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Cards for Circularity (CFC): Reflections on the use of a card-based circular design tool in design education

G Dokter[1], B W Jansen[2], L Thuvander[1], U Rahe[1] , J A Duijghuisen[2]

[1] Department of Architecture and Civil Engineering, Chalmers University of Technology, Göteborg, Sweden.
[2] Faculty of Architecture and the Built Environment, Delft University of Technology, Delft, The Netherlands.

Correspondence: dokter@chalmers.se

Abstract. The transition to a Circular Economy (CE) requires designers to, more than ever, concurrently develop a circular design, supply chain and business model, and anticipate how products and buildings function over time. To address these challenges, recent studies identified specific knowledge and competencies for designers. However, it remains unknown to what extent future designers (students) are prepared to address the CE in design practice. Therefore, this study investigates how architecture students currently interpret the CE concept and whether that aligns with how they apply the concept in a design assignment. For two years, a workshop was organized with a total of 320 architecture students. The students utilized a card-based circular design tool to conceptualise circular solutions for cases varying in scale and context. According to the students, the main challenge of design for a CE relates to holistic perspectives and systems thinking. The students associate the CE strongly with the reuse of existing (waste) materials, yet results of the design assignment show holistic and diverse approaches of incorporating CE principles. The study identified slight discrepancies between experienced challenges and reported necessary knowledge of designing for a CE, which could relate to the changing role of architects in a CE.

Keywords: Circular economy, circular design, design education, architecture, sustainability

1. Introduction

In recent years the circular economy (CE) has gained momentum in business, academia and on political agendas across Europe. A transition to a CE is considered a viable option for tackling the environmental concerns of the built environment, which accounts for 50% of all material extraction and 35% of the EU's waste generation [1].

The CE aims to decouple social and economic prosperity from natural resource depletion and environmental degradation through establishing cyclical flows of resources in which buildings, products, components, and materials are always kept at their highest utility and value [2]. Artefacts in a CE thus need to be developed with a view towards how they might function and change over time, and their entire lifecycle from the design, production, use phase and onwards needs to be conceptualised. Perhaps most challenging is that it requires the design of systems; designers need to go beyond technical design challenges and consider (circular) supply chain configuration, business models, and services to find holistic solutions that capture value from prolonged product and building lifetimes and closed material loops.

Recent research identified specific competences for designers in a CE, emphasizing aspects such as systems and lifecycle thinking, stakeholder management and collaboration, environmental impact assessment, and business model thinking [3]. To a certain degree, design practitioners in Europe are already adapting their practices and capabilities to address the multifaceted challenges of the CE [4].

For a transition towards a CE, it is crucial that design students (as the future design practitioners) are equipped with a comprehensive understanding of the CE concept and the capabilities to apply the concept holistically within the design process. So far, the development of the CE concept and its implementation in practice has been mostly led by practitioners in business and policy environments [1,5], while scholarly discussions on the concept are still developing [6]. In theory, the CE concept builds on the notions of slowing, closing and narrowing resource loops [7], resource value preservation, and a systemic shift in the way people perceive and utilize resources. However, it is not self-evident that the concept is understood as such in design education and applied accordingly within the design process.

To date, few studies have investigated the implications of the CE for architectural education. There is a lack of insight into how architecture students currently interpret the CE concept and whether that aligns with or differs from how it is applied within their architectural design process.

Therefore, this study asks the following question: To what extent does the interpretation of the CE concept by architecture students align with how they apply the concept in a design assignment? For two consecutive years (2020 and 2021), a design workshop was organized with in total 320 architecture students in which the students utilized a card-based circular design tool to design a concept for a circular solution for defined cases that varied in scale and context.

The study has three main objectives: (1) to explore what challenges of designing for a CE were experienced by architecture students in a design assignment, (2) to determine whether the interpretation of the CE concept aligns with the application of the CE concept during the design assignment, and (3) to determine if the experienced challenges by the students aligns with the types of knowledge they report they would need to design for a CE. Additionally, we explore to what extent the design approach, outcomes, and perceived challenges overlap or differ between the student groups in the two different years.

2. Methods

2.1. Research approach and participant selection

To satisfy the aims of this study, two online design workshops utilizing the card-based circular design tool Cards for Circularity (CfC) were organized and conducted in steps (see figure 1). The workshops were organized over two consecutive years (September 2020 & 2021) during a compulsory first-year master programme course to sustainable development in relation to the design professions at a Swedish university. A total of 75 student groups (320 architectural students) participated. The architectural students were from the master program 'Architecture and urban design' (62%), 'Architecture and planning beyond sustainability' (36%), and 'other' (e.g. international exchange students).

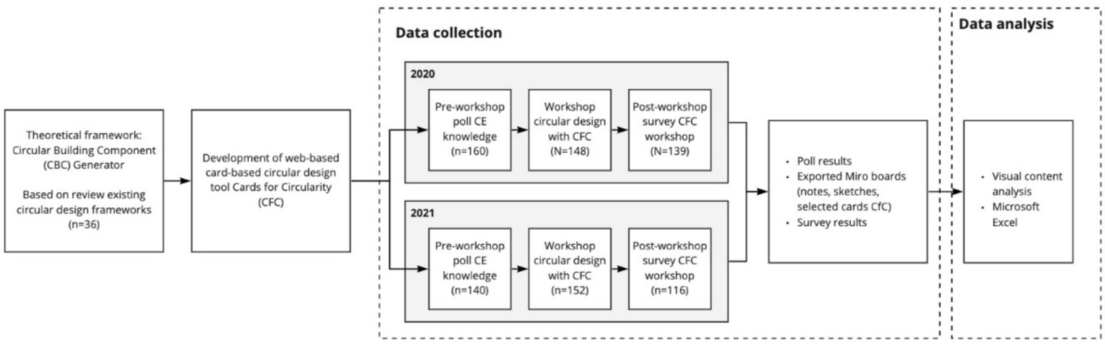

Figure 1. Overview of the research approach of this study.

2.2. *Development of a digital card-based circular design tool*

Various tools have been developed to support design for a CE. Some of these tools originate from practice such as The Circular Design Guide [8], others originate from academics in the form of serious games [9] and card-based tools to support circular design ideation and innovation processes [10,11].

One of the tools, the card-based circular design tool Cards for Circularity (CfC), first presented in [12] and based on a systematic literature review and analysis of 36 existing circular design frameworks [13], is suitable for both the design of products and throughout various scales in the built environment and aims to support the conceptualisation of holistic circular design solutions. The tool distinguishes strategies in three different models (i.e. categories): the technical model (relating to the tangible design of a product, component or building), the industrial model (supply chain configuration), and the business model (financial incentives and arrangements).

The CfC utilized in this study is a further iteration of the tool [12], incorporating two major changes: (1) the inclusion of practical examples on the cards to inspire, broaden perspectives and convey the practical feasibility of the CE and (2) the change to a digital web-based version of the tool to enhance accessibility for digital workshops (in the midst of the COVID-19 pandemic) and enable simultaneous usage by a large number of groups in the context of design education. Figure 2 provides a view of the web-based CfC. There are three different colours of cards (green, grey and orange) distinguishing the technical, industrial and business model, respectively. Each card represents a different strategy that could facilitate circularity and features an example that illustrates how this strategy can be realized.

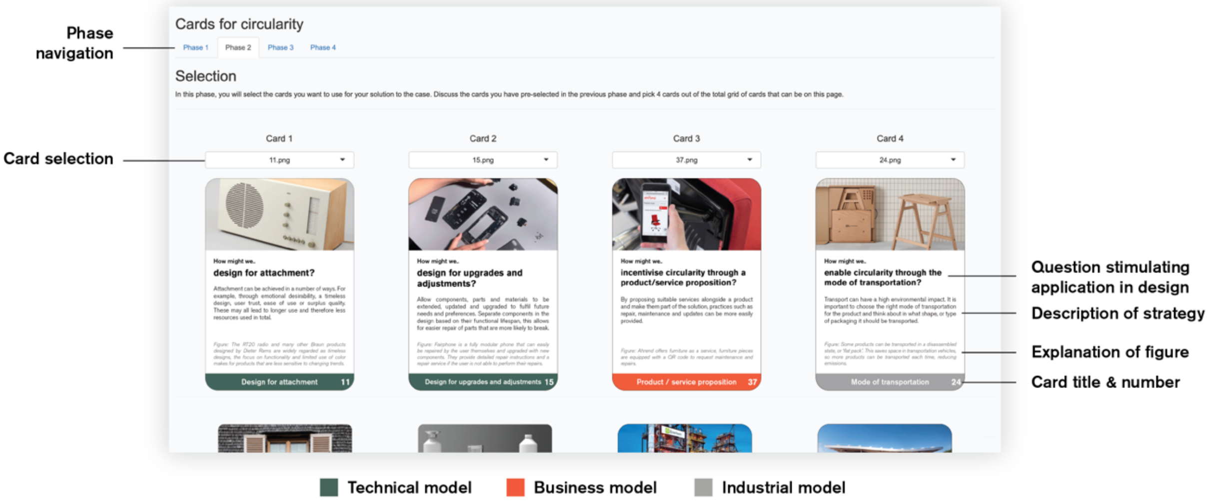

Figure 2. Impression of the web-based design tool Cards for Circularity (CfC) illustrating the layout of the cards in the selection mode.

In the tool, a tab menu allows the user to navigate through 4 different phases of a workshop or design process (orientation, selection, ideation, finalization). The orientation phase focuses on the exploration and familiarization of the different cards and facilitates group discussions about circularity and the different strategies. During the selection phase, four cards are selected that are considered relevant for the design assignment. During the ideation phase, ideas are generated for circular solutions based on the combination of cards. In the finalization phase, the ideas are selected and summarized into a final concept. Table 1 provides an overview of the cards included in the CfC. Both the technical and business model include 17 cards, while the industrial model includes 9 cards.

Table 1. Overview of cards with numbers and card title in the used version of the CfC

Technical model		**Industrial model**		**Business model**	
1	Biological materials	**18**	Partners in supply chain or value network	**27**	Partners in supply chain or value network
2	Technical materials	**19**	Activities	**28**	Owner
3	Type of energy use	**20**	Re-loop activities	**29**	Customer
4	System elements	**21**	(Re-)production processes per (re)activity	**30**	Primary contact customer
5	Amount of elements or resources	**22**	Facilities for activities	**31**	Kind of customer relationship
6	Amount of lifecycles	**23**	System elements	**32**	Primary supply chain contact
7	Expected lifespan	**24**	Mode of transportation	**33**	Kind of collaboration
8	Lifecycle stage of component, part, material	**25**	Distance	**34**	Cost proposition
9	Design for material reduction	**26**	Type of energy	**35**	Financial arrangement
10	Design for energy reduction			**36**	Income division
11	Design for attachment			**37**	Product / service proposition
12	Design for reliability and durability			**38**	Value delivery
13	Design for standardisation and compatibility			**39**	Value capturing
14	Design for ease of maintenance and repair			**40**	Key resources per supply chain partner
15	Design for upgrades and adjustments			**41**	Sale and (re)loop channels
16	Design for disassembly			**42**	Facilities for take back
17	Design for recycling			**43**	Circular business model adoption factors

2.3. Data collection and analysis
The half-day workshops (approximately 5 hours) took place over the online communication platform Zoom and started with a poll to evaluate the participants knowledge and current interpretation of the CE. Afterwards, a short lecture (30 minutes) was organized addressing the concept of a CE, design for a CE, and introduction of the CfC. Following, for the design workshop, the participants were randomly distributed in groups of 3 to 5 people through the ‘Breakout rooms’ functionality in Zoom.

Each group was assigned one out of six design cases, each representing a different level of scale, complexity, and evolution through different timescales, based on the shearing layers by Brand [14]: design of a (A) cooktop, (B) furniture piece, (C) interior wall system, (D) kitchen, (E) façade and (F) structure of a multi-story apartment building. Incorporating this classification into the different cases enabled us to explore whether the different cases (and different scale and time-perspective) also affected the choice of design approach and strategies (i.e. cards). Each group was assigned a board in the online collaborative whiteboard tool Miro to capture thoughts, notes, and sketches during the process. The researchers observed the process of the students during the workshop, and visually evaluated each of the Miro boards afterwards.

After the design assignment was completed, a debriefing session was organized where some groups presented their concept and the entire group could reflect on the workshop and exchange thoughts. At the end of the workshop a survey was conducted through the software Questback to evaluate the tool, the experience of the workshop, and thoughts on design for a CE. The multiple-choice questions in the survey allowed up to 3 answers.

The data was collected in the form of the exported Miro boards, the poll results, and the survey results. Each Miro board was analysed, relevant data was extracted (card selection, designed solution) and imported into Microsoft Excel alongside with the results of the poll and survey for the statistical analysis.

3. **Findings**
In the following chapter, we first present the combined findings from the poll and survey, which relate to the students’ knowledge and interpretation of the CE. Afterwards, we present the findings from the

design assignment, which relate to how the students applied the CE concept in the design process through utilizing the CfC.

3.1. Knowledge of the circular economy and experience with circular design

Figure 3 shows that the students' self-reported knowledge level regarding the CE prior to the workshop is mostly fair; both the 2020 and 2021 student groups have a comparable knowledge level. However, in 2021, relatively more students indicate to have experience working with the CE in design projects (see figure 3, right graph).

The students were also asked what they interpret as the main goals of the CE (see figure 4). Both in 2020 and 2021, similar goals were considered the most important: (1) Reuse of waste materials for new buildings and products, (2) Decrease the environmental impact of buildings, products, services, and (3) Decrease the use of non-renewable materials.

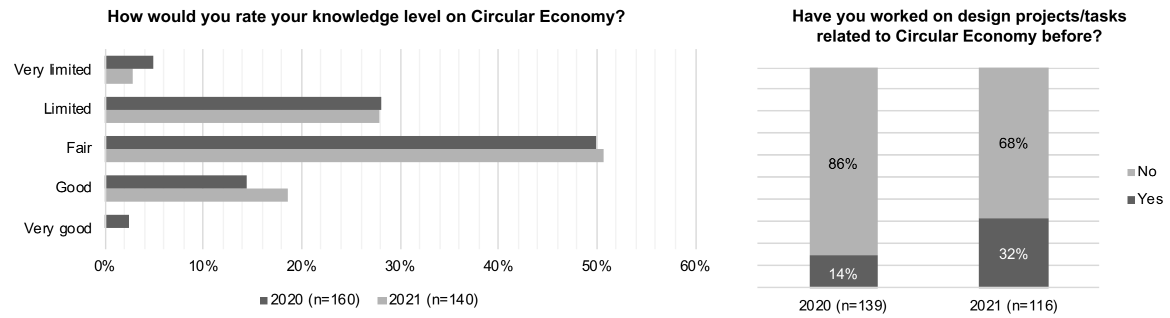

Figure 3. Reported knowledge of CE (left) and experience with CE-related design tasks (right) of the student groups in 2020 and 2021

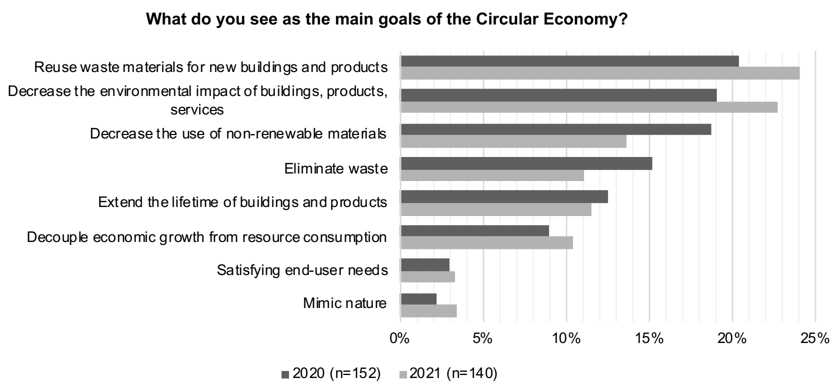

Figure 4. Distribution of responses regarding the main goals of the circular economy.

At the end of the workshop, the students were asked what knowledge they believe would enable them to become better at designing for a CE. When comparing between 2020 and 2021, the results shown in figure 5 indicate that the students agree on 3 knowledge areas considered to be most important: (1) Material knowledge (in terms of durability, lifespan, availability, impact, costs etc.), (2) Circular design methods and tools, and (3) Environmental impact assessment methods.

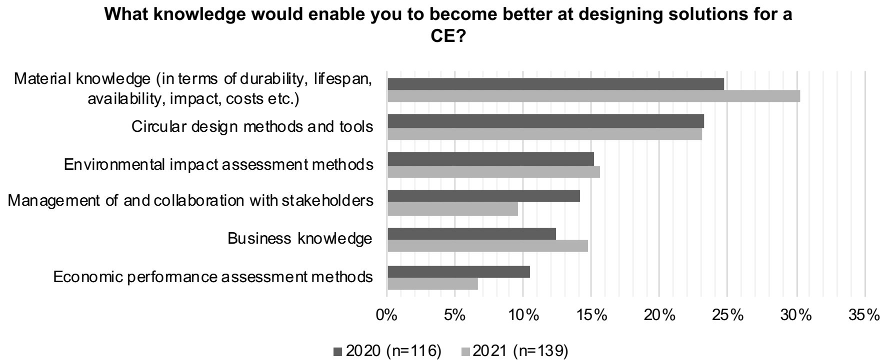

Figure 5. Distribution of responses regarding needed knowledge to address designing for a circular economy

3.2. *Results of the design assignment*

For the design assignment, each student group selected 4 cards (i.e., circular strategies) to work with. In total, 300 cards were selected, 161 in the technical model (54%), 59 in the industrial model (20%), and 80 in the business model (36%). Because the industrial model included less cards than the technical and business model (9 instead of 17), figure 6 shows the selected cards during the design workshop as weighted percentages in relation to the number of cards in each of the models. Most groups selected at least one card in each of the models, but the distribution of cards amongst the models is different per design case. For example, the groups working on the design of an apartment chose relatively more cards of the technical model than the groups designing the furniture piece, and relatively less cards of the industrial model.

Regarding the selection of specific cards, it appears that the same cards were frequently selected in both 2020 and 2021. Figure 7 shows that the most frequently selected cards for both years were 13. (Design for standardisation and compatibility), 1. (Biological materials), 16. (Design for disassembly), and 27. (Partners in supply chain or value network). Furthermore, some cards were only selected in 2020 or 2021, and some of the cards were not selected at all (e.g. 4, 30, 31, see table 1 for explanation).

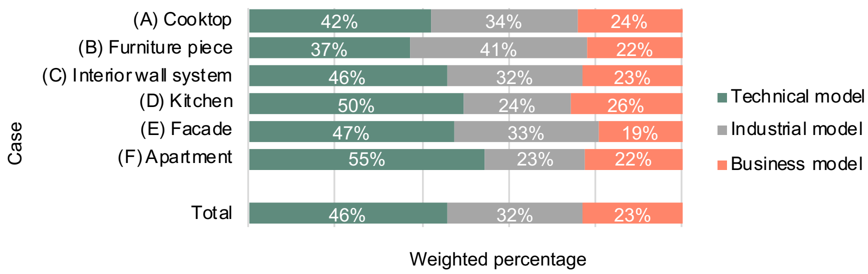

Figure 6. The ratio of cards selected in the technical, industrial and business model per design case. (Percentages are weighted in relation to the number of available cards in each model)

The high selection frequency for specific cards (and low for other cards) might raise the suspicion that certain cards were considered more appealing or interesting by the students than others. However, when asked during the questionnaire 'Why did your group decide to work with the chosen combination of cards?', the majority (51%) answered 'Because they suited the context of our case', followed up by 'Because we felt these cards would be most effective in reducing environmental impact and close resource loops' (24%) and thirdly 'Because the combination of cards seemed interesting/fun' (21%).

The results also show that certain cards were selected considerably more often (or less) in specific cases, suggesting that some strategies were seen as more or less suitable depending on the scale or context of the design task. The most selected card for each case was 10. (Energy reduction) for the cooktop case, 24. (Mode of transportation) for the furniture piece case, 13. (Design for standardisation

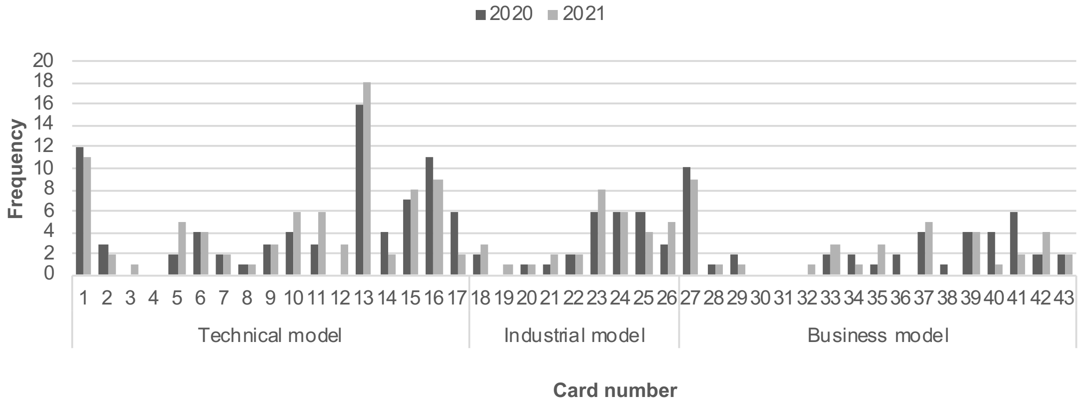

Figure 7. The cards selected by the student groups over 2020 and 2021 arranged by card number.

and compatibility) for the kitchen case, 1. (Biological materials) for the facade case, and 5. (Amount of elements or resources) for the apartment case. For the interior wall system, cards 13. (Design for standardisation and compatibility), 16. (Design for disassembly) and 27. (Partners in supply chain or value network) shared the first spot for most selected card.

When the students were asked what they perceived as most challenging regarding design for a CE the most prevalent answer was 'Holistic perspective and systems thinking' with 19% of the responses in both 2020 and 2021 (see figure 8). The other answers are quite similar in percentage when comparing 2020 and 2021, however 'Business aspects and financial feasibility' seemed to be less of a challenge in 2021 compared to 2020.

The Miro boards the students utilized encompassed their entire design process and were difficult to capture in a single image. Therefore, the images in figure 9 feature only a selected segment of the complete Miro boards they delivered. Without any clear instructions on how the workshop outcomes should look like (the students were only instructed to display the selected cards and present their idea), many of the students seemed to follow similar approaches. The final outcomes often show (visualized in the form of a diagram or flowchart) the selection of cards, the core ideas or principles extracted from each card relevant for the case, and a final concept sketch of the proposed design-solution with clarifications on how these core principles were integrated (e.g. see figure 9, B). The type of solutions proposed by the groups greatly varied, and featured one or a combination of the following: a tangible design artefact (e.g. product, building), a business model or service solution, or a proposed lifecycle with a corresponding chain of steps and activities of the imagined solution.

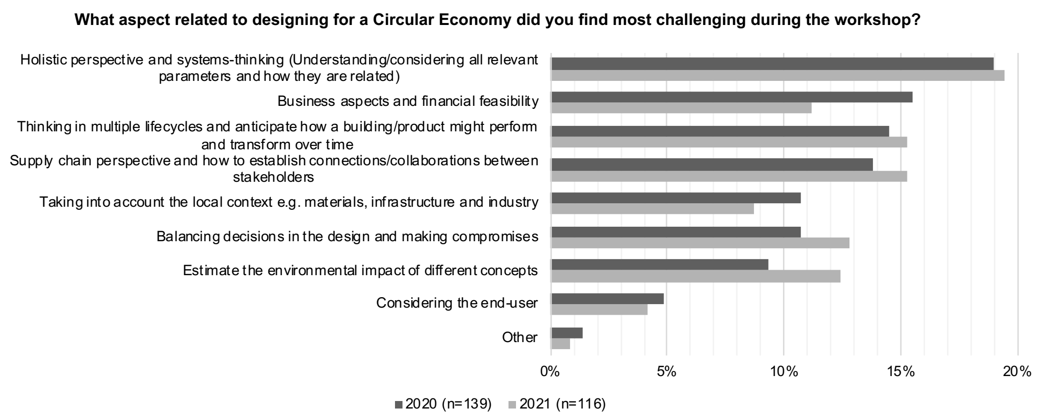

Figure 8. Distribution of responses regarding the most challenging aspects of designing for a circular economy.

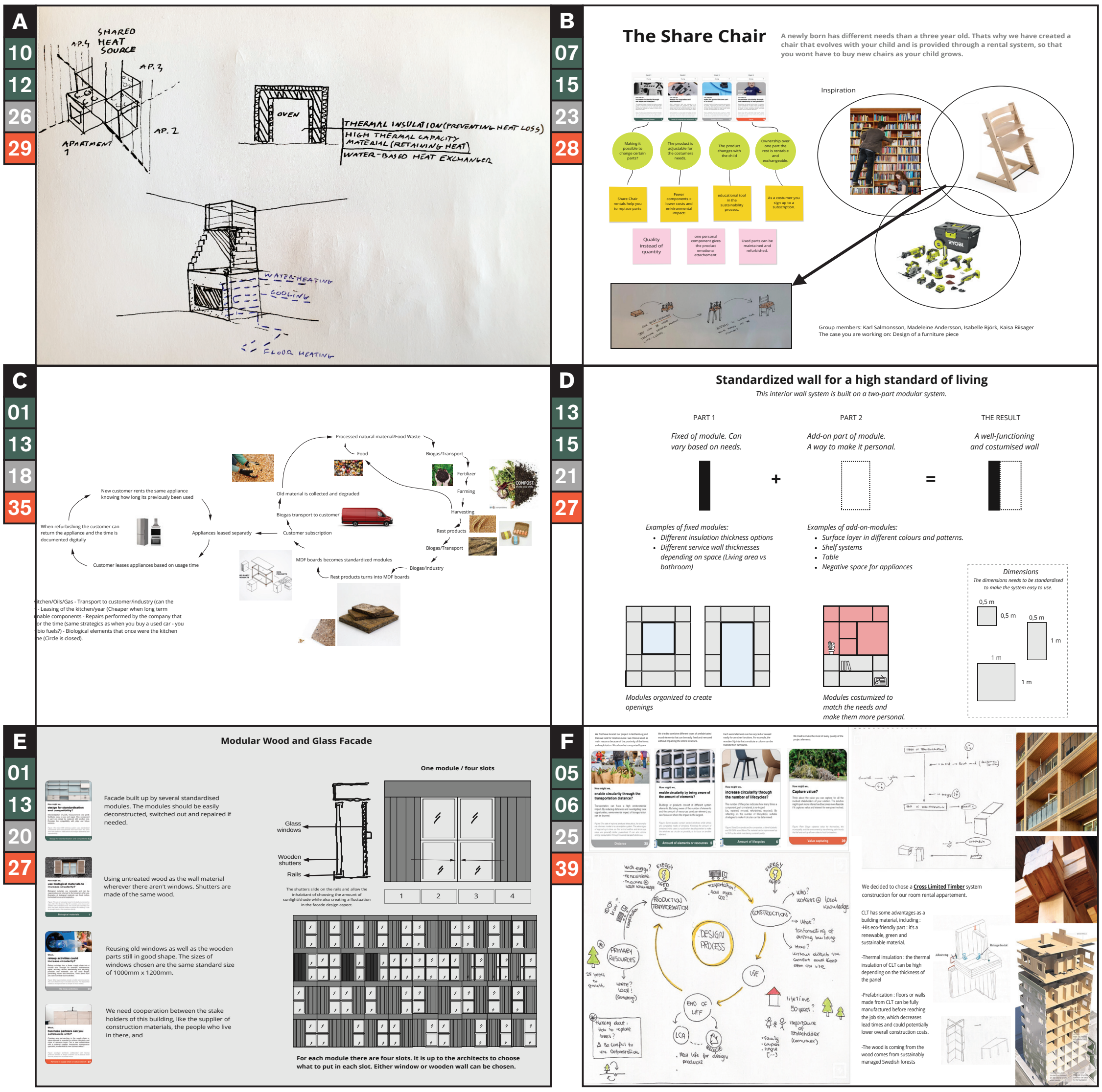

Figure 9. Selection of workshop results, extracted from the Miro boards created during the workshop. Cases: (A) Design of a cook top, (B) Design of a furniture piece, (C) Design of a kitchen, (D) Design of an interior wall system, (E) Design of a façade, (F) Design of an apartment building. Numbers represent the selected cards (see table 1), colours represent the model categories selected.

4. Conclusions and discussions

The primary aim of this study was to investigate how architecture students currently interpret the CE concept and whether that aligns with how they apply the concept in a design assignment. The study gathered data from two design workshops organized one year apart with around 320 first year master students of architecture in higher education. The participating students had to develop a circular solution for 6 different cases using the card-based circular design tool Cards for Circularity (CfC).

The study shows that in both years, the students describe their level of CE knowledge as fair, but the experience of working with the CE in design projects has increased in 2021. In both years, most students consider the main goal of the CE as 'Reuse waste materials for new buildings and products' while 'Decoupling economic growth from resource consumption', which is considered by some scholars as the ultimate goal of the CE [15], was considered substantially less by the students. This could relate to the fact that CE practices in the built environment to date have mostly focused on minimizing and reusing construction and demolition waste [16] which is a trend also observed in design practice [4]. Furthermore, the ambiguity surrounding the CE and the lack of a clear definition [17] might contribute to discrepancies between the students interpretations of the CE concept and definitions in literature.

The main challenge of designing for a CE according to the students in both years was to obtain a holistic perspective and systems thinking, which is frequently highlighted in earlier studies on design for a CE and the required capabilities of designers [3,18]. Other aspects that can be associated with the traditional work scope of architects (considering local contexts and end-users, balancing design decisions) were perceived as less challenging by the students.

Regarding the alignment between the interpretation and application of the CE concept, the findings suggest that the students associate the CE concept strongly with the reuse of (waste) materials, yet the application of the CE concept during the design workshop did not show a similar strong focus on this approach. Instead, the students found diverse ways of incorporating CE principles in the proposed concepts. Many students displayed technical and tangible solutions (e.g. the physical design of products and buildings), but also intangible solutions that facilitate circularity (e.g. service systems and sharing economy principles). Furthermore, a frequent approach was to visually dissect the lifecycle of the artefact in question and present an improved circular lifecycle diagram (with the necessary steps, activities, and actors). Overall, the students demonstrated their ability to approach the design assignment from a systemic perspective and conceptualise lifecycles and supply chains. Notably, in both 2020 and 2021, the same cards were picked frequently. This could suggest that certain cards (i.e. strategies) were preferable, yet the survey results indicated that personal preferences were not a leading factor in the choice of cards. It could relate to some of the cards being familiar or easier to understand and apply.

The students of both 2020 and 2021 mostly agreed that the important knowledge areas to design for a CE are material knowledge, circular design methods and tools, and estimating environmental impacts. Knowledge related to economic aspects and stakeholder management was considered less relevant, yet ‘Business aspects and financial feasibility’ was one of the main challenges of the design assignment. This indicates a slight discrepancy between the challenges perceived by the students of designing for a CE, and the reported needed knowledge to be able to address design for a CE. This is perhaps not surprising; business model design and stakeholder management might not be traditionally associated with the role and responsibility of architects. It is not unlikely that the students consider these areas as less relevant for their imagined profession or responsibilities as an architect. However, such roles become more prominent in the transition to a CE [4], where architects can play a central role by linking different actors [19] and need to communicate the benefits of a circular approach versus business-as-usual. These benefits are often only apparent when considering environmental and economic costs over the entire lifespan, hence appropriate knowledge and methods [20] are needed to communicate these benefits early in the design process.

Finally, some limitations should be noted. First, one limitation of the method is that the students were only able to select 4 cards during the workshop within a limited number of options, thus excluding possible approaches that they would have taken, if they had more creative freedom. Lastly, this study focused only on architecture students. CE education within other disciplines, and the collaboration between disciplines is crucial for a transdisciplinary and holistic approach towards CE. Nevertheless, this study provides a better understanding of the extent to which architecture students are prepared to address the CE within the design process, as well as contributes to a debate on the required knowledge and capabilities of future architects in the transition to a circular and sustainable built environment.

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