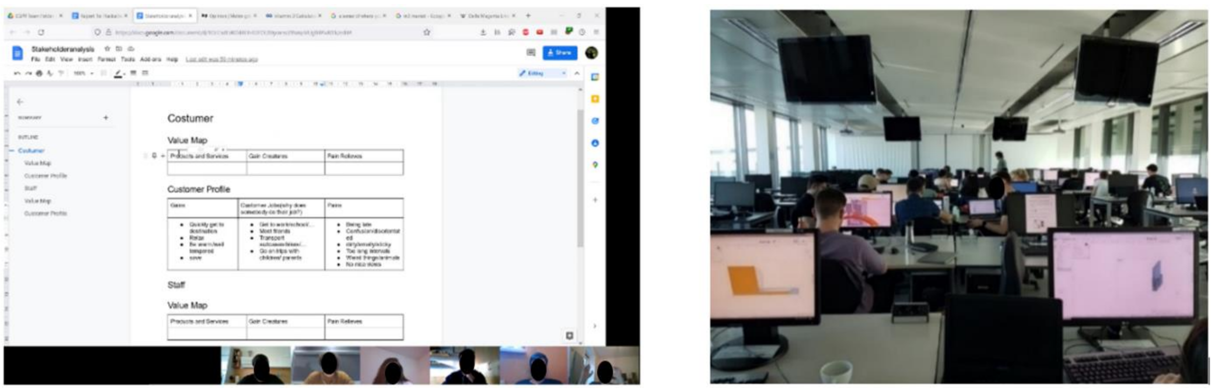

Figure 2. DS activities conducted online(left) and in person (right)

At the beginning of the third phase, students had to conduct an embodiment design of the chosen concept considering technical, economic, feasibility, and maintenance aspects. In this phase, students were introduced to methods related to the creation (e.g., CAD modelling) and evaluation (e.g., finite

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element analysis) of virtual prototypes. More specifically, teams were provided with a fully cloud-based CAD system (i.e., Onshape) that allows access through any web browser. The coaches provided instructions for Onshape, and students were advised to complete an official learning tutorial (Onshape Fundamentals: CAD) before the third DS activity to become familiar with the CAD system. In addition, teams were supported by coaches in order to clarify any potential issues they experienced while using the CAD system. Towards the end of this phase, a third DS activity was organised as a 12-hour face-to-face event whose aim was the creation of a virtual prototype using a CAD modelling approach. At the end of the embodiment design phase, teams had to do feasibility checks and simulations. Finally, students had to pitch their final solution to the company representatives. Company representatives rated Team A as having the best overall solution and Team B as having an innovative sub-solution.

3.2 Data collection and analysis procedure

In total, 40 semi-structured interviews were individually conducted with team members, team leaders, and coaches to collect data on all three DS activities. The data provided insights into the use of methods and ICT tools during the three DS activities. Different perspectives on each phase were collected by interviewing different roles in the project. The interviews lasted between 30 and 60 minutes (27 hours in total). The interviews consisted of three sections adapted to each interviewee's role. The part of the questions was common to each DS activity and focused on the used methods and ICT tools, as well as participant impression of them. Moreover, interviewees were asked to explain the allocated resources (e.g., time, team members) during the DS activity. Furthermore, each DS activity had specific questions that aimed to shed more light on the contextual aspects of the DS activities. Examples of questions that were specific for each DS activity can be found in Table 1. The interviews were analysed using thematic coding analysis to identify initial methods, which were then reviewed for similarities and differences. The methods were assigned to tasks - derived from the course description, DS activities (Banfield *et al.*, 2015) and prior work on the project-based courses (Horvat *et al.*, 2021). Finally, a comparison table was created that was used to identify methods used for each task. Each method was described by its advantages and disadvantages, and with the ICT tool utilised for the creating method content.

Table 1. Interview questions

Focus of questions	**Example of an interview question**
Questions common to each DS activity	What methods did you use? What tools did you use? What is your impression of the tools and methods you used? How did you allocate resources during the DS activity?
1st DS activity: specific questions	How did you find user reviews?
2nd DS activity: specific questions	How did you generate solutions?
3rd DS activity: specific questions	How did you approach CAD modelling?

4 RESULTS

This section presents student teams' usage of design methods and ICT tools during each DS activity. More specifically, Section 4.1 presents results for the first DS activity, Section 4.2 for the second DS activity, and Section 4.3 for the third DS activity.

4.1 First DS activity

Teams reported different working approaches in the first DS activity. In order to save time, team A was advised by their coach to work in parallel on user and market research. This team then presented their findings to the other team members in order to develop a shared understanding. The remaining teams (B, C, D, and E) worked synchronously on one method at a time. After the market and user research, all teams worked synchronously on idea generation.

Teams used various methods for the tasks in the first DS activity (Table 2). For market research, teams B, C, and E utilised PESTEL using a collaborative whiteboard (Miro). Its advantages were that it gave a detailed overview of the different market areas, and the students reported that it was a good way to start market research. On the other hand, teams reported that it was difficult to gather all the information and that it took a lot of time. Team A employed adjusted methods, as they focused only on certain aspects of the provided methods (e.g., PESTEL). They reported that this enabled them to

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focus on the most important aspects of the given design problem and saved time. However, they were aware that focusing on certain aspects could result in a limited understanding of the market and users.
For the user research task, teams reported using AEIOU, User persona, interviews or secondary sources. The AEIOU method received mainly positive feedback. Teams B and C utilised it in Miro and reported that the method provided a detailed description of the users and their behaviour in the context of the design problem, i.e., metro coach in this case. Similarly, user persona also provides a description of the users and their behaviour, but the emphasis is on providing different perspectives. However, this method relies mainly on empathising with the fictional characters, which teams reported as being difficult in this context. This method also took a lot of time, which could be the reason why only two teams (B, E) utilised it. Teams C and D conducted interviews via Teams, which were time-consuming but worthwhile because they obtained a lot of useful information from the users. Team A utilised secondary sources (e.g., reports) and reported that it saved them time and provided them with information that could not be retrieved in the given timeframe. However, this approach was hard to distribute among the seven-member team, as independent work would often result in members finding similar sources. For saving and organising the collected information from market and user research, most of the teams (B, C, D, and E) worked with Miro from the beginning. These teams reported that Miro was a useful tool for collaboration. Only one team (A) did not want to "waste time" trying to understand a new platform like Miro. Instead, they used cloud document editing tools (e.g., Google Docs).
For the idea generation, all teams used brainstorming (Table 2). This method was helpful for creating three visions, as it enabled simultaneous work. Simultaneous work in this task was especially important for teams whose members worked on different market and user research aspects, as it enabled idea creation that addressed various perspectives. However, participants reported that it was difficult to remain abstract and not fixate on a solution. For this task, all the teams utilised a collaborative whiteboard (i.e., Miro) and reported that it helped them to have all the ideas in one place.

Table 2. Used methods and ICT tools in the first DS activity

Task	Methods	Methods pros and cons	ICT tool	Team(s)
Market research	PESTEL	+ Gives detailed views on various market sections; enables parallel work; great to start	Miro	B, C, D, E
		- Hard to grasp all aspects; time-consuming		
	Adjusted method	+ Possibility to focus on the most important aspects of the given task; saves time	Miro	A
		- Might overlook important aspects		
User research	User persona	+ Provides different perspectives of the users	Miro	B, E
		- Time-consuming; hard to empathise with fictional characters		
	AEIOU	+ Provides a detailed description of users	Google Docs	B, C
		- *None reported*		
	Interview	+ A lot of useful information from a detailed interview	Teams	C, D
		- Time-consuming		
	Secondary sources (reports)	+ Saves time; provides information that could not be retrieved in the given timeframe	Internet	A
		- Hard to do work in parallel		
Idea generation	Brainstorming	+ Helpful with visions; simultaneous work	Miro	A, B, C, D, E
		- It is difficult to remain abstract and not fixated on a solution		

4.2 Second DS activity

Similar to the first DS activity, teams reported different approaches in organising the second DS activity. Team A had created a network of problems before the second DS activity so that they could focus only on the concepts during the DS activity. They divided into three sub-teams for each concept, researched and created sketches, presented them to the other team members at the end of the DS activity, and conducted the concept evaluation. Team B first worked together on the network of problems and then in three sub-teams on concept generation. Other teams (C, D, E) also started the DS

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activity by creating a network of problems. However, they created four sub-teams to create four concepts in total.

The teams used different methods for the tasks in the second DS activity (Table 3). Two methods utilised for the problem framing were a network of problems and functional decomposition. All teams created a network of problems in Miro that enabled them to empathise with the passengers easily. However, the network can quickly become overwhelming, making it thus difficult to avoid the repetition of problems. Teams B and E created multiple networks of problems, each related to the topic sought by an individual or sub-team (usually two to four members). In contrast, teams C and D created a single network of problems that incorporated the results of all searches. Students reported that another tool (e.g., Visio, Draw.io) would be helpful for this method because it quickly becomes chaotic and overwhelming in Miro. Team C solved this problem by creating problem clusters and using different coloured sticky notes. Furthermore, functional decomposition was created by two teams (B and D) in Miro. Its advantage was easier understanding of complex problems. On the other hand, it was time-consuming and difficult to understand the difference between functions and needs.

For the concept generation task, teams utilised a morphological table, brainwriting, and brainstorming methods. For the morphological table, teams usually divided among themselves to conduct an internet search for solutions related to each function. Teams also created sketches using a collaborative whiteboard (e.g., Miro) or a CAD tool (e.g., SolidWorks, CATIA). These sketches were then presented using communication tools or transferred to a collaborative ICT tool (e.g., Google Spreadsheet, Miro) so that all members could access the sketch. These visualisations helped team members better understand each other's ideas. In addition to parallel work, this method enabled teams to describe solutions easily. However, teams also reported that it did not quite fit the design problem, as it was difficult to visualise abstract solutions. The brainwriting method also enabled parallel work and supported teams to get different perspectives on their concepts. Finally, brainstorming was also conducted by all teams using Miro. This method supported users to think outside the box. However, teams reported that this way of working might become chaotic when teams work simultaneously.

Table 3. Used methods and ICT tools in the second DS activity

Task	Methods	Method strengths and weaknesses	ICT tool	Team(s)
Problem framing	Network of problems	+ Easy to empathise with the passengers	Miro	B, C, D, E
		- Problem repetition; overwhelming		
	Functional decomposition	+ Easier to understand complex problems	Miro	B, D
		- Time-consuming; hard to understand the difference between functions and needs		
Concept generation	Morphological table	+ Easy to describe the solution; enables parallel work	Miro, CAD	A, B, C, D, E
		- Hard to visualise abstract solutions		
	Brainwriting	+ Gained different perspectives on different solutions; enables parallel work	Miro	A, B, C, D, E
		- *None reported*		
	Brainstorming	+ Thinking out of the box; productive	Miro	A, B, C, D, E
		- It gets chaotic when teams work simultaneously		

4.3 Third DS activity

The third DS activity was usually organised by dividing teams into sub-teams. Team A split into three sub-teams, while other teams (B, C, D, E) split into four. Team A was divided by their prior work on concepts, team B by the country to facilitate communication, while other teams (C, D, E) were split by their knowledge and skills.

All teams employed the same methods for the tasks in the third DS activity (Table 4). For the virtual prototype task, the teams utilised collaborative CAD modelling in Onshape. Its advantage was parallel work on a virtual prototype with an always up-to-date version of the CAD model. On the other hand, this approach caused lagging with especially large files (e.g., metro coach provided by the company). In addition, solutions that were not mechanical were difficult to represent in Onshape (e.g., digital solutions). This was especially accentuated in three teams (A, B, D) with digital sub-solutions (e.g.,

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information panels). Three teams (B, D, E) also conducted initial prototype testing by employing finite element analysis. This method enabled them to conduct quick feasibility tests. However, as teams used different ICT tools (Solidworks, CATIA) for this method than for the CAD modelling (Onshape), they encountered problems transferring CAD models to the finite element analysis.

Table 4. Used methods and ICT tools in the third DS activity

Task	Methods	Method strengths and weaknesses	ICT tool	Team(s)
Virtual prototyping	Collaborative CAD modelling	+ Parallel work on a virtual prototype; Up-to-date version of a CAD model	Onshape	A, B, C, D, E
		- Slow due to the large initial file; Difficult presentation with non-technical solutions		
Prototype testing	Finite element analysis	+ Quick feasibility checks	Solidworks, CATIA	B, D, E
		- Poor integration with used CAD tool		

5 DISCUSSION

The five teams used various design methods and ICT tools in all three DS activities. Methods were usually supported using collaborative cloud-based ICT tools. This section discusses the usage of design methods (Subsection 5.1) and ICT tools (Subsection 5.2) during all three DS activities.

5.1 Using design methods during DS activities

The use of design methods can be divided into three approaches: utilising only one method for the task, utilising several methods for the task, or utilising adjusted methods. Utilising only one method for the task is especially salient in the last DS activity. This aligns with the suggestions that later design phases are narrower than the early ones (Andreasen *et al.*, 2015, p. 175). Another explanation might be that students gathered experience in the first and/or second time-bounded DS activity and were thus focused on fewer methods in order to reach the activity goal in time (Flus and Hurst, 2021). Furthermore, utilising several methods for the task enables designers to conduct the task more comprehensively. This is especially emphasised in the second DS activity, where all teams used three methods to generate concepts to tackle the strengths and weaknesses of each method (Banfield *et al.*, 2015; Flus and Hurst, 2021; Knapp *et al.*, 2016). In addition, teams B and C used two methods for the user research task, which might provide them with a better exploration of the design problem, i.e., the user needs. This focus on two user research methods might have benefited team B, as their sub-solution was rated as the most innovative. On the other hand, team C used the interview as the second method in this task, which might take too much time to reap the benefits within the given timeframe. Finally, utilising adjusted methods is conducted by only one team (A) in the first DS activity. Adjusting the methods to the problem at hand is considered a higher level of design expertise (Lawson and Dorst, 2009). As team A was rated as having the best solution, it could be that this adjustment of the methods enabled them to get critical market and user research information in less time. Therefore, teams perceived as high-performing (A and B) utilised different approaches in the first DS activity. Therefore, the relationship between the methods used and team outcomes should be further explored.

Given the time restrictions of DS activities, teams often selected methods which facilitated the distribution of taskwork between different team members. For example, AEIOU allows clear distribution of work into five categories (activities, environments, interactions, objects, and users) and supports its parallel execution. Parallelisation is important in a team context, as it enables splitting the workload amongst team members (Cash *et al.*, 2019). This distribution of work is especially salient in team A while using adjusted methods in the first DS activity. More specifically, as they reported focusing on specific aspects of the market research, it was difficult to divide tasks among all members. Therefore, they worked in parallel on the user research by analysing secondary resources (e.g., external reports). This enabled them to save time and distinguish different actions that had to be performed by individuals. In this context, individual team members need to share their findings, and it is thus crucial to support the transition between individual and teamwork (Christensen and Abildgaard, 2021). Furthermore, while at the beginning, teams considered parallelisation by the method aspects (e.g., working on specific aspects of the PESTEL analysis), in the second phase, the parallelisation was related to the context (e.g., working on different solutions). Therefore, the way

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teams distribute the work depends on the DS activity. Finally, brainstorming during idea and concept generation was usually conducted by all team members simultaneously, as this method is more effective with a larger number of members (Maaravi *et al.*, 2020).

5.2 Using ICT tools during DS activities

During the course, the teams used different ICT tools to help them in product design. Some of them opted for tools they were already familiar with (e.g., Team A used Google Docs in the first DS activity). This is in line with the finding that students' prior experience largely influences the chosen ICT tool (Verstegen *et al.*, 2016). Despite this prior experience force, all teams adopted a collaborative whiteboard, confirming its usefulness for the DS activities (Verstegen *et al.*, 2016; Vukašinović and Pavković, 2017). While collaborative whiteboard is often adopted, students encountered more issues regarding the use of a collaborative CAD modelling tool. This is in line with prior work that learning additional CAD tools is time-consuming (Horvat *et al.*, 2021). Another reason for this difference between collaborative whiteboard and CAD tool adoption could be due to the available toolsets teams have mastered before the course. More specifically, while teams did not know any tool that could replace a collaborative whiteboard, they were more open to adopting it. On the other hand, students already knew another CAD tool, which might be the reason for less motivation during the adoption period. Therefore, educators should be careful with introducing new ICT tools to teams working on time-bounded intensive activities.

Given that DS activities are time-bounded and conducted in teams (Banfield *et al.*, 2015; Flus and Hurst, 2021), there is a big potential for cloud-based ICT tools. These tools enable synchronous and asynchronous work of team members and always show up-to-date design information (Horvat *et al.*, 2021), which is important in both virtual and physical DS activities. Although synchronous work was found to be less efficient in CAD (Phadnis *et al.*, 2021), continuous sharing of the work in progress increases the awareness of team members' actions (Eves *et al.*, 2018) and might provide teams with more time to conduct taskwork.

Finally, while teams used various ICT tools to gather information (Horvat *et al.*, 2021), they utilised only several tools to present the information (e.g., Google Docs, Miro, Onshape). In this context, teams encountered problems with integration between tasks, especially in the third DS activity. This finding suggests that ICT tools used during DS activities should be compatible in order to save time in transferring information from one ICT tool to another. Therefore, based on qualitative insights from this study, there is a potential to integrate various tools in order to enable easy transition between tasks and also between DS activities (e.g., a transition from Miro in the second DS activity to Onshape in the third DS activity).

6 CONCLUSIONS

This paper investigates the use of design methods and ICT tools in DS activities as part of the project-based course. The results show that teams utilise various methods through three approaches: utilising only one method for the task, utilising several methods for the task, or utilising adjusted methods. Moreover, teams considered several aspects when deciding which method to utilise: the possibility of distributing the work among team members, the time needed to execute the method and their prior experience in using the method. The results on using ICT tools suggest that teams mainly utilise the collaborative whiteboard and CAD modelling. In this context, tools that enable continuous sharing of the work in progress (e.g., cloud-based tools) show great potential for DS activities. Finally, the results show a potential to integrate various tools in order to enable easy transition between tasks (e.g., a transition from collaborative whiteboard to CAD modelling).A limitation is that there should be a more structured selection of the method. In this study, methods were selected based on previous experience and previous courses. However, each course edition has its own specificities and potentially requires tailored approach. Furthermore, a formal introduction of different methods could be incorporated in further studies.

These findings have several implications for research and practice. Firstly, researchers should ensure that team under analysis understands the strengths and weaknesses of design methods and ICT tools. Educators should suggest teams adjust the methods according to the design problem and distribute the work among team members as much as possible. Finally, educators should suggest that teams utilise cloud-based collaborative ICT tools and tools compatible with various tasks.

These findings can be perceived as a first step towards better understanding of the role and use of design methods and ICT tools during DS activities. As such, further studies are required to elaborate on differences between the use of design methods and ICT tools in DS activities and traditional design

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process. Future studies should explore the findings by deepening the understanding of teams' approaches while using design methods and ICT tools. Furthermore, future work should explore the effect of transitioning between individual work and teamwork. Finally, researchers can explore the use of cloud-based tools and constraints related to supporting the various DS activities with one ICT tool.

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