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Stakeholder perceptions on implementing design for disassembly and standardisation for heterogeneous construction components

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Abstract

The reuse of construction components is considered as a higher value process in a Circular Economy (CE) than recycling. However, this is not yet widely adopted as many barriers still prevent the successful integration of the concept. The ISO20887 standard advocates that the implementation of construction standards will benefit circular reuse. Yet, these standards still need to be developed. To better understand the views of the construction sector, a survey was sent to the network of the Green Deal on Circular Construction (GDCC), led by Circular Flanders. The survey (number of recipients = 629, response rate = 16%) investigates the current implementation of Design for Disassembly and the reuse of construction components. Additionally, it investigates the respondents' view on how a further morphological standardisation of components and connections, as well as standardisation of procedures can facilitate this reuse of construction components. The result is a concrete set of action points and corresponding actors who need to take responsibility. The stakeholders point out that there is no legal framework for component reuse. Yet, this framework can only be created through their largescale cooperation to create the needed construction standards that will truly enable the circular reuse of components.

Keywords

Circular economy, design for disassembly, systems thinking, standardisation, waste management, reuse

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Highlights

- Stakeholders' perception of needs and barriers to construction component reuse
- A legal framework for construction component reuse is necessary but missing
- Action points for the standardisation of components and procedures are identified
- Stakeholders need to elaborately cooperate to take up identified action points

Introduction

Construction, renovation and demolition generate large amounts of waste every year. In 2016, the European Union was accountable for 924 million tonnes of construction and demolition waste, which represents 36% of the annual solid waste production in the EU (López Ruiz et al., 2020). Additionally, annual material extraction is quickly rising, tripling between 1970 and 2015 from 26.7 to 84.4 billion tonnes of extracted materials per year (de Wit et al., 2018). Furthermore, the construction sector is, with a global stake of 35%, responsible for the largest portion of waste to landfill (Ajayi et al., 2016). In this regard, the Roadmap to a Resource Efficient Europe, published in 2011, estimates that the construction sector has an influence on 50% of the extracted materials (Herczeg et al., 2014). The concept of a Circular Economy (CE) was proposed as a solution for the abovementioned problem (D'Amato et al., 2020). The essence of the CE can be brought back to the 4R's – Reduce, Reuse, Recycle, Recover – signifying the desired order of the value retention of products and materials, and this on three levels – the micro-, meso- and macro-scale

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(Anastasiades et al., 2020; Kirchherr et al., 2017). A lot of research in the field of circular construction has focussed on materials recycling (Akanbi et al., 2018; Gálvez-Martos et al., 2018; Ghisellini et al., 2018a, 2018b; Huang et al., 2018; Ibrahim, 2016; Jiménez-Rivero and García-Navarro, 2017; Mulder et al., 2007; Nußholz and Milios, 2017) or more explicitly recycling through reverse logistics (Ahmed and Zhang, 2021; Chileshe et al., 2018; Hammes et al., 2020; Li et al., 2018; Wijewickrama et al., 2021). Improving the environmental profile of construction materials and components through the incorporation of waste streams from other production processes has also gained attention (Asim et al., 2021; Carvalho et al., 2014; Marvila et al., 2021; Mendes et al., 2019; Mohan et al., 2021). However, the reuse of construction components is considered as a higher value process in a CE and is of particular importance, because it is environmentally more beneficial than recycling materials (Assefa and Ambler, 2017; Barriball and While, 1994; Cruz Rios et al., 2019; Joensuu et al., 2022; Xia et al., 2020). Several authors (Anastasiades et al., 2021; Cruz Rios et al., 2015; Densley Tingley et al., 2017; Finch et al., 2021; Iacovidou and Purnell, 2016) have investigated and discussed the barriers of reusing construction components. An elaborate example is provided in the research of Rameezdeen et al. (2016), as shown in Table 1.

Table 1. Barriers in order of significance as identified by Rameezdeen et al. (Rameezdeen et al., 2016).

Rank	Major barriers
1	Regulatory environment
2	Additional costs involved
3	Lack of recognitions in construction supply chain
4	Extra effort involved
5	Financial risks associated with reverse logistics
6	Contractual obligations
7	Lack of attention to design for reverse logistics
8	Lack of support from consumers
9	Workplace, health and safety risks associated with reverse logistics
10	Lack of facilities and technology
11	Resistance to change
12	Lack of information sharing

Van den Berg et al. (2020) observed that an economic demand for dismantled components is an important condition to allow for reuse (van den Berg et al., 2020). In this regard, the recently published ISO-20887 (International Organisation for Standardisation, 2020) standard states that applying the principles of design for disassembly (DfD) will support the evolving concept of a circular construction sector, defining the DfD approach as an 'approach to the design of a product or constructed asset that facilitates disassembly at the end of its useful life in such a way that it enables components and parts to be reused, recycled, recovered for energy or, in some other way, diverted from the waste stream'. It is advocated that the demand for dismantled components can be raised through the use of standardised construction components and standardised reversible connection systems (International Organisation for Standardisation, 2020). However, Anastasiades et al. (2021) point out that there is a severe lack of standards, both on component level (attested by (Finch et al., 2021)) and on procedure level, that can mitigate the barriers to reuse construction components. Hence, these still need to be developed, preferably involving all construction stakeholders – designers, contractors, researchers, manufacturers, governments – as they need to support such standards that effectuate the circular reuse of construction components (Anastasiades et al., 2021). This research investigates standardisation from the perspective of all construction components for stakeholders in Belgium through a survey. The framework for the questionnaire is shown in Figure 1.

This graphic representation is translated into the following research questions:

Heterogeneity + DfD: What is the current status on the implementation of DfD and reuse of components? This includes the stakeholders' needs and barriers concerning the matter.

Standardisation: What is the stakeholders' perception on morphological standardisation of construction components and connections to effectuate DfD and reuse of components? This includes the standardisation of different dimensions characterising construction components, as well as connections.

What is the stakeholders' perception on the standardisation of procedures to effectuate DfD and reuse of components? This

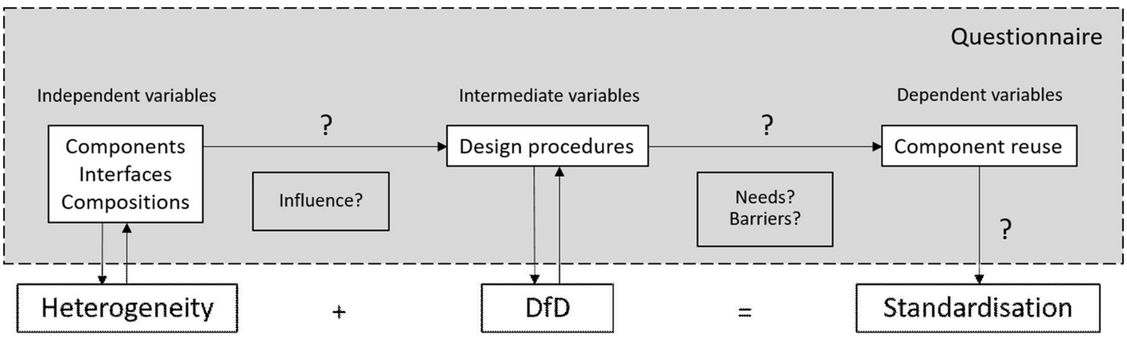

Figure 1. Framework for the questionnaire.

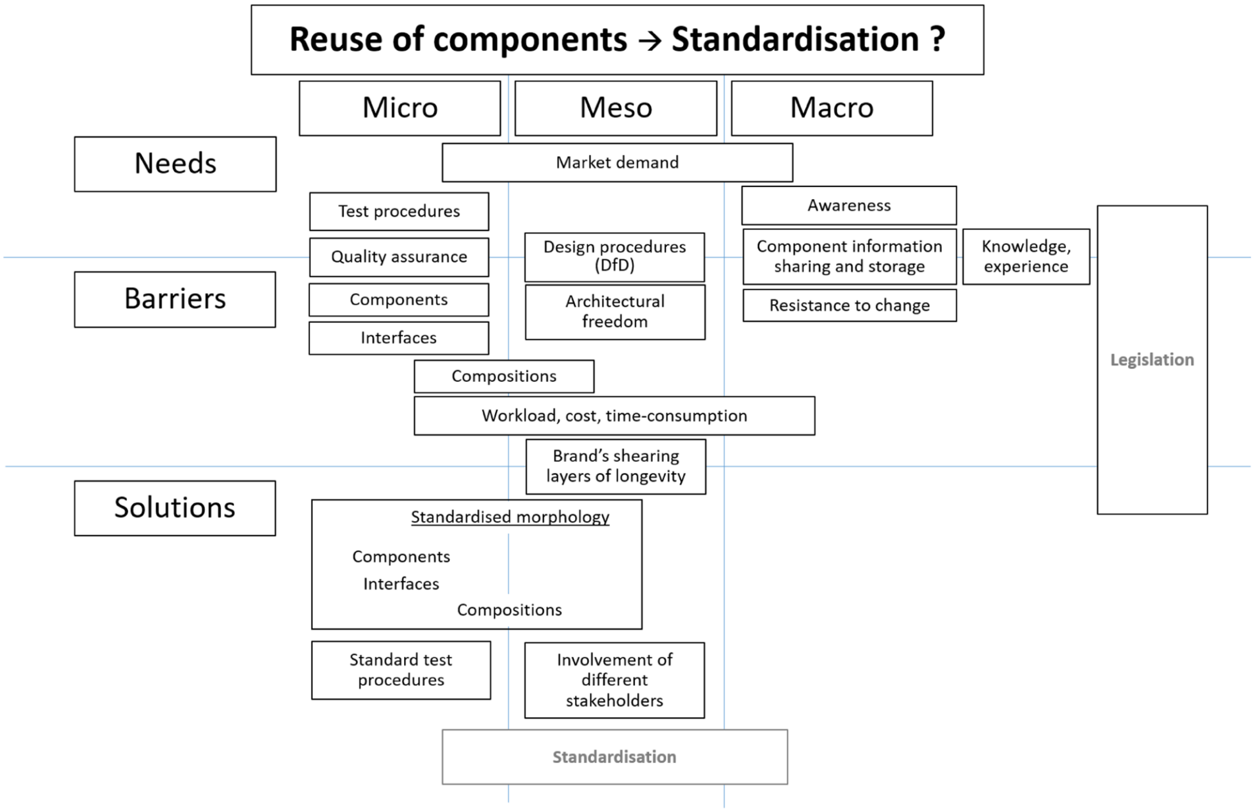

Figure 2. Overview of the research topics and their interconnectivity.

includes cooperation between stakeholders, information sharing and certification of reused components.

In the following sections, first the composition and distribution of the survey are explained. Subsequently, the results are thoroughly discussed and finally, the main findings are recapitulated in the conclusion.

Materials and methods

The necessary construction standards to make circular reuse of components feasible are investigated through an extensive questionnaire which can be found in Supplemental Appendix A. The questionnaire contains three types of questions: multiple choice questions, open-ended questions and Likert scale questions. Preston et al. indicate that a 7 to 10 point Likert scale offers more reliability than a lower point Likert scale (Preston and Colman, 2000). Furthermore, Joshi et al. clarify that a symmetric scale is desirable in order to provide independence for respondents to choose any response in a balanced and symmetric way (Joshi et al., 2015). Therefore, a 7-point Likert scale is chosen in this questionnaire.

The questionnaire was composed using the guidelines prescribed by Fanning (2005). First of all, it is important to determine the purpose of the questionnaire. Subsequently, the research topics, concepts and content of the questionnaire need to be defined (Fanning, 2005). For our questionnaire, these are visualised in Figure 2. This matrix organises the needs, barriers and solutions in the rows according to the three levels of the CE – micro, meso and macro – in the columns. This allows to identify overlaps of certain aspects.

Finally, Fanning prescribes several guidelines with respect to the format of the questionnaire. Following these, the questionnaire consists of four parts: ecological awareness, experiences, future integration and credentials. Each part is preceded by an introductory text to clarify the questions and the topics they deal with. The first, small question set investigates the ecological awareness of the construction stakeholders. The main purpose of this part is to trigger the participants' interest and to orient their attention. Note that the participant's actual answers here are insignificant for the rest of the study. The second question set is designed to obtain information regarding the stakeholders' past experiences with the reuse of components and DfD. The third question set focusses on the necessary conditions to facilitate the further integration of construction standards. The respondents' opinions are asked on the integration of construction standards from a practical, economic and technical point of view. In the final part, respondents are asked to provide their credentials. The goal of these questions is to determine whether different personal factors lead to different opinions. These personal questions are placed at the end of the survey, as suggested in the literature (Fanning, 2005).

To divide construction components into clearly defined categories, Brand's shearing layers of longevity (Brand, 1994) are consistently integrated throughout the questionnaire. The latter is designed to investigate for which layers standardised components have been used in the past and for which layers there is potential for future standardisation. Additionally, the questions differentiate between components, interfaces and compositions as suggested by Vandenbroucke and Brancart (2020), who described the

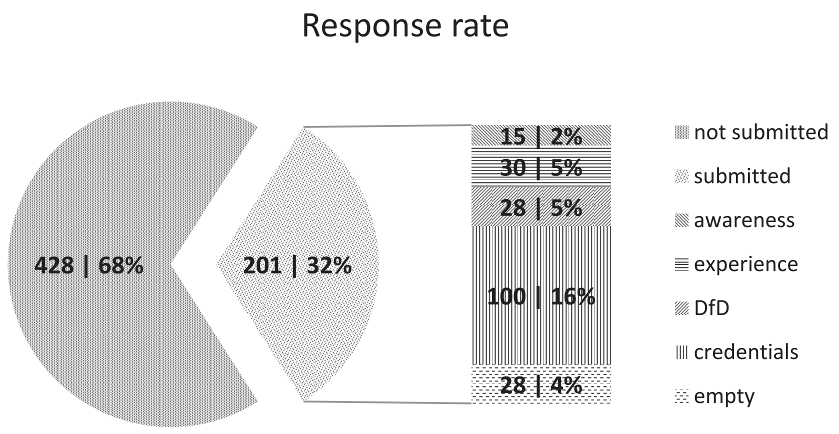

Figure 3. Response rate of the survey, broken down according to the sections where respondents stopped.

desirable properties to allow the disassembly and reuse of components in practice (Vandenbroucke and Brancart, 2020).

The questionnaire was compiled in the survey tool Qualtrics (Qualtrics, 2022). Since the questionnaire contains advanced questions regarding the research topics, the target audience needs sufficient knowledge in the field of circular construction. Therefore, the questionnaire was distributed among the 629 members of the Green Deal on Circular Construction (GDCC) led by Circular Flanders (OVAM, 2022). Since the GDCC is a Flemish project, the questionnaire was distributed in Dutch, in order to avoid language barriers. Of all addressees, 201 people have returned the forms. However, not all submissions were complete, and some were even completely empty. The full overview is shown in Figure 3. One hundred respondents completed the full survey until the last question set, the credentials. Hence, the response rate for the complete questionnaire is 16%. The distribution of stakeholders who completed the survey is shown in Figure 4.

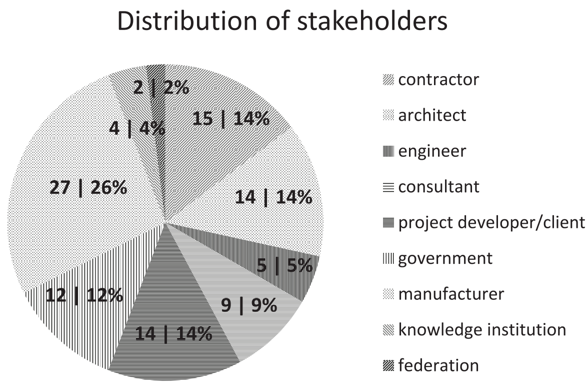

Figure 4. Distribution of stakeholders who completed the survey.

Results and discussion

The results of the survey are shown after each question in Supplemental Appendix A. The questionnaire starts with a question set regarding the ‘ecological awareness’ of the participants. The results show that the respondents are aware of the problematic discrepancy between the amount of excavated raw materials, construction waste and recuperated, reused components. However, according to the respondents’ perception, industrial ecology is not an important factor in the current construction industry. If anything, this means that the construction sector still has a long way to go in terms of shifting towards a true circular construction industry (attested in Adams et al., 2017; Jones and Comfort, 2018).

In the following subsections, the results of the questionnaire are summarised and interpreted in order to answer the different research questions as defined earlier: current status on the implementation of component reuse and DfD; morphological standardisation of components; standardisation of procedures.

Current status on the implementation of component reuse and DfD

The first large section of the survey investigates the respondents’ experience with component reuse and DfD. Importantly, 107 respondents have experience with component reuse (question II.3) and 61 with DfD (question II.5). This is a first good indication for their credibility. Clients and the design team seem to have the largest impact on the decision to reuse components (question II.3e) and to apply DfD (question II.5f). Interestingly, the reuse of components did not cause any large problems (question II.3b) and the reusability test was largely limited to a visual inspection (question II.3h) executed by the design team or contractor (question II.3g). When given the barriers to reuse as identified by Rameezdeen et al. (2016), the respondents (question II.4) identified the lack of regulations and additional costs as the major barriers, followed by time investment. This is in line with the findings of Rameezdeen et al. (2016). However, Rameezdeen et al. (2016) also found that lack of recognition in the supply chain and component availability are major barriers (Rameezdeen et al., 2016), whereas these score only slightly higher than the neutral 4 in the survey results. Additionally, respondents were asked in an open question to specify the challenges they personally experienced (question II.3b). Here, the most mentioned barrier is logistics, both in terms of transportation of reusable components and their temporary storage. Often the technical characteristics (e.g. thermal properties and their dimensions) of the components do not meet contemporary standards anymore which complicates their reuse. The extra time investment needed, damages occurring during disassembly – as the current building stock is not designed and constructed for disassembly – resulting in a shortage of components on site, the higher cost and no quality assurance also rank highly.

Applying DfD seems rather independent from the construction's predicted service life (questions II.5a). Oddly, it was less applied for temporary constructions. Also interesting is that it was less applied for industrial buildings than for offices, residential buildings and schools (question II.5g). No respondents mentioned the integration of DfD for civil constructions. The main reasons to apply DfD are the reusability of components and adaptability to new functions (question II.5h). Of course, the barriers to reuse remain. Given that the regulatory environment is the highest ranked barrier, it is no surprise that only 11% of the respondents indicate that no further legislation is needed (question III.26). Additionally, of the respondents who believe further legislation is needed, 57% indicate that national governments should wait for European legislation, whereas 43% indicate that governments should already implement national legislation. Since the construction sector has a great influence on material extraction (de Wit et al., 2018; Herczeg et al., 2014) and the amount of waste to landfill (Ajayi et al., 2016), more circular construction principles could make for a drastic decrease of the construction sector's ecological footprint. However, the absence of a legislative framework within which stakeholders can operate is perceived as a large barrier preventing circular reuse of components. Hence, it is important that governments take on their responsibility.

Respondents were asked to indicate from a list of construction components, arranged according to Brand's shearing layers of longevity (Brand, 1994), which components they have reused in the past (questions II.3a) and for which components they have applied the DfD approach (question II.5b). Interestingly, the results from both lists do not fully correspond. Tiles are often reused, presumably for their aesthetic properties, but are rarely placed following DfD principles. On the other hand, cladding cassettes are rarely reused, but often placed allowing disassembly. A last example are timber and steel elements which are often reused and also placed taking DfD into consideration. This discrepancy may indicate that in the future more components can be reused, whereas they would have ended up as waste in the past.

From the respondents' answers, it appears that many types of components can be reused and can be constructed for disassembly. Yet, there are still many barriers that need to be resolved before it becomes common practice. The most important barrier being the lack of a legislative framework for the reuse of components within which the construction stakeholders can navigate safely and responsibly.

Morphological standardisation

Polesie (2013) indicates that contractors often perceive standardisation of components, in order to benefit future reuse, as a threat. Their main concern is that standardised components will diminish the uniqueness of construction projects (Polesie, 2013). In this respect, Anastasiades et al. (2021) advocate that in order to ensure project uniqueness, further morphological standardisation should allow for enough architectural freedom. The respondents of the survey are, with a mean value of 4.28 on a seven-point Likert scale, rather neutral when it comes to the statement that morphological standardisation of components will restrict the architectural freedom (question III.10). A break-out according to function shows that contractors, consultants, project developers and manufacturers think architectural freedom will be reduced (mean value higher than 4.50). Interestingly, designers, the government and academic institutions are not at all concerned about this (mean value under 3.50). This may indicate that Polesie's (2013) observation is still valid, but also that the contractors' concern about project uniqueness is probably not well-founded. Respondents do believe that morphological standardisation will simplify the design, manufacturing and execution phase, and reduce the time investment and errors in each phase (questions III.1–9).

In the following, the findings for the morphological standardisation of components and connections are separately discussed.

Standardisation of components. The ISO20887 states that standardised construction components will accommodate circular reuse, since components with standard dimensions can be purchased with greater ease (International Organisation for Standardisation, 2020). The respondents also attest this in the survey (question III.11). The respondents were also asked to rate the feasibility of implementing morphological standardisation for different components in order to benefit their reuse in the future (question III.12). For most components, respondents indicate that further morphological standardisation is possible and desirable. Only few components score under the neutral 4. Mostly, these concern components with glued connections, hence components with an inherent limited reusability. As all standard deviations vary between 1.27 and 1.97, hence lower than 2, the results can be considered representative (MediaLab, 2022). Respondents agree (question III.13) that a further morphological standardisation is possible for all questioned dimensions: profile sections, spans, storey height and connections. Importantly, respondents declare the further trajectory for morphological standardisation to be a shared responsibility of designers, manufacturers and the government (question III.21).

To make circular reuse feasible, components should be manageable, durable and designed in accordance with a dimensional standard (Vandenbroucke and Brancart, 2020). Respondents are (question II.5c) rather neutral about the statement that components should be manageable, whereas they agree that components should be durable and designed according to a dimensional standard. In addition, components should be organised into layers with a similar expected technical and functional lifespan, whereby the layers with a shorter service life are easier to reach (Brand, 1994; Vandenbroucke and Brancart, 2020). Vandenbroucke and Brancart (2020) even go further by stating that components should be independent and thus allow disassembly without removing adjacent components. Additionally, components are preferably prefabricated (Vandenbroucke and Brancart, 2020). Respondents agree with the latter and that layers with a shorter service life should be easier to reach. However, they are more neutral about components being independent. Indeed, it is more important that components can be disassembled and they are organised according to Brand's (1994) shearing layers of longevity. If these criteria are met, only few components need to be removed in order to reach a certain other component.

Standardisation of connections. To allow components' disassembly, Vandenbroucke and Brancart (2020) state that the interfaces, that is, the connections between different components, should be simple, reversible without damaging the component or the connection and designed to allow quick assembly and disassembly (Vandenbroucke and Brancart, 2020). The respondents agree with these statements, but they are rather neutral when it comes to the connections' simplicity (question II.5c). However, the social benefits of DfD are high, as the increased labour-intensity of deconstruction brings opportunities for creating jobs for unskilled workers (Cruz Rios et al., 2015). Yet, this is only true if the connections are simple.

The ISO20887 standard advocates that universal connection systems should be utilised (International Organisation for Standardisation, 2020). In this context, the participants agree that standardised connection systems are a key factor to allow disassembly and reuse of components (question III.14). Most of them even believe that universal components with universal connection systems are the best approach (question III.14a). Connection systems are most relevant for manufacturers, yet their responses follow the same trend: 63% (10) prefer universal components and universal connections, 31% (5) propose manufacturer-dependent components with universal connections, and only 6% (1) prefer manufacturer-dependent components and connections. However, presently, components that are designed for disassembly can in almost half of the cases not be reused with connection systems from other manufacturers (question II.5e). This designates that the further development of universal connection systems is an important condition yet to be fulfilled to make reuse of components feasible. The responsibility to develop these universal connection systems seems to be shared by the complete construction chain (question III.14aa).

When it comes to steel and wood, there are plenty of connections that can be considered to design a building for disassembly. A critical material when it comes to DfD is concrete as it is usually designed and constructed with irreversible, plastic joints. In addition, Wahlström et al. (2020) state that concrete accounts for 42% of building materials used in construction. This fact, combined with the high carbon footprint linked to cement, means that reuse of concrete components could make a great ecological difference (Wahlström et al., 2020). The participants with knowledge regarding concrete were divided when asked whether reversible connections for concrete components would be more costly (question III.15). However, there seems to be a consensus that a reduced execution time could make up for these additional costs (question III.15a). This result indicates that further research regarding reversible connection systems for concrete elements also offers great potential. Since concrete elements are in most cases load-bearing, further research should focus on developing reversible connection systems with favourable mechanical properties, in order to compete with plastic joints.

The ISO-20887 standard advocates that the DfD approach will benefit circular reuse (International Organisation for Standardisation, 2020). Additionally, DfD and reuse of components not only saves energy and raw materials, but could also lead to considerable financial savings (Hosseini et al., 2014; Swift et al., 2015). On a critical note, Andrews (2015) believes that designers must change their thinking and practice and should lead the development of the CE (Andrews, 2015). However, respondents (question III.21) believe that the development and introduction of further morphological standardisation for the benefit of component reuse is a shared responsibility of designers, manufacturers and governments. Additionally, Andrews (2015) indicates that some designers are reluctant to engage with sustainable design (Andrews, 2015), a barrier also identified by Rameezdeen et al. (2016). However, the respondents are less concerned about this barrier (question II.4).

Interestingly, nearly half of the respondents indicate that adapting to a new method of building with standardised and reused components would not require a large investment from the company they work for (question III.22). About 59% of the remaining participants indicate that the investment includes mostly training of employees. For the remainder, the required investments will also include new equipment. Interestingly, 65% of manufacturer respondents indicate that no large investments will be required, meaning they are ready to make the shift. Presumably, again the missing legal framework is the main barrier. Additionally, most participants are prepared to make the necessary investments (question III.23), mostly based on principles and values regarding sustainability and futureproofing (question III.23b). All these indicate that the industry has evolved in the right direction, since Hosseini et al. (2014) observed exactly the opposite.

In summary, it is clear that a lot of research and agreements are still at hand to truly move towards standardised connections and components. This will be a complex process, as indicated by the respondents, because they need to cooperate more elaborately than ever. Again, the implementation of regulations will be key to accelerate this transition.

Standardisation of procedures

Apart from a morphological standardisation of components and connections, also a standardisation of procedures will be required to effectuate the reuse of components and to generally evolve towards a truly circular construction sector. Following the barriers identified by Rameezdeen et al. (2016), the investigated topics are the design process, information sharing, and work, health and safety risks.

Stakeholders' involvement in the conceptual design stage. Abdul-Kadir and Price (1995) state that most vital decisions are made during the conceptual design phase of a project, and that the success of the design, construction and post construction phases are highly dependent on these vital decisions in the conceptual design phase (Abdul-Kadir and Price, 1995). Yet, designing structures is still too often done in the traditional way: the architect focuses primarily on the overall design and shape of a construction and the structural engineer is only called in at a later stage to assure the overall stability of the structure (Christensen and Klarbring, 2009). Furthermore, Heravi et al. (2015) found that designers are less involved in the conceptual design phase than project developers and project managers. Additionally, they revealed that the contractors' involvement in the conceptual design phase of projects was considerably lower compared to other stakeholders (Heravi et al., 2015). In this context, a third of the respondents confirm that engineers are not often involved in the conceptual design stage (question II.6). When they are involved, it usually concerns large, challenging projects and/or civil, infrastructural projects (question II.6a). The majority of the respondents do not believe that engineers should be more involved during the design phase of a project (question II.7). In general, respondents mention (question II.7a) that optimisations of design concepts should be made as early as possible, in order to avoid difficulties during advanced project stages and to optimise material usage. According to the respondents this can only be achieved when the full construction team cooperates from the beginning. In the context of a circular construction sector, respondents mention that a structural engineer's involvement is important to design the structural layer in a way that allows disassembly of structural components at the end-of-life stage. Furthermore, the other layers are attached to the structural layer, so delayed changes in this layer could lead to changes in other layers, which might be in conflict with circular concepts.

Nearly half of the respondents answered that contractors are not often involved in the conceptual design stage (question II.8). In line with the involvement of engineers, contractors are most likely to be involved in challenging projects (question II.8a). However, contractors are less frequently involved in civil, infrastructural projects. Again, the majority of the respondents believe that contractors should be more often involved in the design phase of projects (question II.9). The main reason (question II.9a) is their practical knowledge regarding construction methods, which is believed to be of vital importance, also in the conceptual design phase. In the context of circularity, the most important contribution of a contractor is providing knowledge about whether or not the reuse of components or implementing the DfD principle is technically and economically feasible and how it could be reasonably achieved.

The literature confirms that the involvement of designers (architects and engineers) and contractors in the conceptual phase offers great benefits in terms of the number of necessary design iterations throughout the construction process (Hamidavi et al., 2020; Heravi et al., 2015; Mujumdar and Maheswari, 2018). Consequently, the results indicate that besides standardised, universal connection systems and morphologically standardised construction components, a shift in the main stakeholders' involvement during the design phase is also an important issue. On a side note, it is worth mentioning that the ISO20887 standard advocates that circularity indicators should be used to determine the advances made in the transition to a circular construction sector (International Organisation for Standardisation, 2020). Similarly, these indicators could also be used to measure the effect of the earlier involvement of stakeholders, like engineers and contractors, on the efficiency and the circularity of a construction project.

Information management. In order to reintroduce dismantled construction components into the market, it seems important to store and manage information about each individual component (Guy et al., 2005). In this context, the absence of a standardised system for managing this information, is seen as a barrier preventing the reuse of components. The respondents indicate that materials passports and Building Information Models (BIM) are most suited for this information management (question III.16). In addition, the majority thinks that (question III.16a) the building owner should be responsible for the information management, followed by project developers, manufacturers and public databases. The latter three are on a par with each other. Hence, most participants believe that the client is responsible. On a critical note, this emphasises the importance of a standardised, open format that does not continuously change over time. If not, after a few years the result may be a lot of inaccessible information, wasted time and wasted work. After all, building owners do not use BIM and materials passports themselves and are not able to continuously update building information into new formats, unless this is done automatically in a public database. Heinrich and Lang (2019) point out that it is of primary importance that the materials passport contains all relevant information that defines the residual value of a construction component. More importantly, they state that these data should be shared in a centralised platform, accessible by all stakeholders (Heinrich and Lang, 2019).

Reuse certification and warranty. Lack of information about salvaged components makes it difficult to make safe assumptions regarding their quality and safety to reuse them (Durmisevic, 2018). Testing, both destructive and non-destructive, can also be standardised, thus taking away these risks for designers (Akbarnezhad et al., 2014; Densley Tingley et al., 2017; Hobbs and Adams, 2017). Unfortunately, such standards have not yet been drafted (Anastasiades et al., 2021) and this is also clear when reviewing the participants' responses. The respondents are divided on where the technical assessment of dismantled components should be performed (question III.17). Participants who indicated that it is component-dependent, explain (question III.17d) that complex components potentially need more assessment and maintenance compared to simple components. Also, for each type of component, the construction team should look for the logistically most logical and efficient solution. The respondents who answered that manufacturers should perform the assessment, explain (question III.17a) that they know their product best. Furthermore, the manufacturer is best suited for issuing a warranty on reused components. The most mentioned reason for an external organisation to perform the technical assessment (question III.17c) is their neutrality and independence.

Respondents already brought forward the importance of logistics, and indeed, the intermediate storage of components is also an issue that needs to be considered along with testing the components on their reusability. Respondents point out (question III.18) that manufacturers and external parties, like brokers, are the preferred stakeholders to assist in this intermediate storage.

According to the respondents, the stakeholders that should take on a leading role in the standardisation of the technical assessment of potentially reusable components (question III.19) are manufacturers and external parties. To a lesser extent, the government and designers are also suggested to take the lead. Furthermore, most respondents indicate that (question III.20) the manufacturers should take the responsibility for the reused components. Alternatively, a shared responsibility between the different stakeholders and an additional insurance are also brought forward.

The survey points out that a lot of work still needs to be done in order to create the legal framework that the different construction stakeholders so desperately need. Yet, the respondents are positive (question III.25) that in the next 10 years, the construction industry is able to make a complete shift to DfD and the corresponding reuse of components. However, respondents conclude by emphasising that it will only be possible (question III.24 and III.27) when the much-needed legal framework has been established. Additionally, they emphasise that the economic feasibility needs to be safeguarded, and a major mind-shift towards the reuse of components needs to be made.

Conclusions

The needs and barriers for the implementation of construction standards, with the purpose of enabling circular reuse of components, were investigated by means of a survey. This survey consists of an extensive questionnaire which was distributed amongst the 629 members of the GDCC. The response rate for the total survey was 16%. There is a consensus both in literature and amongst the respondents about the barriers to reusing components. The significance of this investigation over previous research is that it led to the identification of several concrete action points and actors that should engage in them. These are shown in Table 2. The most significant action points, brought forward by over 80% of the respondents, are highlighted in bold. Thus, in order of importance, these should be prioritised for further research.

Table 2. Summary of action points.

Main subject	Action point	Description	Actors
Morphological standardisation	Standardisation of components	Most components can be morphologically standardised in terms of sections, longitudinal and transversal dimensions. This can coincide with a standardisation of spans and storey heights	Designers Manufacturers Governments
	Standardisation of connections	**Universal connection systems that ease the interchangeability of components and allow for true DfD**	**Designers Manufacturers Governments**
Standardisation of procedures	Stakeholders' involvement in conceptual design phase	The involvement of architects, engineers and contractors in the conceptual design phase reduces the number of design iterations and results in a more efficient and circular construction	Designers Contractors
	Information management	**Materials passports and BIM are perceived as the most suited means to store the necessary information, but the format is yet to be standardised**	**Designers Manufacturers Contractors Governments**
	Test procedures	**Reclaimed components should undergo a certain testing in order to guarantee their quality and safety to reuse them. A procedure should be set out for testing components on their reusability. This test procedure should accommodate the specificity of different components as well as the condition they are in**	**Manufacturers External parties**
	Warranty	**The reuse of components comes with a responsibility to guarantee the quality and safety to reuse them. After adequate testing, the reused component should thus be certified with a warranty**	**Manufacturers Insurance companies**
	Logistics	A clear strategy for intermediate storage of reusable components needs to be thought out. This strategy will be closely coupled with the test procedure for reclaimed components	Manufacturers External parties
General	**Legislation**	**There is no legislative framework for the reuse of components. This should be largely solved when all previous action points are formalised into this legislative framework**	**Government**

If anything, this investigation clearly points out why the critical aspect 'standardisation to enable component reuse' has not been addressed yet. The summary in Table 1 dramatically shows how many stakeholders need to cooperate in this process. Moreover, they need to cooperate in a way they are not used to and have never done before. The stakeholders point out that there is no legal framework for component reuse in which they can navigate. Yet, this framework can only be created through their elaborate cooperation to transition from heterogeneity to standardisation in order to truly enable the circular reuse of components.

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Supplemental material

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