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Mapping the practice of circular design: a survey study with industrial designers and architects in the Netherlands and Sweden

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Abstract: Design practitioners are central actors in the circular economy, but knowledge is lacking regarding current trends, challenges, and knowledge needs related to circular design. This study surveyed 114 design practitioners in the Netherlands and Sweden, focusing on architects and industrial designers. The findings reveal that 63% had experience with circular economy in design projects, and 66% reported organisational adaptations. Projects focused on circular economy more frequently employed strategies like design for disassembly and circular business models. Differences between architects and industrial designers primarily regarded the focus on material reuse and disassembly. Practitioners actively develop tools and engage in new networks and collaborations to support circular design. Yet challenges remain, particularly on a business-level, related to material knowledge and economic and environmental assessment. The study concludes that major challenges associated with circular design appear mostly beyond the direct influence of designers and require further coordinated efforts between governments, design practice, industry, and research.

Keywords: circular economy; circular design; circular business models; industrial design; architecture; sustainability.

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1 Introduction

In recent years, the Circular Economy (CE) has turned from a niche discussion into a mainstream buzzword. Reports and academic outputs are produced in rapid succession, ambitious plans have been implemented on an EU-level (European Commission, 2020a), and companies are increasingly exploring how CE strategies can be incorporated into their organisation and offering. Governments are expected to adopt policies and intervention strategies to accelerate the transition towards a CE, and address the various barriers (cultural, regulatory, market) that are currently associated with the limited progress in practice (Kirchherr et al., 2018).

Designing for a CE encompasses various challenges that require novel approaches and extended competences (De los Rios et al., 2017; Sumter et al., 2021). Thus far, the development of supporting tools and frameworks for circular design has been fragmented and uncoordinated, and there is a limited understanding of the actual needs of design practitioners in regards to operationalising circular design (Cambier et al., 2020). Furthermore, since a coherent conceptualisation of circular design is lacking, and the concept has been driven by practitioners in diverse environments, it is not unlikely that different actors (including designers) adopt their own interpretations and frameworks. Hence, gathering empirical insights from design practice is relevant to gain a better understanding of current CE efforts and foster the alliance of scholars and practitioners, which is needed to catalyse both efforts in CE theory and practice and bring about rapid change (Blomsma et al., 2022).

While some studies have investigated current CE efforts, challenges, and needs amongst design practitioners (Cambier et al., 2020; Dokter et al., 2021; Münster et al., 2022; Sumter et al., 2020), these studies have been mostly qualitative and based on interviews. To date, there have been few quantitative studies deploying surveys to understand the wider adoption and mainstreaming of circular design. Hence, there is a lack of understanding of the efforts in design practice, whether those efforts align with CE principles, and what challenges are encountered in practice. In addition, there is a lack of knowledge of how designers can contribute to the CE transition, and what is needed to support them in advancing circular design practices. In recent years, the R-imperatives (e.g., reduce, reuse, recycle) and associated hierarchical taxonomies of design strategies have become a common vernacular in the context of circular design. Yet, few studies have investigated what circular strategies design practitioners focus on in design practice, and whether those practitioners display certain characteristics.

The primary aim of this study is to investigate the current foci, efforts, challenges, and knowledge needs of the design practitioners related to circular design. A secondary aim is to explore what relationships exist between the perspectives and characteristics of the design practitioners, and their focus in terms of circular design.

A survey study was conducted with a focus on the Netherlands and Sweden, two countries which have national plans and strategies for the implementation of CE, including sustainable and circular design as a focal area. Point of departure is a previously conducted interview study (Dokter et al., 2021) and focus is on two types of design practitioners, namely architects and industrial designers. Both architects and industrial designers are relevant to study as they have a vital role in enabling the design of products and buildings in line with CE principles (European Commission, 2020a, 2022).

2 Theoretical background

2.1 Design for a circular economy

Circular design (sometimes referred to as design for a CE) can be defined as a design approach that aims to create artefacts, services, and systems that are restorative and regenerative by nature, so that resources are always kept at their highest utility and value, and waste generation and pollution are minimised. Circular design greatly overlaps with sustainable design approaches in terms of general principles and approaches and can be considered under the design for sustainability (DfS) umbrella (Allen et al., 2023; Ceschin and Gaziulusoy, 2016). One distinctive attribute of circular design is the underlying principle of a closed-loop economy of resources, thus striving to resolve issues related to waste generation and resource efficiency rather than mitigating them, in contrary to other sustainable design approaches (e.g., eco-design) (den Hollander et al., 2017).

Circular design poses specific challenges for designers related to human factors (e.g., consumer behaviour and acceptance towards circular business models), material knowledge, thinking in systems and multiple lifecycles, and concurrently developing circular solutions and business models (Sumter et al., 2020). Moreover, challenges related to external constraints limit the possibilities for designers to incorporate circular design principles (relating to regulations and policies, client willingness, market dynamics) (Dokter et al., 2021; Münster et al., 2022). Another dimension of circular design is the design of products tailored to service-based and circular business models, which incentivise – and offer the potential of capturing value (social, economic, and environmental) of the continuous use and recovery of resources (Bocken et al., 2016).

The term circular design has been popularised the last decade by actors in policy and business environments such as the Ellen MacArthur foundation, who collaborated with design and innovation company IDEO to develop the Circular Design Guide (Ellen MacArthur Foundation, IDEO, 2017).

Since then, a diversity of circular design guides, methods, and tools have been developed by various actors (NGOs, trade unions, consultancies, manufacturers) targeted towards different design disciplines (product design, fashion, architecture, interior design, service design). Thus, a wide variety of supporting tools and methods have been made available for designers to incorporate CE principles in their design work. However, it is not well-known how designers engage with circular design in practice, and whether the current design knowledge, tools, and methods sufficiently support designers in tackling challenges related to designing for a CE.

2.2 Practical implementation of circular design and implications for designers

In the context of architecture, Cambier et al. (2020) noted the oversupply of tools that illustrate the basic principles of circular building and highlighted the mismatch between ongoing developments and the actual needs of practitioners. Lofthouse and Prendeville (2018) drew parallels between the current technocratic framing of the CE and the early eco-design discourse and urged for incorporating (past) lessons from both within and outside the discipline of sustainable design. In the context of eco-design for example, Ahmad et al. (2018) pointed out that many sustainable product design tools were developed with limited practical utility. The same authors argued that coordinated and responsible efforts amongst practitioners, governments, societies, and researchers are needed to ensure the successful uptake of sustainable product design tools.

To date, there have been some investigations into how circular design has been adopted in practice. Münster et al. (2022) studied the adoption of CE principles by retail designers and found that the designers' influence to incorporate circular design is ultimately dependent on market economics and willing clients. The authors emphasise that there is a need for a systemic and collaborative approach between all stakeholders in the retail design process and that the central role that design can play needs to be articulated, practised, and broadcast. Dan and Østergaard (2021) studied how fashion designers can aid the transition to a CE. They suggest that fashion designers can take three central roles (prevent, facilitate, and advise) but that this would require systemic and organisational changes (related to designer knowledge, dynamic capabilities, better design management, and balanced power structures). Sumter et al. (2020, 2021) interviewed and surveyed industrial designers and defined a comprehensive set of skills and competences to successfully design for a CE. These include systems thinking, anticipating future use cycles of products, assessing environmental impacts, stakeholder collaboration, and business and material knowledge. A case study carried out by De los Rios et al. (2017) indicated that industrial designers have to develop deep material knowledge, proficiency in service design, and a richer understanding of social behaviour to design for a CE.

In the context of the construction industry, Charef and Lu (2021) explained that many circular design strategies are not common practice as they require a disruption of conventional design practice and a radical shift in the way that projects are structured. Kanters (2020) argued that architects could play a central role in the transition to a circular building sector by linking different actors, yet this would require additional leadership capabilities and deeper material knowledge. Dokter et al. (2021) conducted interviews with industrial designers and architects in consultancy settings and found that these disciplines have a different focus towards CE implementation, but both see a necessary shift from design projects as short-lasting temporary efforts towards longer term client relationships to encourage lifecycle engagement (and thinking) and interventions that ensure circularity in the long-term. The study also identified that some practitioners are able (and willing) to take a role in the CE transition by linking actors and facilitating collaboration between actors across value chains.

Overall, there have been limited quantitative studies on the uptake of circular design amongst design practitioners. A large-scale survey focusing on the architectural profession in Europe conducted in 2020 and 2022 (Architects' Council of Europe, 2022, 2020) revealed that the proportion of architects who frequently use 'circular design' were 15% and 12%, respectively. The same survey also revealed that circular design is mostly self-taught (between 60–70% of respondents), and few architects received formal (or informal) training.

Based upon the current literature, it is apparent that there are prevalent systemic challenges that inhibit design practitioners in advancing design efforts aligned with CE principles and that circular design poses specific challenges and requires additional capabilities. Moreover, the transition from a linear to a circular economy also seems to represent shifts in the role of design practitioners in practice. Yet, the wider practical implications of circular design for architects and industrial designers have so far been under-explored. There is a limited understanding of the main challenges, foci, and efforts related to circular design on a wider scale.

3 Methods

A survey was distributed to architects and industrial designers in the Netherlands and Sweden. Data were analysed through descriptive statistics to satisfy the first aim of the study (i.e., to investigate the current foci, efforts, challenges, and knowledge needs of the design practitioners related to circular design), while a robust regression analysis was performed to satisfy the second aim (i.e., to explore what relationships exist between the perspectives and characteristics of the design practitioners, and their focus in terms of circular design). The following section describes the sampling procedure, survey development, and analysis.

3.1 Sampling procedure and data collection

The focus is on architects and industrial designers working in practice across the Netherlands and Sweden. Both countries have an active agenda promoting CE and circular design, thus representing suitable candidates for inquiry into how circular design is being adopted in practice. Both disciplines share similar goals in slowing and closing resource loops to advance the transition to a CE (European Commission, 2020a) and share similarities in the design process, typically following a cycle of cognitive processes and iterative steps to deal with ill-defined design problems (Cross and Roozenburg, 1991). In addition, industrial designers and architects share common concerns related to materials, usability, structural integrity, and ergonomics; the disciplines frequently intersect in areas such as furniture design, interior design, lighting design, and design of building components (e.g., kitchen design).

Studying architecture and industrial design despite the differences in terms of competences, scale, lifecycle perspective, business context, and regulatory constraints can thus provide valuable insights aside from the common objective of closing resource loops:

1. synergising design perspectives could further enable holistic approaches towards the systemic and multi-scalar challenge of a CE
2. investigating approaches and efforts across disciplines can provide a basis for further dialogues and knowledge exchange
3. increasing the understanding of the overall advancement of circular design within design practice.

The Dutch CE implementation plan defined ‘circular design’ as one of 10 overlapping themes (Rijksoverheid, 2021). It is shaped by the bottom-up initiative and governmental supported organisation ‘Circo’, which educates and activates designers and manufacturers in designing circular products, services, and business models. The Swedish government defined circular product design as a focus area in their CE implementation plan (Regeringskansliet, 2021), formulating a top-down approach that focuses on areas such as extended producer responsibility, standards for circular design, and accessible environmental information for consumers.

In the Netherlands, there were 40,000 architects active in 2018 (CBS, 2018) and 3100 industrial designers between 2003–2005 (CBS, 2007). In Sweden, there were around 11,000 architects and 2000 industrial designers active in 2018 (SCB, 2020). To gain an understanding of the current awareness and efforts regarding circular design amongst design practitioners, we followed a purposive sampling method (Groat and Wang, 2002) and targeted professional unions for designers and architects. In doing so, we targeted not only CE frontrunners, but ensured a random sample of design practitioners from different design disciplines, organisations, and experience levels. Experiences and perceptions of designers across different organisational structures can differ substantially (Björklund and van der Marel, 2019). For example, in-house designers at a product manufacturer, compared to a design consultancy, are typically involved in more phases of the design process (from design brief to realisation and beyond), might share more responsibilities, and may have a greater influence on those phases. Therefore, it is important to consider that perceptions and practices regarding circular design and the extent to which designers can influence and contribute to CE practices might differ drastically depending on individual roles, scale, structure, and context of organisations.

The survey was distributed through three channels. First, trade unions for both industrial designers and architects in the Netherlands and Sweden were asked to distribute the survey through their newsletter and social channels; two organisations accepted the request (resulting in 17 responses). Second, the survey was distributed through LinkedIn on public pages of the trade unions and pages directed towards industrial designers, architects, and circular design (resulting in 32 responses). Lastly, emails were sent directly to addresses gathered from the trade unions and the authors' professional network (resulting in 102 responses). Responses were gathered between 24 October 2022 and 30 December 2022.

In total 155 responses were collected. 20 responses were excluded as they were from participants outside the Netherlands and Sweden. Another 21 responses were excluded as they represented disciplines outside of architecture and industrial design (i.e., graphic design, service design, UI/UX design). This resulted in a total of 114 valid responses. Table 1 provides a full sample description with the demographic characteristics of the respondents.

Table 1 Sample description showing characteristics of the respondents

	Total (*n = 114*)		*Sweden* (*n = 73*)		*The Netherlands* (*n = 41*)	
Background variable	*N*	*%*	*N*	*%*	*N*	*%*
Design disciplines						
Architecture *	66	58	34	47	32	78
Industrial design	48	42	39	53	9	22
Organisation type						
In-house employment (e.g., at a company that offers a product or service)	20	18	11	15	9	22
Consultancy	59	52	35	48	24	59
Freelance (self-employed)	26	23	23	32	3	7
University/Higher education	2	2	1	1	1	2
Public sector	4	4	3	4	1	2
Other	3	3	0	0	0	0

Table 1 Sample description showing characteristics of the respondents (continued)

Background variable	*Total* (*n = 114*)		*Sweden* (*n = 73*)		*The Netherlands* (*n = 41*)	
	N	*%*	*N*	*%*	*N*	*%*
Organisation size						
1–9 employees	53	46	38	52	15	37
10–49 employees	31	27	12	16	19	46
50–249 employees	12	11	6	8	6	15
250 + employees	18	16	17	23	1	2
Years of experience						
0–1 years	3	3	2	3	1	2
1–3 years	6	5	3	4	3	7
3–5 years	7	6	1	1	6	1
5–10 years	20	18	9	12	11	27
10–20 years	33	29	25	34	8	20
More than 20 years	45	39	33	45	12	29

*Includes architects, interior architects, landscape architects, and urban planners.

3.2 Survey development

Table 2 provides an overview of the survey questions and modules (see supplementary material for the survey template). The survey consisted of 17 questions, of which 4 were open-ended and 13 close-ended. Two of the open-ended questions were conditional follow-up questions and only asked when participants reported positive to 'new networks and collaborations' and 'changes to offered services' in relation to organisational CE adaptations.

The survey was designed to take around 10 min to complete. To reduce completion time, a multiple-choice format was used for questions number 1–15 except for question 6 and 10 which used a 5-point Likert scale to assess level of CE knowledge and perspectives and attitudes towards a series of statements, respectively. The multiple-choice questions were complemented with optional open input fields in the case that correct answer alternatives were missing.

To gain an understanding of the current foci of participants regarding circular design, we asked respondents who reported having worked on CE-focused projects to indicate what design strategies they have incorporated in such projects. Participants without CE experience were shown the same list of strategies but were instead asked which of these design strategies they have generally incorporated in design projects. We used a list of strategies adapted from (Ellen MacArthur Foundation, ARUP, 2022) which is a comprehensive framework based on relevant international practices and policies. Additionally, it is one of few frameworks that lists design strategies in hierarchical groupings (based on the extent they retain resource value). The list was modified and expanded so that, aside from architects, it would be applicable to industrial designers. Moreover, we added two strategies which addressed circular business models and material reuse, as they were identified as relevant design strategies in current practice (Dokter et al., 2021). We are aware that in practice, certain design strategies are not fundamentally better than others, given that their effectiveness and compatibility always depend on the characteristics of a given artefact, context, and business constraints (Bakker et al., 2014). Therefore, the purpose of adopting the hierarchy was not to explore which design practitioners perform 'better', but to explore whether there are relationships between the perspectives and characteristics of the design practitioners and their focus in terms of incorporated strategies. Table 3 shows the final list of strategies incorporated in the survey. In the remainder of this paper, we will refer to the strategies according to their number and label.

Table 2 Survey modules and general list of questions

Survey module	*No.*	*General questions*
Characteristics	1	In which country do you work?
	2	Within what design discipline are you mainly working?
	3	What type of organisation do you work for?
	4	What is the size of your organisation?
	5	How many years of professional experience do you have in the field of design?
CE knowledge & experience	6	What is your knowledge of the circular economy?
	7	Have you worked on any projects that focused on the circular economy?
Focus	8*	Which design strategies have you incorporated in projects that focused on the circular economy?
	9	Which design strategies have you incorporated in projects?
Efforts	10	To what extent do you agree with the following statements? (Statements relate to efforts regarding circular design)
Challenges	11*	According to you, what are particular challenges of designing for a circular economy?
Organisational changes	12–14	What has changed in your organisation to adapt to the circular economy?
Needed knowledge	15	What (additional) knowledge do you need to design for a circular economy?
Other	16	According to you, what is the most important goal of a circular economy?
	17	Are there any topics missing in this survey that you would like to see addressed or expanded on in the future?

*Question asked only when answering positively to question 7.

Table 3 Overview of strategies (S) included in the survey

No.	*Label*	*Full strategy description*
S1	Avoid	Avoid unnecessary new construction/production
S2	Utilisation	Increase product or building utilisation (more efficient use, e.g., sharing products)
S3	Longevity	Design for longevity (design for an optimal lifetime)
S4	Adaptability	Design for adaptability (upgrades and adjustments)
S5	Disassembly	Design for disassembly (accessible material joints)
S6	Efficiency	Increase material and energy efficiency
S7	Non-renewables	Reduce the use of virgin and non-renewable materials
S8	Carbon-intensive	Reduce the use of carbon intensive materials (e.g., steel, plastic, cement)
S9	Reuse waste	Reuse waste or spare materials for new products or buildings
S10	Hazardous	Design out hazardous/pollutant materials
S11	Services	Incorporate circular services and business models

Source: Adapted from Ellen MacArthur Foundation, ARUP (2022)

The question assessing experienced challenges of designing for a CE was only asked to respondents that also reported CE experience, and we used a list of challenges identified by Dokter et al. (2021), complemented with challenges extracted from literature (see Appendix 1 for the full list of references). For the questions focusing on strategies and challenges, an 'other' field was added to capture potentially missed strategies and challenges.

The survey was designed in the online data collection platform Questback and translated in three languages (English, Dutch, Swedish) with the support of native speakers. A test version of the survey was completed by 11 participants (design researchers and practitioners) and the survey was revised according to their feedback.

3.3 Descriptive data analysis

The data was imported into IBM SPSS Statistics version 29. We used contingency tables to analyse the categorical variables (i.e., answers from the multiple-choice questions) and deployed chi-square tests to assess whether significant associations exist between the responses of participants according to the survey modules and their demographic characteristics (country, design discipline, experience, organisational type, and size). To determine statistical significance, we used $\alpha = 0.05$.

For question 10, related to efforts on circular design (5-point Likert scale), a Shapiro-Wilk test indicated that the resulting data for each statement was not normally distributed ($p < 0.001$). Therefore, we used the non-parametric Mann-Whitney U test to analyse the ordinal data and compare differences between two independent groups (industrial designers against architects, the Netherlands against Sweden, and participants with and without experience of CE projects). Some of the independent variables had more than two groups (e.g., organisational type, organisational size). In these cases, a Kruskal-Wallis test was used.

A bivariate analysis was conducted to examine the relationships and potential correlations between variables in the survey modules organisational changes, experienced challenges, and needed knowledge for circular design. The purpose of this analysis was mainly explorative and to guide further investigation and discussion.

The open-ended question regarding ‘new networks and collaborations’ resulted in 43 qualitative answers. These answers were imported into NVivo (version 1.7.1), analysed, and thematically clustered to better understand the types and frequency of new networks and collaborations initiated by industrial designers and architects to adapt to the CE.

3.4 Regression analysis

Seven metrics were developed which assess to what degree the participants incorporate circular design strategies and capture practices from a different perspective, emphasising different strategies in the framework. The development of CE indicators using metrics from surveys has been well documented. For example, Kristensen and Mosgaard (2020) provide several contributions where CE indicators are developed from metrics. Inspired by these studies, Table 4 provides an overview of the strategies used to calculate the different metrics. The numbers in the table indicate the weight of each strategy.

Table 4 Circular design strategies used as dependent variables in the different metrics

		Metrics						
Principle	*Strategies*	*CEsum*	*CEwgt*	*CEimp*	*P1*	*P2*	*P3*	*P4*
P1. Build nothing	S1. Avoid	1	4	5	1			
P2. Build for long-term use	S2. Utilisation	1	3	5		1		
	S3. Longevity	1	3	4		1		
	S4. Adaptability	1	3	4		1		
	S5. Disassembly	1	3	4		1		
P3. Build efficiently	S6. Efficiency	1	2	3			1	
	S7. Non-renewables	1	2	3			1	
P4. Build with the right materials	S8. Carbon-intensive	1	1	4				1
	S9. Reuse waste	1	1	3				1
	S10. Hazardous	1	1	3				1

The first metric (CEsum) calculates the sum of all strategies. Based upon the question whether a certain strategy has been incorporated in design projects, we either assign a 1 (yes) or a 0 (no). The second metric (CEwgt) and third metric (CEimp) explore whether assigning different levels of importance to strategies will reveal certain characteristics of practitioners who have incorporated those strategies. In the metric CEwgt, we assigned importance based on the hierarchy of the four principles suggested in the Circular Buildings Toolkit by Ellen MacArthur Foundation, ARUP (2022). CEwgt, thus, is a weighted sum where P1 is weighted 4 times more than strategies in P4. The metric CEimp instead uses the ‘impact level’ provided in the Circular Buildings Toolkit for each strategy on a 6-point scale. This provides a more granular understanding of efforts by the practitioners.

We excluded S11(Services) from the metrics as it should be considered more of an economic strategy than a technical design strategy and it does not directly correspond to any of the principles. S9, reuse waste, was assigned a value based on discussions between the authors. Finally, since each strategy relates to a specific principle, we also defined four metrics based on the different principles where the strategies are contained in respective groups. The motivation behind these last four metrics was to be able to capture differences between participants based on their focus on the four principles.

To further understand the foci of the participants in relation to their characteristics, the defined metrics were used as dependent variables and the other responses were taken as independent variables. To extract the most important factors in explaining the performance of the design practitioners in relation to the metrics, each of the survey modules were used as regressors. A first set of models was evaluated in relation to

1 the characteristics of participants
2 circular design efforts
3 organisational changes
4 experienced challenges
5 needed knowledge for circular design.

From these regressions statistically significant variables were isolated and new regressions were performed.

These results are available in the supplementary material, and they indicate the main drivers within each of the survey modules. In all cases robust ordinary least squares (ROLS) was used to estimate the regression coefficients. This method is preferable over OLS in the presence of outliers. Since only 114 responses were collected, all were used in the regression. While Logit or Probit models are commonly deployed in the presence of a binary dependant variable, ROLS will still produce valid results and was preferred for consistency, interpretation of the results, and the explorative aim of the analysis.

The significant variables from each module were combined to understand the main contributing factors to the performance of the design practitioners in terms of incorporated strategies. It should be noted that in this step, the module regarding challenges was omitted because that question was only asked to participants that reported experience with CE projects. Finally, statistically insignificant variables were excluded and a final set of regressions containing the most relevant variables that explain the level of circularity were obtained. Overall, the analysis should be considered as explorative and seen as a direction for further research and discussions.

4 Results

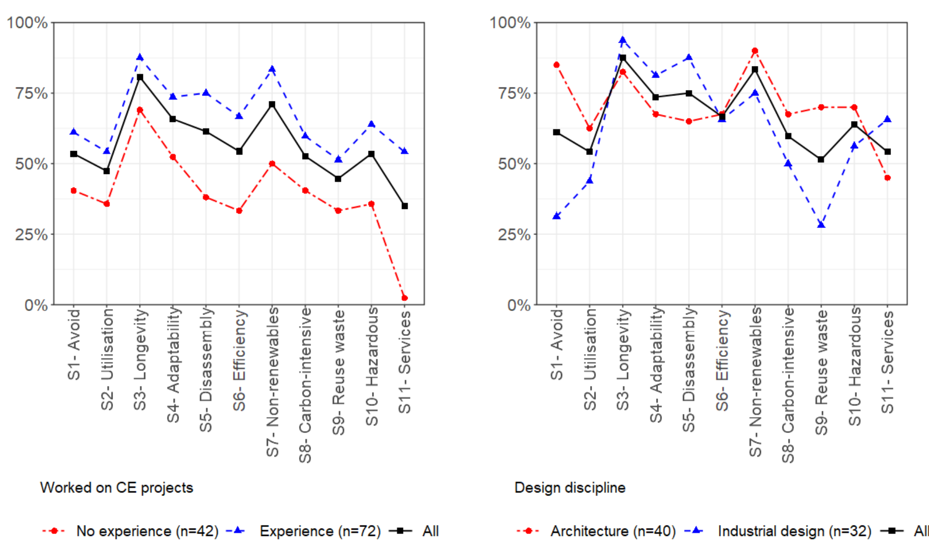
This section presents the results from the survey and is structured according to the aims of the paper. We present comprehensive findings encompassing all study participants while also differentiating between architects and industrial designers, alongside other participant characteristics.

4.1 *Current foci of design practitioners regarding circular design*

Overall, 72 participants (63%) had experience with CE-focused projects. This percentage was similar across countries and disciplines. To assess whether certain strategies are more frequently incorporated in CE-focused projects, the proportion of design practitioners who incorporated the listed design strategies was compared between respondents with CE experience and without CE experience (see Figure 1, left diagram). Overall, the test results indicate that for all the different design strategies, the proportion of design practitioners with CE experience was higher. The test yielded significant results at ($p < 0.05$) for the strategies S1, S3-7, and S10-11 (see supplementary material for all test results), indicating the difference in proportions between the two groups is statistically significant. The results showed that the difference in proportions was highly significant at ($p < 0.001$) for the strategies S5 'Design for disassembly', S7 'Reduce virgin non-renewable materials', and S11 'Incorporate circular services and business models'. For both participants with and without CE experience, S3 'Design for longevity' was the most frequently incorporated strategy. S11 'Circular services and business models' has been incorporated by the majority of participants with CE experience, but only by few of the participants (2%) without CE experience.

The right diagram in Figure 1 shows the incorporated strategies by industrial designers and architects with CE experience. The strategies were compared to investigate whether the focus towards circular design differs. The results indicated that a higher proportion of architects incorporated the strategies S1 'Avoid unnecessary new construction/production' and S9 'Reuse waste or spare materials for new products or buildings', while a higher proportion of industrial designers incorporated S5 'Design for disassembly'. These differences in proportions were significant at ($p < 0.001$) for S1 and S9 and ($p < 0.05$) for S5. While there were differences for the other strategies, these were not found statistically significant.

Figure 1 Design strategies incorporated by participants with and without CE experience (left), and design strategies incorporated by industrial designers and architects in CE projects (right) (see online version for colours)



4.2 Organisational changes, challenges, and needed knowledge for circular design

4.2.1 Organisational changes

The results indicated that most of the participants' organisations have undergone changes to adapt to the CE. 66% reported at least one of the listed changes, and only 16% reported specifically that 'nothing has changed in our organisation'. Overall, the most reported efforts to adapt to the CE relate to

1 identifying new materials, techniques and technologies that support circular design of products and buildings

2 developing methods, strategies, and tools to address circularity within the design process

3 new networks and collaborations outside organisations.

No significant differences were found between the design disciplines and the reported organisational efforts aside from having compiled written documents and guidelines in place for circular design ($p = 0.03$). The results revealed a significant association (at $p < 0.01$) between organisational size and whether a dedicated CE expert had been appointed or whether changes or extensions were made to the offered services. Moreover, we also found significant associations (at $p < 0.05$) between organisational size and internal education regarding design for circularity, and whether compiled written documents and guidelines are in place.

For the respondents who reported new networks and collaborations, the open-ended follow-up question revealed diverse answers (Figure 2). Architects reported a combination of regional initiatives for circular building, collaborations with universities and research institutes, suppliers and platforms for reused materials, circular dismantling companies, and experts on various topics (e.g., sustainable installation, construction, and building). Industrial designers pointed out dedicated industry networks for a CE and network initiatives on a regional and EU level. Industrial designers also reported collaborations with universities and research institutes, external experts, manufacturers, and material suppliers.

4.2.2 Challenges

The most prevalent challenges when designing for a CE were

1 business aspects and financial feasibility

2 limited willingness of companies to invest in circular solutions

3 estimating environmental impacts over the entire lifespan.

As shown in Figure 3, the results indicated slight differences in experienced challenges between industrial designers and architects. The chi-square test indicated a significant difference only between the proportion of architects and industrial designers that experienced 'Current regulations and policies' ($p < 0.001$) as a challenge.

Figure 2 Overview of new networks and collaborations according to industrial designers and architects (see online version for colours)

4.2.3 Needed knowledge

Most participants perceive themselves to have a fair to good knowledge of CE ($M = 3.34$, SD = 0.92). There were no significant associations between CE knowledge and country of the respondents or design discipline.

Regarding the need for additional knowledge to be better able to design for a CE (Figure 3), the respondents ($n = 113$) emphasise a need for knowledge to deal with technical challenges such as

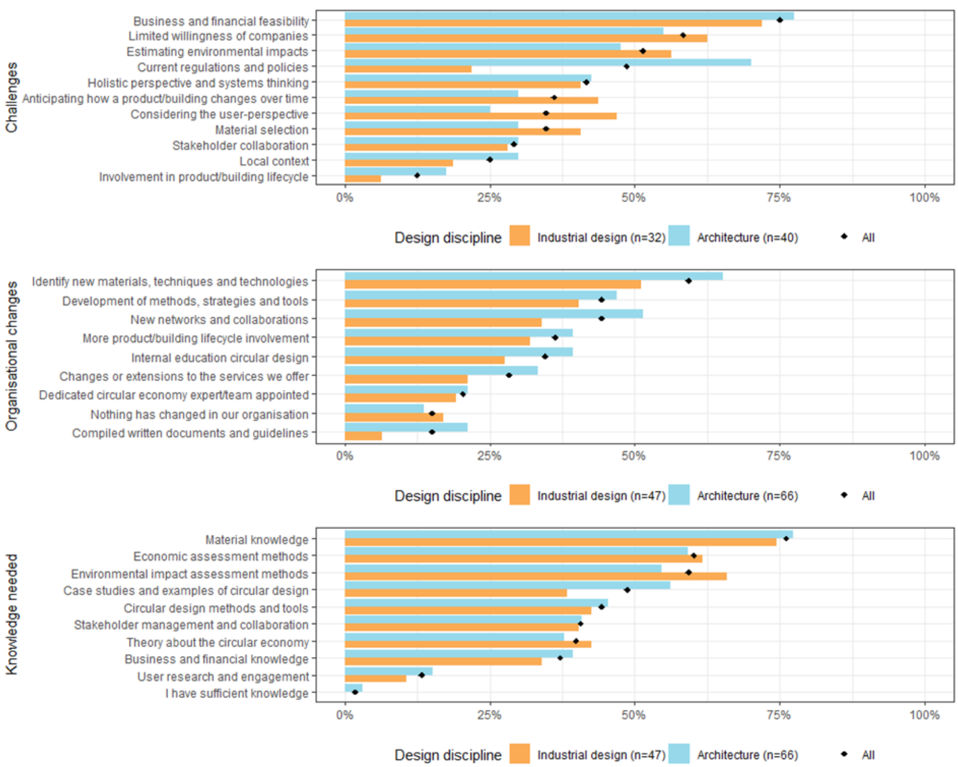
1 material knowledge

2 environmental impact assessment

3 economic assessment methods.

Comparing architects and industrial designers, both show a high degree of alignment between the necessary knowledge, and we did not find any significant differences. Furthermore, we found no significant relationships between the needed knowledge and the country, organisation size, and years of professional experience of the participants.

Figure 3 Organisational changes, challenges, and needed knowledge reported by the design practitioners in relation to designing for a circular economy. For the challenges and needed knowledge, participants were able to select up to five answers. For the organisational changes, the question did not limit the number of answers (see online version for colours)



4.2.4 Relationships between organisational changes, challenges, and needed knowledge

A correlation matrix was generated to explore relationships between organisational changes, challenges, and needed knowledge. The full matrix is available in the supplementary material. The matrix revealed that there were significant correlations between certain organisational changes and the need for knowledge (see Table A2 in Appendix 2). For example, positive correlations were found between internal education within organisations for circular design, and the need for knowledge on stakeholder management and collaboration, and economic assessment methods. A positive correlation was also found between tool and method development for circular design, and the need for knowledge on economic assessment methods.

The analysis also revealed that certain challenges were positively correlated with the need for related knowledge, such as assessing environmental impacts and knowledge of environmental impact assessment (see Table A3 in Appendix 2). Challenges related to business aspects were positively correlated with business knowledge, and the challenge of material selection was positively correlated with material knowledge. The limited willingness of clients was positively correlated with the need for case studies and examples of circular design.

4.3 Current efforts regarding circular design

Figure 4 shows the current efforts regarding circular design and indicates that most of the respondents already use tools and methods that support circular design. Furthermore, while a considerable number (around 40%) of the respondents work with concrete CE goals and requirements in projects and perform circularity assessments during design processes, there is also a substantial group (around 30%) that does not seem to take efforts on these matters.

Comparing architects and industrial designers, the results from the Mann-Whitney U test indicated significant differences for the statement 'involvement of wider network of stakeholders' ($U = 1224$, $p = 0.032$) and the statement 'requirement of different business models' ($U = 1038$, $p = 0.002$). This suggests that the architects are more active in involving a wider network of stakeholders in projects and appear to believe more strongly that different business models are needed for rewarding design work. Most architects appear to involve a wider network of value chain stakeholders when engaging with CE projects and co-create solutions together with stakeholders, while only around one-third of the industrial designers undertake efforts on these points.

4.4 Relationships between circular design focus and the perspectives and characteristics of the respondents

Table 5 shows the distribution of the metrics capturing incorporated circular design strategies and how they correlate with each other. CEsum shows that the average amount of incorporated strategies was 5.9 (SD = 2.6). As expected, this variable has a high correlation with CEwgt ($r = 0.97$) and CEimp ($r = 0.99$), as well as P2 ($r = 0.78$) and P4 ($r = 0.83$). CEwgt has a mean of 13.6 (SD = 5.8), and CEimp has a mean of 22.2 (SD = 9.7). Lower correlations were found between the different principles. Especially P1 and P2 ($r = 0.17$) and P1 and P3 ($r = 0.18$) showed weak correlations.

Table 5 Distribution of the different metrics and the correlations between the metrics

Vars	*CEsum*	*CEwgt*	*CEimp*	*P1*	*P2*	*P3*	*Mean*	*SD*	*Min*	*Max*
CE sum							5.9	2.6	0	10
CE wgt	0.97						13.6	5.8	0	23
CE imp	0.99	0.98					22.2	9.7	0	38
P1	0.46	0.56	0.52				0.5	0.5	0	1
P2	0.78	0.84	0.80	0.17			2.6	1.2	0	4
P3	0.68	0.63	0.63	0.18	0.36		1.0	0.8	0	2
P4	0.83	0.69	0.80	0.31	0.46	0.43	1.8	1.1	0	3

Figure 4 Efforts by architects and industrial designers to adapt to the CE (see online version for colours)

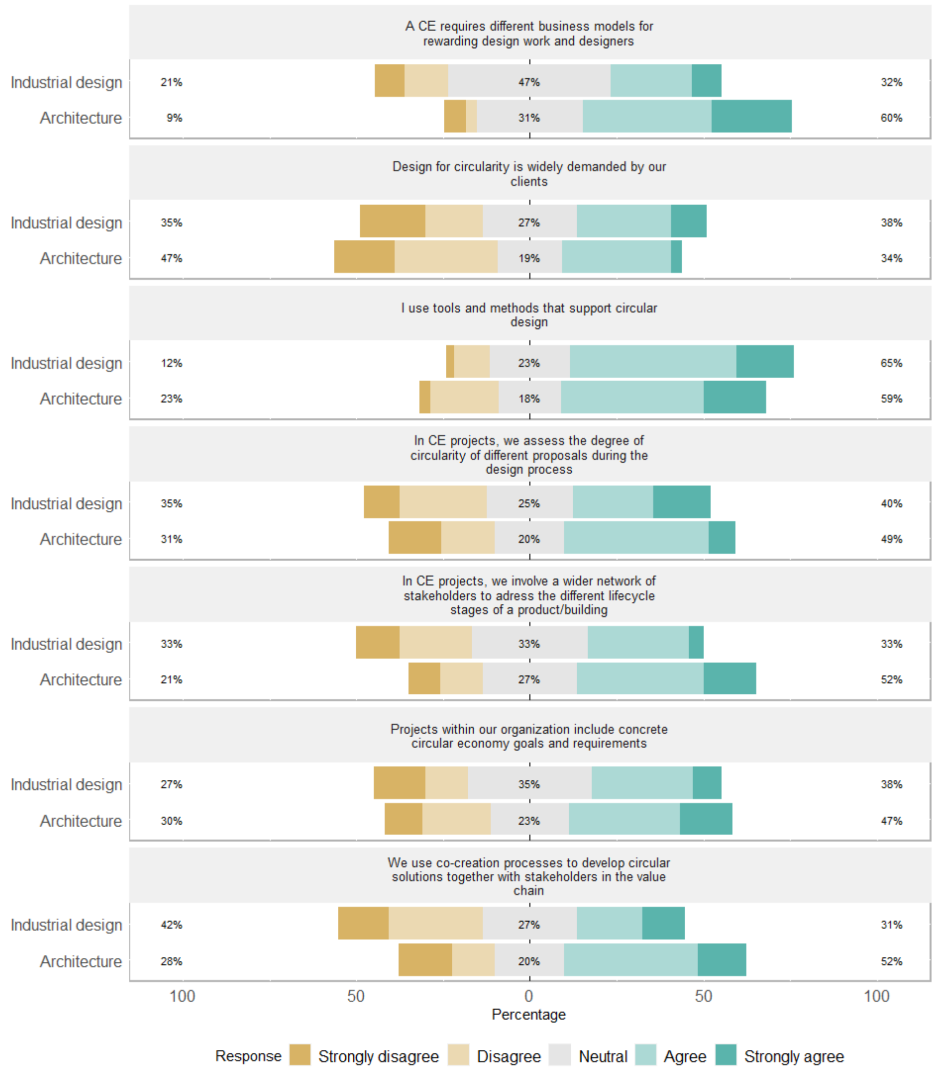


Table 6 summarises the regression results and shows the significant variables within each survey module for each of the metrics. These results are intermediate results where only statistically significant variables at 1%, 5%, and 10% from each survey module were kept. The results indicate that organisational changes were the most effective predictor for the metrics (average R^2 of 28%), followed by the characteristics of the respondents (24%), and organisational efforts (20%). While Table 6 shows similar results for the first three metrics (CEsum, wgt, imp), notable differences occur when comparing the principles P1-P4.

Table 6 Main significant variables across survey modules for each metric

Survey module	*Metric*		
	CEsum	*CEwgt*	*CEimp*
Characteristics	Company size * (–) CE Knowledge** CE Expirience**	Industrial designer* (–) CE Knowledge** CE Experience**	Industrial designer*(–) CE Knowledge** CE Experience**
Efforts	Use of tools ***	Use of tools ***	Use of tools ***
Challenges	Systems thinking* Local context* Env. Impact*** Business*	Systems thinking* Env. Impact*** Business*	Systems thinking* Local context* Env. Impact*** Business*
Organisational changes	Lifecycle involvement* Networks&collab*** Method development*** Material research*	Networks&collab*** Method development***	Lifecycle involvement* Networks&collab*** Method development*** Material research*
Needed knowledge	CE theory *** (–)	CE Theory ** (–)	CE Theory * (–)

	Metric			
Survey module	*P1*	*P2*	*P3*	*P4*
Characteristics	Industrial designer*(–)	CE Experience* CE Knowledge**	CE Experience**	CE Experience* CE Knowledge*
Efforts	Use of tools *	Circularity assessment***	Use of tools *	Use of tools *
Challenges	Regulations***	Env. Impact*** (–) Material selection* (–)	User perspective* (–)	Local context** Env. Impact*
Organisational changes	Internal education***	Networks&collab*** Method development***	Networks&collab*** Method development***	Networks&collab*** Material research**
Needed knowledge	CE Theory ** (–)		CE Theory ** (–)	

Negative correlations are marked with a (–).

Significance levels used: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

For P1 (relating to avoiding new construction and production) there was a negative correlation with industrial designers, and the only significant challenge was current regulations and policies. For P2 (strategies focusing on lifetime extension) there was a positive correlation with efforts on circularity assessment, and a negative correlation with the challenge of estimating environmental impacts. P3 (build efficiently) showed a negative correlation with the challenge of considering user-perspectives. Finally, P4 (build with the right materials) was positively correlated with the challenge of considering the local context and the organisational change of advancing material research. For the survey module of needed knowledge, the only significant variable was CE theory, yet it should be noted that this module explains less than 10% of the variation in the dependant variables.

Table 7 shows the final regression, in which only significant variables in each survey module were used, and the most influential factors on the probability of incorporating circular design strategies (including type of strategies). The first three metrics (CEsum, CEwgt and CEimp) have the highest adjusted R^2, which explains between 45% to 49% of the total variability. For these metrics, none of the respondents' characteristics (e.g., country, experience level, organisational type and size, CE knowledge and experience) were significant factors. Overall, the results indicate that both the use and the development of tools and methods for circular design are significantly correlated with higher levels of CE activity across the three metrics. Material research efforts is also positively correlated with the metric CEsum and CEimp. However, for the metric which more strongly prioritises P1 and P2 (CEwgt), networks and collaborations is a significant factor while material research efforts are no longer significant.

Table 7 Final results of the regression analysis showing the most influential factors for incorporating design strategies according to the different metrics

Survey module	*Most influential factor*	*CE*(sum)	*CE*(wgt)	*CE*(imp)	*P1*	*P2*	*P3*	*P4*
Efforts	Use of tools and methods	0.97^{***}	1.54^{**}	3.53^{***}	0.09^{*}			0.33^{***}
		(0.19)	(0.48)	(0.73)	(0.04)			(0.09)
	Circularity assessment					0.29^{***}		
						(0.08)		
Organisational changes	Tool and method development	1.62^{***}	4.07^{***}	6.26^{***}		0.78^{***}		0.47^{*}
		(0.44)	(0.96)	(1.64)		(0.20)		(0.21)
	Material research	1.58^{***}		5.78^{***}				0.73^{***}
		(0.38)		(1.43)				(0.19)
	New networks and collaborations		2.76^{**}				0.54^{***}	
			(0.94)				(0.13)	
	Internal education circular design				0.20^{*}			
					(0.08)			
Needed knowledge	CE theory				-0.19^{*}			
					(0.08)			
Discipline	Industrial Design				-0.47^{***}			
					(0.08)			
	R^2	0.49	0.45	0.48	0.37	0.29	0.13	0.31
	Num. obs	113	113	113	113	112	113	113
	RMSE	1.83	4.21	6.94	0.40	0.96	0.71	0.93

Significance levels used: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

P1 is the only model with a binary dependent variable and the only model where discipline is significant. In this case, the coefficient is negative which reinforces the idea that industrial designers are less active with strategies that aim to avoid new construction and production. The model P3 shows only one significant variable related to new networks and collaborations, however these results should be interpreted with care as this model can only explain 12% of the total variability.

Interestingly, factors such as organisational goals for working with CE, whether CE is widely demanded by clients, or the extensive involvement of stakeholders in projects were not identified as significant factors for the level of activity regarding incorporated circular design strategies.

5 Discussion

In the following section we discuss the overall contribution of our study and the potential implications of our findings for design practice. We also define potentials for future research to advance circular design in practice.

5.1 Current efforts and focus of design practitioners regarding circular design

To date, most studies assessing practices and perspectives related to circular design have been qualitative and directed towards ‘frontrunners’ and experts in the area of sustainability and circularity (Cambier et al., 2020; Dokter et al., 2021; Kanters, 2020; Rios et al., 2018; Sumter et al., 2020). This paper contributes to the few quantitative studies (Sumter et al., 2021) and as it targeted a broader range of practitioners, i.e., members of trade unions for industrial designers and architects, it provides a more nuanced and representative picture of design practitioners.

The study found that the majority of participants from both the Netherlands and Sweden had experience with projects that focused on CE. Overall, design practitioners with CE experience more frequently incorporated the listed design strategies in projects. Strategies such as design for longevity appeared as common practice for most survey participants. Yet, some strategies were significantly more often incorporated by participants with CE experience, such as design for disassembly, reduce the use of non-renewable and virgin materials, and circular services and business models. Design for disassembly and circular services and business models are key strategies for circular product design (Bocken et al., 2016), and therefore might be strongly connected to the notion of circular design and current efforts in practice.

The results indicated that design practitioners with higher circular design activity (measured in incorporated strategies) are characterised by both the use and development of tools and methods to support circular design. This finding aligns with Dokter et al. (2021) who noted that designers actively develop (and customise) tools and methods to tackle CE-related challenges in the design process. Moreover, it could reflect that existing circular design support tools and methods are not sufficient or readily available (Cambier et al., 2020; Kanters, 2020).

Previous research noted that higher levels of circularity might be associated to firms with certain characteristics (e.g., start-ups vs. incumbent firms) (Henry et al., 2019). Interestingly, we did not find any substantial differences in terms of incorporated strategies between respondents of different company sizes and types.

Consistent with Dokter et al. (2021), the results of this study indicated different foci in regard to circular design amongst architects and industrial designers. The architects more frequently incorporated strategies related to the reuse of materials on a building level and avoiding new construction, whereas the industrial designers more frequently incorporated strategies that facilitate lifetime extension and circular business models. Qualitative comments provided by the architects suggested that reusing building materials for new construction is currently a viable strategy which has direct impact (in terms of reducing carbon footprints and resource consumption), while the long-term effectiveness of strategies such as design for disassembly and material passports remain uncertain and unproven at scale. Previous studies highlighted the (uncaptured) potential of service-based solutions in the built environment (Joensuu et al., 2020). The results of this study suggest such solutions are not uncommon in practice, as almost half of the architects incorporated strategies related to circular services and business models in projects.

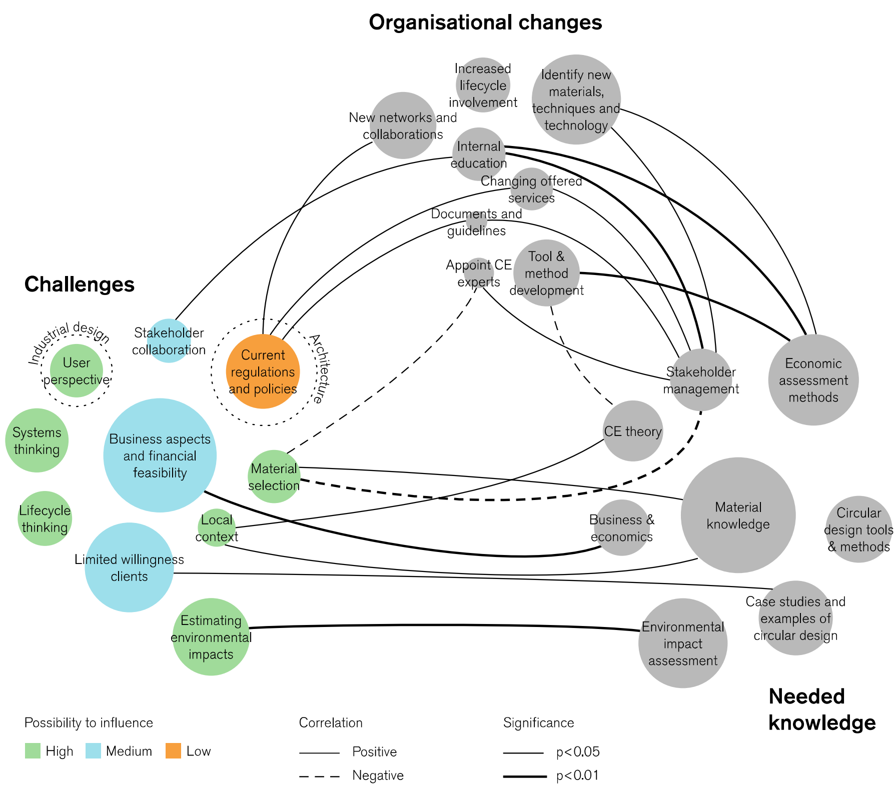
5.2 Addressing the current challenges related to circular design

Figure 5 provides an overview of significant correlations found between experienced challenges, organisational changes, and knowledge needs. The purpose of the figure is to frame a discussion on the current situation in design practice and explore how to increase circular design capacity. While previous research has identified challenges and capabilities for circular design, the contribution of our paper lies in providing quantitative evidence of the current challenges, efforts, and knowledge needs from the perspective of architects and industrial designers.

As seen in Figure 5, some of the most prevalent challenges (limited willingness of companies to invest in circular solutions, current regulations and policies, business aspects and financial feasibility) can be considered difficult to influence by designers. Although 'business aspects and financial feasibility' was the most common challenge and significantly correlated with the need for better knowledge of business and economics, it did not appear as a prioritised knowledge field for the design practitioners. Yet, many respondents pointed at the need for economic assessment methods. Especially when conveying the potential benefits of circular value propositions over other design proposals that might require less up-front investments, designers are increasingly challenged to assess environmental and economic impacts over entire lifespans. Such capabilities might not (yet) be typically connected to the role, interests, and responsibilities of design practitioners. As pointed out by Sumter et al. (2021), competences related to circular business propositions and environmental impact assessment become important when designing solutions tailored to circular business models and service-based revenue models.

Interestingly, while most of the participants in this study already use tools and methods that support circular design, most participants highlight the need for more knowledge of tools and methods (e.g., regarding environmental and economic assessment). This further raises the question whether currently available design tools and methods sufficiently address challenges faced in practice related to circularity. Furthermore, not only the development, but also guidance on the use of design support tools is important (Cambier et al., 2020) as well as coordinated efforts between research, practice, and governments to ensure adoption in practice (Ahmad et al., 2018). Moreover, practitioners might not necessarily need more assessment methods, but rather standardised methods for assessing circularity attuned to the workflow of designers (Kanters, 2020). We also found that the limited willingness of clients was positively correlated with the need for case studies and examples of circular design, suggesting that designers could benefit from case studies and examples of best practices (Cambier et al., 2020) to convey the value and feasibility of circular solutions to clients.

Figure 5 Overview of the correlations between experienced challenges, organisational changes, and needed knowledge of the design practitioners. The connections represent significant correlations (at $p < 0.05$ or $p < 0.01$). The size of the circles refers to the relative importance of the variable based on amount of survey answers. Two noteworthy differences in experienced challenges between architects and industrial designers are pointed out through dotted circles. The colours represent the relative influence designers have on the challenges (see online version for colours)



Collaborative innovation between upstream and downstream stakeholders is a widely discussed challenge for a CE (Brown et al., 2021; Konietzko et al., 2020), yet challenges and knowledge related to stakeholder collaboration and management did not appear as prominent issues for the respondents. Perhaps the industrial designers and architects consider themselves proficient in addressing these issues. Facilitating collaborations and connections is not necessarily a new challenge for designers (Manzini, 2009), yet the CE expands the scale at which this needs to be done (Dokter et al., 2021)

Challenges related to consumption behaviour and the acceptance of circular value propositions have been discussed in literature (Lofthouse and Prendeville, 2018; Selvefors et al., 2019). Although almost half of the industrial designers found considering the user-perspective a challenge for circular design, this was not reflected in the need for knowledge about user research, and other challenges appeared more crucial. This could suggest that the participants already feel confident and knowledgeable in their ability to navigate such challenges.

The survey results revealed a variety of new networks and collaborations to adapt to the CE, and especially the architects reported a wider involvement of stakeholders and co-creation processes to design solutions for a CE. This could be related to the increasing scale and complexity of the built environment and broad variety of stakeholders, which might increase the need for collaboration and co-creation to realise holistic solutions (Kanters, 2020; Pomponi and Moncaster, 2017). This suggests that, depending on the scale of the design challenge and intervention, the relative importance of stakeholder collaboration and co-creation as a component of the circular design process increases. Particularly the architects felt strongly that the CE requires different models for rewarding design work, which could relate to Galle et al. (2018) who highlighted the limited involvement of architects in construction value chains relative to the long-term impact of their design choices.

Current regulations and policies appeared as one of the major obstacles for architects, which can be explained by the current focus within architecture on the reuse of obsolescent building materials for new construction (Dokter et al., 2021), a strategy that is faced with constraints as building components are governed by strict regulations (Condotta and Zatta, 2021; Nußholz et al., 2020). This challenge was positively correlated with new networks and collaborations. Many respondents appeared to engage in a variety of regional, industrial, and international networks promoting the circular design of products and the built environment. It is likely that these networks provide fruitful ground for knowledge exchange, collaboration, and addressing challenges related to design for a CE.

Finally, participants most frequently mentioned the need for more material knowledge, which was correlated with the challenge of selecting materials in the design process, and the challenge of understanding local contexts. As already discussed in literature (De los Rios et al., 2017; Kanters, 2020; Lilley et al., 2019), designing products and buildings according to principles of slowing and closing resource flows might require a deeper understanding of materials (e.g., regarding their impact, availability, durability, wear, and tear). Understanding local contexts (in terms of material availability, infrastructure, industrial capacities) is common for architects, but might become more essential for industrial designers considering European ambitions of reducing the dependency on global manufacturing value chains and moving towards more resilient locally based production systems (European Commission, 2020b).

5.3 Limitations

This study has several limitations. By focusing on trade unions, we might have excluded groups of designers that are not members of these organisations. The perspectives of the Netherlands and Sweden might not be representative of the EU, therefore we cannot generalise the findings to the entire European context. Furthermore, it is difficult to distinguish between sustainable and circular design as we do not know how participants interpret the difference between circular and conventional design practice. Yet, by distinguishing between participants with and without CE experience, we were able to highlight some differences in design focus. A limitation of the study is the relatively small sample size compared to the target population. Therefore, the results should be considered tentative and complemented with further and larger inquiries. Obtaining high response rates from a disperse target population is practically challenging, yet considering the explorative nature of the study and the fact that there are few comparable studies, the paper nevertheless provides valuable insights into the contemporary practices of circular design. By targeting trade unions, we have taken measures to achieve a diverse and representative sample that reflects the population (e.g., different organisational types and sizes, and levels of experience). Another limitation of the survey is that we do not know the context in which the strategies were implemented, challenges were experienced, and efforts took place. To improve the robustness of the results, future research could aim to recruit larger and more diverse samples (e.g., other design disciplines) with a higher response rate.

6 Conclusion

Based upon a survey with 114 design practitioners in the Netherlands and Sweden within the disciplines of architecture and industrial design, this study contributes to a better understanding of the current foci, efforts, challenges, and knowledge needs of architects and industrial designers related to circular design. In addition, through a set of metrics capturing circular design activity, the study explored characteristics of design practitioners that are actively incorporating circular design strategies. While previous studies on the implications of the CE for design practice have been mostly qualitative, the contribution of this paper lies mainly in the quantitative insights on the wider adoption of circular design.

The results indicate that circular design is a thriving concept amongst the surveyed design practitioners. 63% had experience with the CE in design projects, while 66% reported one or more organisational changes to adapt to a CE. The study identified significant differences between design strategies incorporated in CE-focused projects compared to design projects that did not focus on CE. Strategies such as design for disassembly and circular services and business models were incorporated more often in CE-focused projects. Design practitioners that were highly active in terms of incorporating circular design strategies according to the defined metrics, were characterised by both the use and development of tools and methods to support circular design. Furthermore, the study found different foci between architects and industrial designers, where architects had a greater focus on the reuse of materials on a building level, and industrial designers on design for disassembly and designing for circular business models.

To increase circular design capacity and tackle current challenges, our study provides several insights. First, the design practitioners require deeper material knowledge and better ways of assessing environmental and economic impacts during the design process to advance circular design efforts. Second, organisations are actively adapting to circular design and design practitioners undertake efforts to develop tools and methods for circular design, identify new materials and technologies, and engage in new networks and collaborations. Third, while stakeholder collaboration and management are common issues for a CE, the design practitioners do not appear to see this as a major challenge for circular design. Instead, the lack of expertise and challenges in some areas seem to be compensated by actively engaging in a variety of new networks and collaborations, which further promotes circular design in practice. Still, we conclude that the major challenges for circular design are systemic in nature and mostly beyond the direct control of designers. These will require further coordinated efforts between governments, design practice, industry, and research.

Further empirical research is needed to better understand the actual needs of design practitioners working within increasingly complex design processes, to ensure that challenges are addressed, and future tools are practically relevant and impactful. In addition, while this research provided some insight into what design strategies are implemented by architects and industrial designers in CE-focused projects, more research is needed to understand the context in which certain design strategies are impactful (when and why certain strategies are applied), considering the economic and environmental effects of one design approach vs. another.

For design practice, it is relevant to know that (regional, national, international) networks and initiatives exist that promote circular design, and that engaging in (and facilitating) collaborations across disciplines, value networks, and sectors is vital to enable holistic circular solutions that contribute to a CE.

For research, it is important to support such initiatives when possible and ensure that knowledge for circular design is both practically relevant and easily accessible for design practitioners. Furthermore, it is vital that design practice and education are provided with a coherent and holistic understanding of circular design, aligned with the underlying principles and goals for a CE.

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Competing interests

The authors declare that there are no conflicts of interest.

Authors' contributions

G.D. planned the study with support from L.T. and S.H. G.D. collected the data. G.D. and J.C. performed the data analysis with input from L.T., S.H., and O.R. G.D. and J.C. wrote the paper with input and support from L.T., S.H., and O.R. All authors read and approved the final manuscript.

Ethics approval and consent to participate

Not applicable.

Availability of data and materials

The aggregated data used for this study are available based upon request. The data are not publicly available as they contain references to names of organisations and initiatives.

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Appendix 1

Table A1 Challenges identified from literature on design in the context of a circular economy

CE challenges	*References*
Anticipating how a product/building functions and changes over time	Bakker et al. (2014), De los Rios et al. (2017), Franconi (2020), Lilley et al. (2019), Mestre and Cooper (2017), Moreno et al. (2016) and Sumter et al. (2020)
Gaining a holistic perspective and think in systems	Andrews (2015), De los Rios et al. (2017), Dokter et al. (2021), Ghisellini et al. (2016), Moreno et al. (2016), Sumter et al. (2018, 2020, 2021) and Whalen et al. (2018)
Taking into account the local context (e.g., materials, infrastructure, industry)	Dokter et al. (2021) and Kozminska (2019, 2020)
Estimating environmental impacts over the entire lifespan	Baldassarre et al. (2020), Brydges (2021), Cambier et al. (2020), den Hollander et al. (2017), Dokter et al. (2021), Royo et al. (2023), Sumter et al. (2018, 2020, 2021)
Considering the user-perspective and consumer behaviour	Bakker et al. (2015), De los Rios et al. (2017), Lofthouse and Prendeville (2018), Poppelaars et al. (2020), Rexfelt and Selvefors (2021), Selvefors et al. (2019), van Dam et al. (2021), van Weelden et al. (2016) and Wastling et al. (2018)
Business aspects and financial feasibility	Baldassarre et al. (2020), Bocken et al. (2016), den Hollander (2018), Dokter et al. (2021), Moreno et al. (2016) and Sumter et al. (2018)
The collaboration between stakeholders involved in the lifecycle of a product/building	Adams et al. (2017), Bocken and Konietzko (2022), Brown et al. (2021), Dan and Østergaard (2021), Debacker et al. (2017), Dokter et al. (2021), Hart et al. (2019), Leising et al. (2018), Moreno et al. (2016), Münster et al. (2022), Ordoñez and Rahe (2013), Sumter et al. (2021) and Van Doorsselaer (2021)
The involvement of designers/architects in the different stages of a product/building lifecycle	Debacker et al. (2017), Dokter et al. (2021) and Galle et al. (2015)
Material selection during the design process	Cambier et al. (2020), De los Rios et al. (2017), Dokter et al. (2021), Kanters (2020), Lilley et al. (2019), Ordoñez and Rahe (2013)
Current regulations and policies	Dokter et al. (2021), Moreno et al. (2016), Münster et al. (2022) and Van Doorsselaer (2021)

Appendix 2

Table A2 Correlations between experienced challenges, needed knowledge, and organisational changes

		Organisational changes						
		Dedicated circular economy expert/ team appointed	*Compiled written documents and guidelines*	*Changes to the services we offer*	*Internal education circular design*	*Development of methods, strategies and tools*	*New networks and collaborations*	*Nothing has changed in our organisation*
Challenges	Business aspects and financial feasibility	–0.143	0.000	0.068	0.066	0.033	0.098	**–0.280***
	Material selection	**–0.257***	–0.179	–0.206	–0.103	–0.153	–0.153	–0.050
	Considering the user–perspective	0.004	–0.109	–0.021	–0.163	–0.035	–0.212	**0.333****
	Stakeholder collaboration	0.080	0.171	0.194	**0.240***	–0.077	0.108	–0.022
	Involvement in product/ building lifecycle	–0.047	0.000	–0.089	–0.043	–0.021	–0.021	**0.275***
	Current policies and regulations	0.203	**0.282***	**0.255***	0.022	0.089	**0.258***	0.007
Knowledge	Theory about the circular economy	–0.097	–0.140	–0.070	–0.058	**–0.215***	–0.142	**0.214***
	Stakeholder management and collaboration	**0.207***	**0.206***	**0.239***	**0.346****	0.132	0.096	–0.147
	Economic assessment methods	0.052	0.089	–0.010	**0.286****	**0.252****	0.033	–0.113

*$p < 0.05$; **$p < 0.01$.

Significant correlations (at $p < 0.01$ and $p < 0.05$) are marked in bold.

Table A3 Correlations between challenges and needed knowledge

		Knowledge							
		Theory about the circular economy	*Material knowledge*	*Environmental impact assessment methods*	*Stakeholder management and collaboration*	*Business and financial knowledge*	*Economic assessment methods*	*Case studies and examples of circular design*	*I have sufficient knowledge*
Challenges	Estimating environmental impacts	–0.048	0.048	**0.305****	0.175	0.006	0.166	–0.052	–0.122
	Business aspects and financial feasibility	–0.018	0.018	–0.098	0.147	**0.343****	–0.017	0.049	**–0.280***
	Material selection	0.159	**0.238***	0.084	**–0.361****	–0.004	–0.081	–0.045	–0.087
	Local context	**0.237***	**0.273***	0.033	–0.082	0.114	0.017	0.081	0.206
	Limited willingness of companies	–0.005	0.133	–0.143	0.120	–0.168	0.035	**0.280***	–0.140

*$p < 0.05$; **$p < 0.01$.

Significant correlations (at $p < 0.01$ and $p < 0.05$) are marked in bold.