INTERNATIONAL DESIGN CONFERENCE – DESIGN 2024
https://doi.org/10.1017/pds.2024.300

Analysis of collaborative CAD user actions in design sprint: insights from an educational setting

Jelena Šklebar ✉, Tomislav Martinec, Stanko Škec and Mario Štorga
University of Zagreb Faculty of Mechanical Engineering and Naval Architecture, Croatia
✉ jelena.sklebar@fsb.hr

Abstract
Design sprints complement traditional teaching methods, especially in project-based learning courses. While this approach can potentially change Computer-Aided Design (CAD) usage, it is still underexplored. Therefore, this study explores the influence of design sprints on embodiment-focused CAD activities in project-based learning by examining differences in patterns of CAD user actions, focusing on design space and action types. The case involves two higher-graded and two lower-graded student design teams monitored with a non-invasive method across a two-day design sprint event.

Keywords: *computer-aided design (CAD), collaborative design, CAD usage analysis, design sprint, project-based learning*

1. Introduction

Design education is gradually experiencing a change with the introduction of short and time-intensive approaches like hackathons and design sprints. They are complementing or even replacing traditional teaching methods (Flus and Hurst, 2021), especially as a part of project-based learning (PBL) (Horton *et al.*, 2018), that design education is mainly based on (Dym *et al.*, 2005), providing students with the opportunity to solve problems in real-world projects (Huić *et al.*, 2023). Design sprints are problem-solving and innovation events but are specifically tailored to a particular organisational context, typically operating on a shorter time scale. These well-planned processes employ a variety of steps and tools to generate creative solutions and test them (Ferreira and Canedo, 2019), all facilitated by a team of design sprint participants. With a predefined time-based limitation, design sprints offer a dynamic approach to problem-solving (Banfield et al., 2015), reflecting design iterations, where an outcome is expected to be produced within a set timeframe that includes repetitions or cycles (Banfield et al., 2015). The integration of design sprints as active learning tools within PBL approaches has been explored across various domains, including computer programming (Ferreira and Canedo, 2019), UX/UI design, and design and product development (Huić *et al.*, 2023). Despite its increasing popularity, there is a gap in design research regarding the understanding of how design sprints influence design activities within project-based courses. This gap is particularly pronounced in design activities such as Computer-Aided Design (CAD) activities. CAD plays a vital role in a variety of engineering design activities as it is used for the generation and manipulation of digital representation of design, particularly in the conceptual, embodiment, and detailed design phases. As CAD undergoes a shift from being a standalone, both taught and applied in work/industrial environments, to becoming cloud-based, thus transforming into a collaborative, real-time, multi-user endeavour, there is significant potential for its application in fast-paced, short, and intensive events like the design sprints.

Hence, as the first step towards the overarching aim of exploring the integration of CAD activities within the educational context in a design sprint format, this study's objective is to analyse CAD user actions concerning design space and action type, motivated by the following research questions: *What patterns of CAD usage do higher- and lower-graded teams exhibit during embodiment design sprint events, and how do these patterns differ from those observed in studies examining collaborative CAD usage?*
This paper analyses CAD activities in design sprint, covering related work, methodology, experimental setup, data collection, cleaning, analysis during design sprints. It then presents results on analyses of CAD user actions, followed by a discussion comparing findings with relevant literature.

2. Related work

Computer-aided design (CAD) stands as a crucial design supporting system. It is used in various design phases to create and test digital representations of design, i.e., virtual product concepts or prototypes, prior to actual production (Azemi *et al.*, 2018). Examining CAD activities has been gaining considerable research attention, especially after the transformation of CAD systems from standalone to collaborative, transitioning from local computers to cloud-based, synchronous systems accessible from any web browser. This focus is driven by its ability to address common CAD collaboration challenges such as synchronous editing limitations, seamless file-sharing issues, and the visibility of design changes (Cheng *et al.*, 2023). In addition to Sadeghi et al.'s (2016) suggestion that capturing design process information could help to better understand the design process and its challenges to improve designer productivity, collaborative CAD can provide a suitable platform for a non-intrusive collection of data on user action. This data can then be used as a proxy when examining the overall design process, ensuring it does not impact or interfere with both the designer and the CAD modelling process (Celjak *et al.*, 2023). Thus, Gopsill et al. (2016) evaluated the potential of providing a non-intrusive approach for the monitoring, and assessment of designers and the engineering design process. They, for example, discovered that performing the *deleting* CAD user action has been identified as the main contributing factor to the sequence length and time spent on CAD modelling the component (Gopsill *et al.*, 2016).
In addition to that, researchers have been extensively studying various aspects of collaborative CAD usage by examining both behavioural (e.g., CAD user actions and their sequences) and outcome aspects (e.g., quality of representations of design compared to design requirements) (Sadeghi *et al.*, 2016). The studies focusing on collaborative CAD have been either individual- or team-based. The former compares individual or traditional usage of CAD with those used in teams, whereas the latter examines teams while using synchronous collaborative CAD. With reference to the former, the findings of Stone et al. (2017) indicate that teams employing synchronous collaborative CAD outperformed individual users. In addition to that, individuals within teams demonstrated slightly lower performance (in terms of completeness of CAD model and time required to complete the model) compared to their counterparts working alone. In contrast to Stone et al.'s study on a team-based level, in their examination of CAD user actions among collaboratively working pairs, as opposed to individual work, Phadnis et al. (2021) found that the pairs demonstrated lower CAD performance and generated CAD models of lower quality. On the other hand, by studying and comparing teams in synchronous and collaborative CAD setups, Celjak et al. (2023) compared CAD actions performed by low-performing and high-performing teams. They revealed that low-performing teams leaned towards actions involving *creating a part* or *assembly*, *editing* and *deleting parts*, and *reversing* CAD user actions. In contrast, high-performing teams were characterized by a higher frequency of actions related to *deleting a part* and *editing an assembly*, highlighting distinct modelling patterns between these two types of teams. Furthermore, Deng et al. (2022) introduced a new framework for interpreting CAD user analytic data: Multi-User CAD Collaborative Learning Framework (MUCAD-CLF). The framework classifies CAD user actions by categorizing them based on design space and action type.
Moreover, in a comparison of collaborative CAD teams based on the team members' CAD experience—comprising teams with all experienced users, a mix of novices and experienced users, and teams consisting entirely of novice users—the study of Deng et al. (2022) revealed that teams with novice CAD users demonstrated a higher proportion of *Reversing* actions. In contrast, experienced teams carried out a greater proportion of CAD actions related to *Viewing* and engaged in more *Constructive* (actions that visibly modify the design) actions.

https://doi.org/10.1017/pds.2024.300 Published online by Cambridge University Press

Furthermore, concerning PBL and CAD usage, particularly in the context of design sprints, there has been limited research on CAD activities. Huić et al. (2023) studied four teams engaged in a one-day design sprint focused on CAD virtual prototyping tasks. Despite working in a co-located setting and utilizing collaborative synchronous CAD, the study revealed that teams typically organized themselves into subteams and encountered technical challenges related to large CAD files. However, the authors did not explore behavioural or output aspects of CAD usage in their analysis.
In conclusion, researchers have explored team-based CAD user actions, uncovering collaborative modeling patterns. However, it's unclear if these insights vary in a design sprint context. Motivated by the rise of design sprints in design education and enhanced CAD collaboration capabilities, this paper aims to bridge this gap by examining collaborative CAD user actions.

3. Methodology

3.1. Experiment description

Data for this research was gathered from the internationally distributed PBL design course, involving four universities along with an industrial partner (Huić *et al.*, 2023). Four virtual student teams (Teams A, B, C and D) were assigned with a design task of developing a personal transportation sidewalk vehicle, guided by design requirements provided by representatives from the industrial partner. The project comprised three phases (problem definition, conceptual design, and embodiment design), each initiated as a design sprint activity. The primary focus of this research study is the third phase, specifically the third design sprint activity, conducted online. In the design sprint, teams were assigned the task of conducting an embodiment design for concepts selected in the previous, conceptual, design phase. The objective was to deliver a detailed CAD model of the design solution using the collaborative, multi-user, cloud-based CAD system, Onshape, accessible through any web browser. The third design sprint activity extended over two days in April 2022, totalling eight hours, with four hours allocated to each day (from 16:00 to 20:00 on Thursday and 15:00 to 19:00 on Friday). Each team member was located separately, using an online communication tool, MS Teams, in addition to Onshape. Students were free to self-organize with the condition of working collaboratively, without being informed about the experiment. During CAD work, each mouse and keyboard input or user action within the CAD system was non-intrusively recorded and saved as analytical data in the form of a chronological audit trail (Onshape log file). This dataset was subsequently utilized for the analysis of CAD user actions in the design sprint.
Furthermore, each of the four teams consisted of ten members, with participants drawn from all four universities, bringing together a total of 40 mechanical engineering students, spanning both undergraduate and graduate levels. The gender distribution included 3 females and 37 males, resulting in Teams C and D being exclusively male, while Teams A and B included 2 and 1 female participants, respectively. Participation required completion of a CAD course at the associated university; however their CAD skills were not evaluated before the design sprint. The authors did not have insights into whether students had any previous experience participating in the design sprint format within an educational setting. Throughout the course, including the studied design sprint activity, each team received support from one or two academic coaches who facilitated the process.
Upon the completion of the design sprint event, each team presented their final CAD model to company representatives, receiving feedback for further development. In addition to that, company representatives graded teams based on criteria of CAD model maturity, design approach, and the feasibility of the solution. Teams with the higher grades will be further referred to as the higher-graded teams, while those with lower grades will be designated as lower-graded teams.

3.2. Data collection, cleaning and analysis

The data collection process was non-intrusive followed by extraction of Onshape log files (chronological audit trail). The data recorded within log files represents actions of the constructions and modifications to features in the CAD document (e.g., creating a sketch, deleting a part), and behavioural actions (e.g., switching a tab) that team members performed during the two-day design sprint, including actions of the constructions and modifications to features in the CAD document (e.g., creating a sketch, deleting a part), and behavioural actions (e.g., switching a tab). Each data point within the collected dataset includes timestamps, document and tab details, the performing team member, and the CAD user action's name. To ensure accurate analysis, actions not within the study's focus were excluded from the dataset, such as those automatically logged by a CAD system and the multiple recorded actions for only one CAD action (e.g., when a user creates a sketch) (Celjak *et al.*, 2023).

The analysis of the acquired dataset was further conducted by using MUCAD-CLF developed by the ReadyLab (Deng *et al.*, 2022). Using the framework, the analysis is facilitated by adopting a coding scheme that enables the two-folded classification of CAD actions collected from each team member's analytic data - CAD actions concerning design space and action type - thus enabling a comparative analysis. CAD user actions concerning design space are further divided into constructive and organizing actions. *Constructive* actions visibly modify the design and, as the name suggests, include the two primary design spaces - *Part Studio* and *Assembly*. Organizing CAD actions are behavioural and includes actions performed while managing *the* workspace (tabs, versions, branches) (Deng *et al.*, 2022). The second classification, the one referenced to the action types, categorizes several of them: *Creating*, *Revising* (*Editing, Deleting, Reversing*), *Viewing*, and *Other* (Deng *et al.*, 2022; Gopsill *et al.*, 2016). The detailed CAD actions coding scheme, referenced to the design space, is summarized in Table 1, while the one referenced to the CAD action type is summarized in Table 2. Finally, in order to achieve the objective of this study, the analysis focuses on identifying patterns among

Table 1. Design space-based CAD actions coding scheme (Deng et al., 2022)

	Constructive Actions				**Organizing Actions**	
	Part Studio		**Assembly**			
Action Type Name	*Sketching*	*3D Features*	*Mating*	*Visualizing*	*Browsing*	*Other Organizing*
Summary of Sample Actions	Add/modify a sketch	Add/edit a Part Studio feature	Add/delete a part from Part Studios	Drag parts/ workspace	Create/ delete/ rename a tab	Create/ merge version/ branch
	Copy/paste a sketch	Delete a sketch/Part Studio feature	Insert/edit/ delete an Assembly feature	Call animate actions	Open/close a tab	Undo/redo/ cancel an operation

Table 2. Action type-based CAD actions coding scheme (Deng et al., 2022)

Action Type Name	**Creating**	**Revising**			**Viewing**	**Other**
		Editing	*Deleting*	*Reversing*		
Summary of Sample Actions	Add a sketch/Part Studio feature/ Assembly feature	Edit a sketch/Part Studio feature/ Assembly feature	Delete a sketch/Part Studio feature/ Assembly feature	Redo/undo /cancel an operation	Open/close a tab	Create/ delete/ rename a tab
	Add a part from Part Studio in Assembly		Delete a part in Assembly		Call animate actions	Create/merge version/ branch

teams with similar grades in CAD user actions at the team level. This includes examining both the total number of actions by each team and the team-based actions divided by each day of the design sprint, leveraging both classifications approaches. Data analysis utilized the open-source Python scripts (Github MUCAD-CLF), developed by the research team responsible for the framework used to analyse the dataset (Deng *et al.*, 2022).

https://doi.org/10.1017/pds.2024.300 Published online by Cambridge University Press

4. Results

The data analysis was conducted by using the collected dataset of CAD actions performed by two higher-graded (Team A and Team C) and two lower-graded (Team B and Team D) teams during the two-day design sprint activity in the embodiment design phase. After cleaning the initial dataset as outlined in the Methodology section, there remained a total of 15200 CAD user actions performed collectively by the four analysed teams. Team A executed 2912 actions, Team B 4820 actions, Team C 4950 actions, and Team D 2571 actions, as illustrated in Figure 1. The results are presented by applying each classification approach at the team level (Table 1 and Table 2), considering the total number of actions, and then distinguishing the results for each of the two design sprint days.

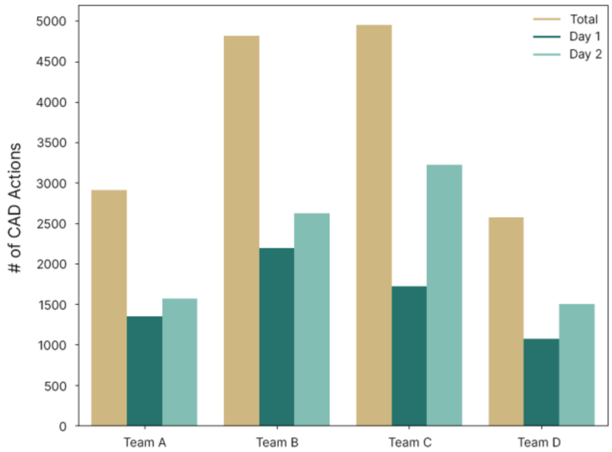

Figure 1. Distribution of performed CAD actions

4.1. Team level - total number of CAD actions

The distribution of CAD actions provides an insight into how teams divided their work in terms of differences and similarities related to design space (Figure 2.a) and action type (Figure 2.b) during the CAD modelling process performed in Onshape within a two-day design sprint.

Concerning the distribution of CAD actions in the design space, as observed in Figure 2.a, all teams allocated more than 50% of their total CAD actions to the *Organizing* CAD actions. The most frequently used CAD action was *Browsing*, followed *by the Other Organizing* actions. The higher-graded teams performed more *Organizing* actions, particularly *Browsing*, compared with the lower-graded teams. However, their share of *Other Organizing* actions is lower than that of the lower-graded teams. In contrast, lower-graded teams performed more *Constructive* actions, with shares of 49,5% for Team B and 43,9% for Team D, compared to 39% and 32,1% for Team A and Team C, respectively. Within the presented shares of the *Constructive* actions, there is not a regular pattern regarding the distribution of these actions in the Part Studio and Assembly space. Namely, Teams A and D performed more actions in Part Studios design space (80,9% and 50,2%, respectively) compared to Team B and C who focused more work on Assembly with shares of 74,7% and 52,9%, respectively.

Furthermore, concerning action type, as depicted in Figure 2.b, the most frequently used CAD action is *Revising*, encompassing *Editing*, *Deleting*, and *Reversing* actions, for three out of four observed teams (A, B, and D), with respective values of 41,4%, 33,4%, and 52%, in alphabetical order. However, for the higher-graded team C, *Revising* (38%) is the second most frequently used action after *Viewing* (21,2%), indicating no evident pattern regarding the most frequently performed actions among the observed teams. Conversely, for Teams A, B, and D the Viewing action was the second most frequently used action. Furthermore, within the *Revising* category of CAD actions, the similarity among all four teams emerges in *Reversing* as it is the most frequently performed action with the range of 15,5% - 27,7% followed by *Editing* (13,1% - 18,7%) and *Deleting* (4,8% - 6,5%), respectively. There is no similarity among teams of similar grades in terms of *Creating*, the action type that holds the highest percentage in Team A (20.1%), a value twice that of the other higher-graded Team C (10.1%). Conversely, lower-graded teams exhibit similar percentages in the *Creating* action, with Team B at

https://doi.org/10.1017/pds.2024.300 Published online by Cambridge University Press

17.8% and Team D at 20%, both comparable to the value of the higher-graded Team A. Finally, similarity among teams of similar grades is observed in the *Other* action type, which was more often used by lower-graded teams compared to those graded higher.

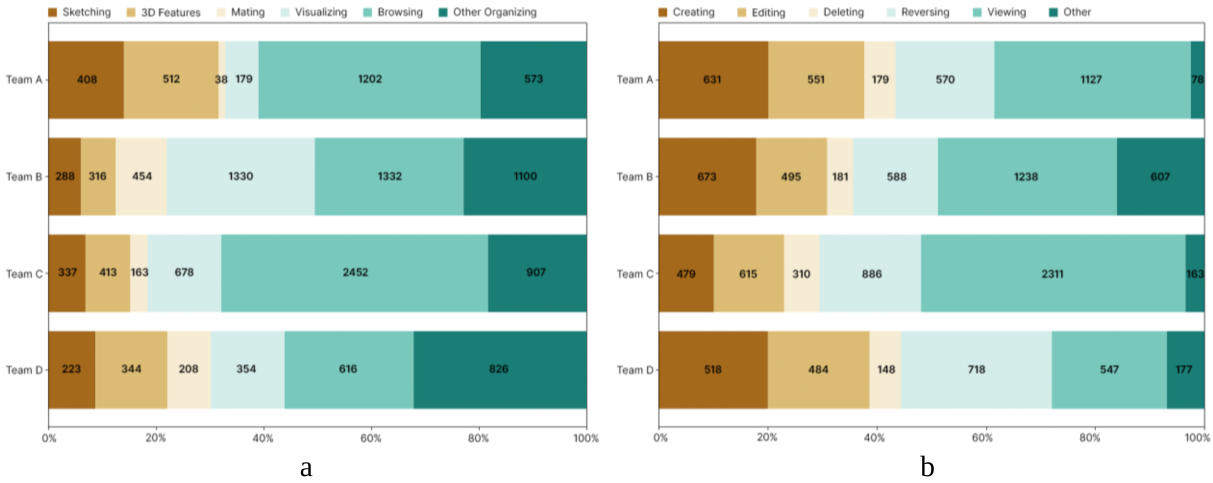

Figure 2. CAD action distribution by teams, referenced to design space (a) and action type (b)

4.2. Team-level comparison between two days of design sprint

Comparison of the CAD action distribution concerning design space analysis over two days provides deeper insights into how teams managed their design sprint time. The number of CAD actions performed, when two design sprint days were compared, was higher on the second day than the first one for all four teams, as shown in Figure 3. During the first day Team A performed 46.2%, Team B performed 45.5%, whereas Team C and Team D performed 34.8% and 41.4% of the total number of CAD actions, respectively.

Concerning design space CAD user actions, all four teams exhibited a common trend in decreasing Part Studio actions while increasing Assembly actions over two days. Moreover, Team A did not engage in any Assembly-related actions on the first day, only incorporating them during the second day of the design sprint. Concerning *Part Studio* actions, the ratio between *Sketching* and *3D Features* remained similar for all four teams throughout both days of the design sprint.

In the context of *Assembly* actions, teams also share a similarity in that they all performed an increased number of both *Mating* and *Visualizing* actions during the second day, as compared to the first.

Additionally, when it comes to *Organizing* actions, there are certain distinctions between teams that cannot be assigned to their grades. Specifically, Team A performed an increase in the number of *Organizing* actions carried out over the two-day design sprint, whereas other teams experienced a decrease. Among these, there are teams, such as Team A and D, that increased the proportion of *Browsing* actions performed over the second day, in contrast to the remaining teams who reduced their share of *Browsing* actions.

Furthermore, comparing CAD user actions with reference to the action type during the two-day design sprint, as shown in Figure 4., reveals that Teams A and B reduced the share of *Creating* actions, while Teams C and D maintained the same level. When it comes to the *Revising* actions (*Editing*, *Deleting*, and *Reversing*), Teams A and D reduced their share on the second day. On the other hand, Teams B and C maintained a steady proportion of these actions throughout both days of the design sprint. The most significant change in Teams A and B is observed, among the *Revising*, in the *Editing* action type, which experienced the most substantial drop in share over the two days of the design sprint. The remaining *Revising* actions, specifically *Deleting* and *Reversing*, maintain consistent shares in both - the overall number of actions and within the *Revising* category across both days of the design sprint. However, Team A stands out with a reduction in the share of *Reversing* actions, both in the total number of actions and within the *Revising* action type. In the context of *Viewing* actions, there is an difference between Teams A and D, and the rest two teams. While both Team A and Team D increased their share of this action type during the second day compared to the first one, Team D's increase was slightly greater

https://doi.org/10.1017/pds.2024.300 Published online by Cambridge University Press

than Team A's. Conversely, Team B experienced a decline in the share of *Viewing* on the second day, whereas Team C's share remained similar across both days.

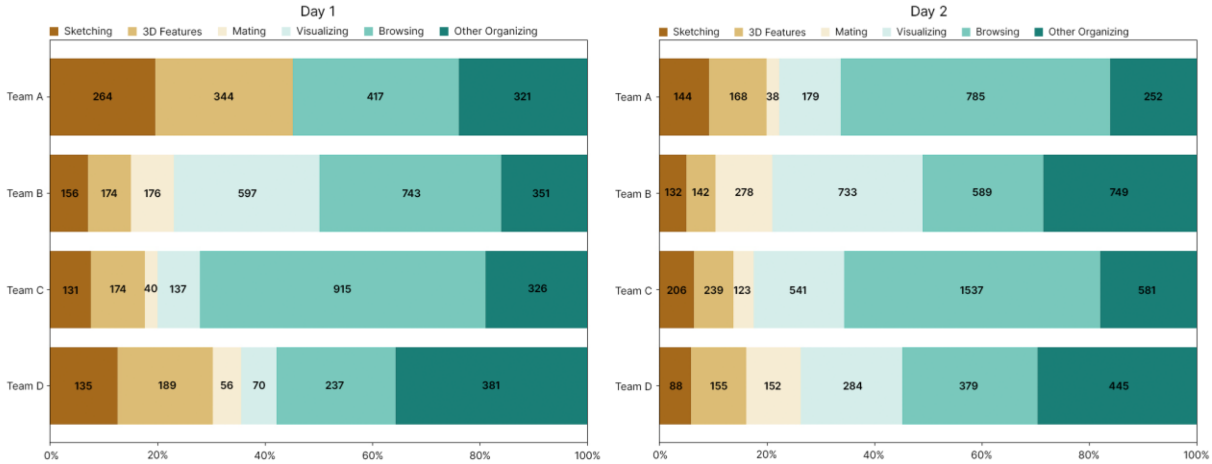

Figure 3. CAD action distribution in design space over two days of design sprint

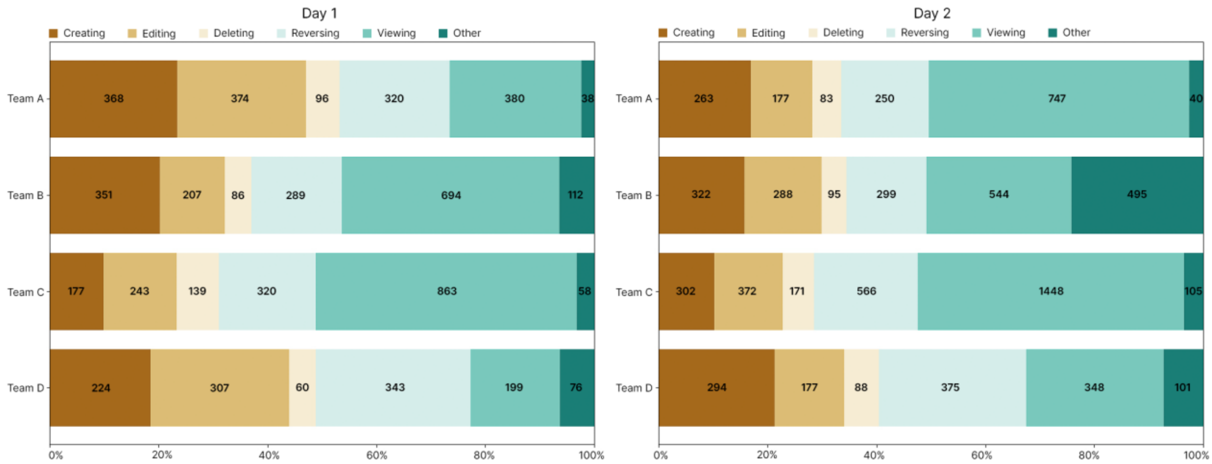

Figure 4. CAD action distribution in action type over two days of design sprint

5. Discussion

The study's objective was to explore CAD usage patterns in design sprint format among four internationally dislocated student teams. It focuses on collaborative CAD usage during online design sprint, comparing team-wise CAD usage through a structured review of relevant literature fosuced on conventional collaborative CAD usage during PBL (Celjak *et al.*, 2023) or case study (Deng *et al.*, 2022) and a two-day analysis.

5.1. Team-wise CAD usage

The identified patterns of CAD usage among various teams concerning design space are compared with the findings of Deng et al. (2022). They conducted a study on CAD activities involving 13 teams comprising both experienced and novice designers collaborating on an open design challenge in an educational setting. A key similarity observed is the consistent use of Part Studio actions, such as *Sketching* and *3D Features*, across all studied teams. This uniformity aligns with the observations made by Deng et al. (2022), suggesting a common approach to these fundamental CAD activities.
The analysis results, further, diverge when it comes to *Assembly* actions. Unlike Deng et al. (2022), our analysis did not identify a common pattern in the use of the *Mating* and *Visualizing* CAD user actions within *Assembly*, suggesting a difference in how teams approach these tasks. While they propose that the differences might emerge due to varying levels of CAD experience - with more experienced teams

https://doi.org/10.1017/pds.2024.300 Published online by Cambridge University Press

favouring *Assembly* actions - our data does not explicitly support this hypothesis as the study lacks an assessment of the CAD skills of team members. Also, contrary to Deng et al. (2022)'s assertion that an increased number of *Browsing* actions may signal difficulties in workload distribution, by frequently switching between Part Studios and Assembly tabs and thereby wasting design time, our findings present an opposing view. Namely, the observed teams received higher grades despite having larger proportions of *Browsing* actions compared to lower-graded teams. Moreover, the notable variability in *Browsing* actions among the teams could be attributed to the organization of CAD activities within design sprints, where teams usually divide themselves into sub-teams (Huić *et al.*, 2023). Furthermore, in terms of CAD actions concerning the action type within the design sprint format, the study found a series of insights that both corroborate and diverge from the existing literature on collaborative CAD usage. Predominantly, a tendency among three out of four observed teams to prioritize the *Creating* over *Editing* actions, aligning with Deng et al. (2022) data, but diverges from Celjak et al. (2023), who suggests that *Editing* is the most frequent CAD action. This implies that teams predominantly concentrated on generating new features or experimenting with their different aspects, possibly without revising them, taking a more iterative approach for enhanced design. The inclination toward creating over editing can be, in addition, attributed to the time constraints inherent in the design sprint.

The anticipated CAD usage patterns distinguishing high- and low-performing teams, as suggested by Celjak et al. (2023), are not evident in this study's findings. Higher-graded teams did not engage in more *Editing* actions, and their patterns of *Creating* and *Editing* varied significantly, with one such team having around 40% of both *Creating* and *Editing* actions, while the other had almost half as much. There isn't a consistent pattern for lower-graded teams, either. It was anticipated that they would have the highest proportion of the *Reversing* and *Creation* actions (Celjak *et al.*, 2023), and while one of the lower-graded teams aligns with this expectation, the other does not.

Concerning the *Deleting* action, it holds one of the smallest proportions among CAD actions, contradicting Gopsill et al.'s (2016) findings that deleting is the primary factor contributing to sequence length and time spent modelling the component. When attempting to further establish a connection between the proportion of *Revision* actions (*Editing*, *Deleting*, *Reversing*) and the proportion of *Constructive* actions, no consistent pattern emerges that would, for example, support Deng et al.'s (2022) observation. They suggest that a larger proportion of *Constructive* actions is more likely to be revised as the count of *Constructive* actions increases. This is evident in the similarity of the proportion of *Revising* actions across all four teams, despite variations in the number of performed *Constructive* actions. Lastly, in the context of the *Other* actions, the higher-graded teams performed fewer of these actions than the lower-graded teams, a finding that is in alignment with the observation of Celjak et al. (2023). The study, therefore, presents a complex picture of team-wise CAD usage in the design sprint environment, indicating the patterns of CAD user actions may be subject to a variety of influencing factors that go beyond the scope of the study. An in-depth examination of criteria used for team grading by industrial partner representatives (CAD model maturity, design approach, and the feasibility of the solution) is crucial, as solely relying on the analysis of CAD actions without considering influencing factors may provide rich insights into CAD usage within the design sprint format. Additionally, considering factors such as CAD outcome-related aspects (quality and complexity of a CAD model), process-related elements (idea generation process, communication, coordination), and team-related factors (team dynamics) alongside the presented CAD usage analysis may provide valuable insights into CAD usage within the design sprint format in an educational setting. Given the educational context, it is especially important to expand the study by evaluating students' CAD skills before and after the design sprint to gain insights into CAD learning aspects.

5.2. A two-day comparative analysis

Upon comparing the CAD user actions during two days of design sprint, it was observed that on the initial day, all teams predominantly focused on designing individual parts, with a reduction in such actions on the following day. Conversely, the focus shifted towards *Assembly* on the second day for all teams. The difference is the higher-graded Team A which did not engage in any *Assembly* actions on the first day. This pattern indicates a common strategy where teams initially prioritize partial solutions, diverging from the practice identified by McComb et al. (2017) that high-performing teams start with assembly design early on to assess the quality of developed concepts.

Team A's lack of *Assembly* actions on day one could explain the significant increase in organisational actions on the second day, suggesting that much of Team A's efforts on the first day were likely carried out by subgroups or individual contributors (Huić *et al.*, 2023). Consequently, the exchange of work among team members became more evident on the second day. Moreover, Team A's exclusive attention to *Part Studios* and disregard for *Assembly* led to a surge in creation and revision or modification (*Editing*, *Deleting*, and *Reversing*) actions on the first day, followed by a decline on the second day. This behaviour contrasts with the other groups, which showed a steady rate of such actions across both days of the design sprint. Furthermore, the proportion of *Editing* actions either remained constant or decreased over the two days of the design sprint, challenging the findings of Celjak et al.(2022) that the use of *Creating* actions is more frequent at the beginning of the CAD modelling, with the use of *Editing* actions increasing towards the end. That could be attributed to time constraints imposed by the design sprint format. The frequency of *Reversing* actions was consistent across both days, as students had been familiarized with the software prior to the design sprint, which is in line with the typical design and CAD modelling process. It contrasts with longer formats, and longitudinal studies, as found by Celjak et al. (2022), where a high percentage of *Reversing* actions at the start indicates designers exploring the software's capabilities.
When it comes to *Viewing* actions, the higher-graded teams increased or maintained their engagement in using these actions on the second day, possibly to review the created CAD models. Conversely, lower-graded teams performed more *Other* actions on the second day, with a reduction of *Viewing* actions, which, according to Celjak et al. (2023), may indicate challenges in workspace management. Finally, as this study is cantered on the comparison of CAD user actions, conducting an in-depth analysis of the final CAD models (solution itself, modelling process, geometry complexity) could enhance the depth of the study's findings.
The outcomes of this study reveal differences from the established body of research on collaborative CAD usage within traditional educational settings, suggesting that the design sprint introduces a distinct approach to design education. However, relying solely on the analysis of CAD actions from the ten-members collaborations in the design sprint may not be sufficient. Moreover, the study does not establish whether the correlation of the teams' grades and variables that could describe the CAD or design learning outcomes within design sprint is positive or negative. Therefore, in addition to previously mentioned factors that could influence the outcomes, but not incorporated within the study due to its scope, differences may also be attributed to the open-ended nature of the design sprint CAD task. It likely plays a role in the varied strategies taken by the teams in their design and CAD modelling process in the context of a design sprint. As a result, future research should consider the nature of the task, as well as the team-related aspects. Extending the analysis by encompassing team dynamics or team performance factors such as communication and coordination would enrich the acquired insights.

6. Conclusion

The paper provides insights into how student teams employ CAD systems during a design sprint in an educational setting. This is achieved through non-intrusive data collection followed by the analysis of CAD user actions referred to the design space and action type classifications. The design sprint event was conducted within the internationally distributed design course, involving four universities and an industrial partner. The focus is on the embodiment design phase of a personal transportation sidewalk vehicle, executed online through a two-day design sprint using the cloud-based CAD system, Onshape. The analysis further reveals common trends and variations across higher- and lower-graded teams, shedding light on their CAD usage patterns. Concerning higher-graded teams showed varying proportions of *Creating* and *Editing* actions. Team A's unique approach, delaying *Assembly* actions until day two, challenges the common belief that high-performing teams initiate assembly design early, suggesting a potential shift in design sprint practices. Lower-graded teams exhibited variability in CAD actions, failing to conform to expected patterns. One lower-graded team aligned with anticipated trends, compared with the research in a conventional education setting, in *Reversing* and *Creating* actions, while the other did not. According to related literature, this suggests potential challenges in task management and workspace organization, emphasizing the need for further research. The study not only highlights differences among teams of the same grading but also in comparison to existing literature on CAD usage in conventional educational settings. Future research should delve into a comprehensive examination based on the criteria

https://doi.org/10.1017/pds.2024.300 Published online by Cambridge University Press

used to grade student teams. This involves an exploration of the design and CAD modeling process, potentially through longitudinal analysis, considering both output-related analysis, (analysing CAD models and their complexity), and team-related analysis such as team dynamics, communication, and coordination. Finally, addressing limitations in the future work, such as a small sample size, absence of background data on students' CAD, design, and team skills, and the lack of experienced designers in the study, will help determine the suitability of the design sprint format for CAD education.

Acknowledges

This work is funded by Ministry of Science, Education and Sports of Republic of Croatia, and Croatian Science Foundation project IP-2022-10-7775: Data-driven Methods and Tools for Design Innovation (DATA-MATION). The authors would like to thank the students for their participation in the design sprint experiment.

References

Azemi, F., Mehmeti, X. and Maloku, B. (2018), "The Importance of CAD/CAE systems in development of Product Design and Process of Optimization", University for Business and Technology, https://dx.doi.org/10.33107/ubt-ic.2018.344.

Celjak, R., Horvat, N. and Skec, S. (2022), "Exploring the Potential of Tracking CAD Actions in Project-based Courses", CAD Solutions, LLC, pp. 302–307, https://dx.doi.org/10.14733/cadconfp.2022.302-307.

Celjak, R., Horvat, N. and Škec, S. (2023), "Comparing Collaborative CAD Modelling Patterns of High-Performing and Low-Performing Teams", Proceedings of the Design Society, Vol. 3, Cambridge University Press, pp. 1007–1016, https://dx.doi.org/10.1017/pds.2023.101.

Cheng, K., Davis, M.K., Zhang, X., Zhou, S. and Olechowski, A. (2023), "In the Age of Collaboration, the Computer-Aided Design Ecosystem is Behind: An Interview Study of Distributed CAD Practice", Proceedings of the ACM on Human-Computer Interaction, Association for Computing Machinery, Vol. 7 No. CSCW1, pp. 1–29, https://doi.org/10.1145/3579613.

Deng, Y., Mueller, M., Rogers, C. and Olechowski, A. (2022), "The multi-user computer-aided design collaborative learning framework", Advanced Engineering Informatics, Elsevier Ltd, Vol. 51, https://dx.doi.org/10.1016/j.aei.2021.101446.

Dym, C.L., Agogino, A.M., Eris, O., Frey and D.D. (2005), "Engineering Design Thinking, Teaching, and Learning", The Research Journal for Engineering Education, Vol. 94 No. 1, pp. 103–120.

Ferreira, V.G. and Canedo, E.D. (2019), "Using design sprint as a facilitator in active learning for students in the requirements engineering course: An experience report", Proceedings of the ACM Symposium on Applied Computing, Vol. Part F147772, Association for Computing Machinery, pp. 1852–1859, https://dx.doi.org/10.1145/3297280.3297463.

Flus, M. and Hurst, A. (2021), "Design at hackathons: New opportunities for design research", Design Science, Cambridge University Press, https://dx.doi.org/10.1017/dsj.2021.1.

"Github MUCAD-CLF". (2022), available at: https://github.com/ReadyLab-UToronto/MUCAD-CLF/tree/v1.0 (accessed 15 November 2023).

Gopsill, J., Snider, C., Hicks, B., Gopsill, J., Snider, C., Shi, L. and Hicks, B. (2016), "Computer-aided design user interaction as a sensor for monitoring engineers and the engineering design process", DS 84: Proceedings of the DESIGN 2016 14th International Design Conference, pp. 1707–1718.

Horton, A., Weiner, S. and Lande, M. (2018), "Project-Based Learning Among Engineering Students During Short-Form Hackathon Events".

Huić, I., Horvat, N. and Škec, S. (2023), "Design Sprint: Use of Design Methods and Technologies", Proceedings of the Design Society, Vol. 3, Cambridge University Press, pp. 1317–1326, https://dx.doi.org/10.1017/pds.2023.132.

McComb, C., Cagan, J. and Kotovsky, K. (2017), "Capturing Human Sequence-Learning Abilities in Configuration Design Tasks Through Markov Chains", Journal of Mechanical Design, Transactions of the ASME, American Society of Mechanical Engineers, Vol. 139 No. 9, https://dx.doi.org/10.1115/1.4037185.

Phadnis, V., Arshad, H., Wallace, D. and Olechowski, A. (2021), "Are two heads better than one for computer-aided design?", Journal of Mechanical Design, American Society of Mechanical Engineers (ASME), Vol. 143 No. 7, https://dx.doi.org/10.1115/1.4050734.

Sadeghi, S., Dargon, T., Rivest, L. and Pernot, J.-P. (2016), "Capturing and analysing how designers use CAD software", Tools and Methods for Competitive Engineering (TMCE'16), pp. 447–458.

Stone, B., Salmon, J., Eves, K., Killian, M., Wright, L., Oldroyd, J., Gorrell, S., et al. (2017), "A multi-user computer-aided design competition: Experimental findings and analysis of team-member dynamics", Journal of Computing and Information Science in Engineering, American Society of Mechanical Engineers, Vol. 17 No. 3, https://dx.doi.org/10.1115/1.4035674.

https://doi.org/10.1017/pds.2024.300 Published online by Cambridge University Press