Circularity challenges and solutions in design projects: An action research approach

Conference Paper · September 2019

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CIRCULARITY CHALLENGES AND SOLUTIONS IN DESIGN PROJECTS: AN ACTION RESEARCH APPROACH

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Design professionals need to fundamentally rethink their design practices in light of a transition to a circular built environment. Traditional design approaches result in static buildings that poorly adapt to changing user needs and leave conventional demolition as the only viable end-of-life option, which results in significant amounts of waste. A 'circular' model of production is currently worldwide promoted as an alternative, but little is known about how circularity thinking may be implemented in design projects. This research therefore aims to explore how circularity challenges can be better understood while attempting to solve them in an actual project. An action research approach was adopted to study a pioneering renovation of a primary school building in the Netherlands. Circularity challenges were observed during 17 design meetings with different design disciplines and client representatives over a six-month period. A Circular Project Model was consequently developed to provide an overview of linear and circular material flows. The use of this model during a workshop with 22 designers showed that the practitioners could identify and exemplify key circularity challenges in design, such as building code compliance, complexity of buildings and ease of demolition. It also helped them in finding solutions for some of the challenges, including assessing reuse potentials of materials in existing buildings, designing with future disassembly and reuse in mind and promoting commitment among clients and other stakeholders. This action research study hence offers new opportunities for researchers and practitioners to understand and solve circularity challenges in design projects.

Keywords: action research, circular economy, design management, renovation

INTRODUCTION

As part of an emergent transition towards a circular economy, design professionals need to fundamentally rethink their design practices. The construction industry is recognized as one of the most resource intensive and polluting industries (Cheshire, 2016). One of the root causes of the significant amounts of construction and demolition waste associated with the industry is the designers' traditional view of their creations being permanent (Durmisevic, 2006). As a result, most buildings can poorly adapt to changing user needs. New usages do happen though and they "persistently retire or reshape buildings" (Brand, 1994). The designs then typically leave conventional demolition, in which a building is converted into mixed waste, as the only viable end-of-life option. To allow building transformations and recovery practices, researchers have proposed a "circular" model of production that is restorative or regenerative by design (Ellen MacArthur Foundation, 2013; Pomponi

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This paper was presented as a working paper at the ARCOM 2019 Conference, Leeds, UK, 2-4 September 2019. Please contact the authors before citing.

and Moncaster, 2017). Design professionals, however, lack systematic methodologies to help them implement circularity thinking and documented examples of real-world circular design practices are still scarce.

Construction management research has overlooked possibilities to cope with circularity challenges. While issues around energy flows are widely explored, the idea of a circular economy is relatively new in construction (Leising, Quist, and Bocken, 2018). The concept is often simply "depicted as a combination of reduce, reuse and recycle activities" (Kirchherr, Reike, and Hekkert, 2017), but its implications for design appear to be fundamental. One branch of design studies focuses on designing buildings with components extracted from an old building. Gorgolewski (2008), for example, found that designers need additional information to design effectively with recovered components and must be aware of the associated risks, economics and implications to the project. Other design studies focus on designing new buildings so that components can be disassembled and reused in the future (Durmisevic, 2006). Both design approaches pose significant challenges for the project teams, such as the complexity of buildings, low value of materials at end-of-life and a lack of awareness across supply chain parties (Adams, Osmani, Thorpe, and Thornback, 2017). How to deal with such challenges is still poorly understood, which limits the construction industry's eminent transition from the use of new and disposable materials towards reuse.

This paper therefore tries to provide new opportunities to better understand and deal with circularity challenges in design. The next section presents an action research approach to explore the topic. Using data from an actual - pioneering - design project collected over a six-month period, the authors then present a Circular Project Model and reflect on its implementation during a workshop. The paper concludes with insights into possibilities to understand and solve challenges that designers face when trying to implement circularity thinking in their projects.

ACTION RESEARCH DESIGN

This research aims to explore how circularity challenges can be better understood while attempting to solve them in an actual design project. Since implementing circularity thinking in projects represents a complex problem with technical and organizational challenges, a research approach based on engaged scholarship was selected. Engaged scholarship is a form of research that advances both science and practice through engagement of scholars with practice (Van de Ven, 2013; Voordijk and Adriaanse, 2016). The researchers here engaged with practitioners who sought to change 'something' in an actual design project so as to enhance circularity. This study was thus designed as action research, an engaged scholarship type of research that aims at building and testing theory in a real-world problem-solving context. Action research consists of five interrelated steps that researchers perform in collaboration with practitioners (Azhar, Ahmad, and Sein, 2009): I - Diagnosing (identifying research problems); II - Action planning (developing an intervention); III - Action taking (implementing the intervention); IV - Evaluating (assessing the outcomes); and V - Specifying learning (abstracting different types of knowledge).

The action research approach was adopted within the context of an architectural and engineering design project. The project concerns the renovation of a primary school building (which houses two schools) located in the eastern part of the Netherlands. The building has two building layers and a gross floor area of approximately 3,750 m2. Originally constructed in 1978, it does no longer meet the requirements of its users. Cost calculations had shown that replacing the building (through demolition and new-build) grossly exceeded the available budget. It was therefore decided to renovate the current building instead. Together with this planned renovation, ownership of the building would transfer from the local municipality to two separate primary school associations. The researchers decided to collaborate with the architectural and engineering design professionals involved in this project, because the scope concerned a 'circular and sustainable renovation'. Since there are still very few documented examples of actual projects in which circularity thinking has been implemented, this project qualifies for a "unique" (Yin, 2009) case.

In line with the tenets of action research, data was collected during all five research steps. The first mentioned researcher collaborated with several design professionals over the course of the project. He observed 17 design meetings over a six-month period and received minutes of these and 6 other design meetings. About half of the meetings were meant to review a design-in-progress together with the clients; half of the other meetings were meant to discuss design issues between designers, in particular between the architectural and the Mechanical, Electrical and Plumbing (MEP) disciplines. The researcher also collected project data, such as design files, schedules and detailed cost estimations, and he visited the school building twice, photographing building characteristics with a focus on materialization. To plan for 'action', he then developed a Circular Project Model. The first two authors implemented this model in the project through organizing an interactive workshop with design professionals. This workshop was audio-recorded, and the relevant discussions were transcribed verbatim afterwards. The first researcher also discussed and evaluated the action together with the leading design professionals on the day after the workshop. Data analysis consisted of marking, coding and organizing the meeting minutes, transcription and other project documents. All three authors regularly convened to reflect and discuss the different types of knowledge generated during the study. This (one-off) action research cycle ultimately resulted in detailed insights about the design for a planned circular and sustainable renovation.

'CIRCULAR AND SUSTAINBLE RENOVATION' RESULTS

The results are split into five phases, corresponding with the action research cycle.

I - Diagnosing: Inflated ambitions

This study started when the clients and local government decided to change the scope of the focal design project to a "circular and NZEB (nearly zero-energy building) renovation" instead of a maintenance variant. They had earlier determined a direction for the project by investigating and opting for "very sustainable" rather than "default" maintenance - a decision that was mainly motivated by their desire to significantly lower the exploitation costs (i.e. energy bill) of the school building. Meeting minutes dating 1.5 years before the researchers' involvement suggested that the project stakeholders already thought of some initial 'circular' measures, such as 'leasing light', by then. Circularity ambitions were only formalized with the change of scope; the goal became to "design the first (natural) gas-free and circular school" of the Netherlands. These ambitions allowed the design team to acquire some national and provincial innovation subsidies - in particular to realize a disconnection from the nation-wide gas grid. The team assumed the renovation to become "a reference project" and several professional publications and news articles promised likewise.

But translating the inflated ambitions into actual circular design solutions turned out to be challenging. The primary focus of the design team was not on circularity, but on reducing the building's energy consumption through adding a new thermal shell - with new materials. While the design professionals had abundant expertise on energy performance, as observed during several technical discussions, knowledge about the concept of a circular economy was limited - especially within the MEP discipline. The architectural design discipline initially treated the concept mainly as about the "conservation of materials." These designers tried to find new purposes for existing materials available on site. One idea was to reuse gravel façade panels to construct seats for an amphitheatre located at the schoolyard - later the idea was replaced by a proposal to reuse them for a "climate proof" rainwater basin. Some other ideas were: reusing the steel window frames to build a landmark structure demarcating the entrances of the two schools; reusing timber window frames to reinforce the steel roof; and reusing mineral ceiling tiles as insulation material in cavity walls. The MEP design team leader argued that such a view on materials is completely new for his team, even though his designers and engineers felt they are "already working towards sustainability" with a focus on energy. Installations were simply deemed "too old" to reuse.

New opportunities to gain insight in and deal with the circularity concept were thus needed. The leader of the architectural design discipline wanted to "investigate" and "gain more experience" in circular design, whereas the first mentioned author suggested potential for other types of circular design measures during some meetings. It was then collaboratively decided to plan for action and further explore the concept.

II - Action planning: A Circular Project Model

A Circular Project Model was developed to provide insight into (a transition to) circular construction. The authors aimed to integrate theoretical knowledge about the circular economy concept with domain-specific knowledge. As such, guiding principles for developing the model were: (i) the view of construction as a project-based and location-specific practice, (ii) a material flow perspective and (iii) an explicit distinction between new materials, waste and reused materials. Using these three principles, the first mentioned author developed a Circular Project Model (Figure 1) that captures both linear and circular material flows. Linear construction projects comprise flows of new materials that are being transported to a construction site (arrow 1) and waste that is moved away from the site (arrow 2). In circular construction projects, alternatively, materials recovered from an old building are transported to a construction site (arrow 3), materials are recovered and reused at the same site (arrow 4) and/or materials are recovered and transported for reuse in another new building (arrow 5). While traditional, linear projects rely solely on new materials for construction and treat those same materials as (poorly recyclable) waste at the end-of-life stage, circular construction projects ideally keep all materials 'in the loop' through continuing reuse. In practice, however, projects typically consist of a combination of different types of material flows. The developed model can, accordingly, be used to visualize the degree of circularity for any type of project (new-build, renovation or demolition) through adjusting the arrow thicknesses of the relevant material flows.

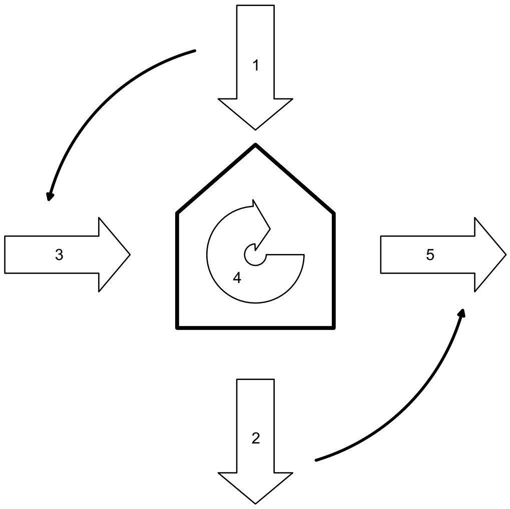

Figure 1: Circular Project Model with large arrows (1-5) representing material flows around a construction project and small arrows indicating a 'transition' from linear to circular practice: 1=new materials; 2=waste; 3=reuse of recovered materials (from an old building); 4=recovery and reuse (from and in the same building); 5=recovery of materials for reuse (in another building)

III - Action taking: A workshop to explore potentials

The Circular Project Model was applied and tested during a collaborative circularity workshop at the architectural firm's office. The first two authors presented the model step-by-step and facilitated a structured discussion about the challenges in circular construction. The workshop was attended by 22 design professionals, including the MEP design team leader. All participants got an A3 paper with the model (and some writing lines) and pens/pencils. Not all design professionals were involved in the focal project: as such, the workshop also served as an intervention to share knowledge and generate awareness about circularity thinking within the firm. The architectural design team leader consequently started with introducing the focal case project, describing problems with the existing school building and some preliminary design solutions. The researchers tried to support this project introduction by distributing photos of the building. They then guided the participants through four steps related to the model, asking them to individually: (i) write down 'typical' types of materials for all five flows; (ii) adjust the arrows' thicknesses to indicate the expected volumes of those flows, (iii) specify the expected end-of-life scenarios for materials flowing to/at the site, and (iv) suggest any design measures to improve circularity. This part of the workshop supported design professionals to individually consider whether (or not) a transition from linear to circular construction practice would be possible. The researchers finally tried to collaboratively develop possible ways of addressing circularity challenges through facilitating a structured group discussion about the similarities and differences between the individual responses.

IV - Evaluating: Overview of circularity challenges

The workshop-based action was effective in identifying circularity challenges in the ongoing design project. The researchers and practitioners found that the project intervention resulted in an overview of linear and circular material flows - and the possibilities and impossibilities for change. This was evidenced by an analysis of the individual workshop forms, the transcribed group discussion and an evaluation with two of the leading design professionals on the day after the action took place. That is, the workshop structured around the Circular Project Model revealed several circularity challenges (Figure 2). These represent aspects of the trade-offs between linear and circular material flows (which typically favour the first).

The workshop participants realized that the great majority of the materials in the renovation project would be new (flow 1 in Figure 1) instead of recovered from other buildings (flow 3). The architect involved in the project explained that they indeed "typically renovate a façade with new timbers and new stucco" and that most materials are thus original. The architectural design team leader then asked the architect whether there would also be a recovered variant available of the proposed timber. While it appeared that had not been seriously considered as an option, the architect hypothesized that the supplier "may be able to give reclaimed timber the same treatment as new ones" so that products would get a similar shade of the desired type of grey. Many other products were also designed as new ones, while several workshop forms suggested that recovered products would be suitable alternatives for typical architectural materials (such as glass, timber, window frames and doors). Regarding the MEP systems, participants doubted whether recovered installations could meet today's higher (energy) requirements. The MEP design team leader said that they work with new products, because "we also need to deal with NZEB design requirements, which forces us to meet certain quality levels. It is then quite counterintuitive to work with relatively old, reclaimed materials." He exemplified this with the rapid adoption of LED technologies, which made previous lighting technologies - and their fixtures - less interesting to reuse. "Of course one can modify the lamp fixtures, but then costs will increase tremendously," he added. The look and feel of materials also influences reuse possibilities for installations. One workshop participant claimed that "for power outlets and switches, one could perfectly use recovered materials, but an architect often prefers a slightly more modern product."

Other challenges concerned the trade-offs between processing materials at the end-of-life stage as waste or recovering them to enable reuse (flow 2 and 5). For some materials, like asbestos, there was no discussion as it is common practice (and/or required by law) to remove such materials. For other materials, there was less consensus. Regarding the floor covering, for example, one participant speculated that it is cheap and easy for a demolition contractor "to simply order a waste container and get it moved away." The MEP design team leader also argued that it is not interesting to consider reuse for many materials: "we looked at the emergency exit signs [for example], but they have outdated icons" which do not meet building code regulations. He questioned again the "added value" of modifying such materials - in this case to prevent waste. Other people suggested that certifications, for example regarding fire safety, are a significant challenge as well: a door may need to be fire resistant for about 30 minutes now, "but it is very well possible that the test method is completely different than 20 years ago." Other materials, on the other hand, appeared to have more reuse potential. "This project has a nice grid size of 2.50 m. I see that as a modular size," explained a BIM modeller. The balustrades that are attached to some balconies may thus be reused elsewhere, "because their sizes are matching so nicely. And perhaps because it is vintage." Another participant thought that the architectural firm could organize reuse at a firm level: "we have a school building [like here] and, at the same time, we have a new-build project for the police [elsewhere], for example. Well, if 30 doors can be recovered here, we may reuse them for the police office." Another added that this implies "that the architect must then already take that into account" during the design process.

The workshop participants finally discussed design decisions for materials that would be reused for the school building itself (flow 4). "I think most materials are reused, because the foundation, floors, walls and the roof are just kept," said one. The design professionals disagreed over whether or not this could be seen as 'reuse' because those respective materials are not changed or moved during the renovation. For the installations, the MEP design team leader argued that the trade-off is "keeping or new" and that it is difficult to reuse products of the existing building. Such difficulties sometimes require creative solutions, as the project's cost estimator illustrated with an example: "we can reuse the window frames to strengthen the steel roof." This is a more feasible solution than reusing them for the new windows again, because in the latter alternative "they need to be cut, they need to be transported away from the site, they need to be repainted and so on." The possibilities and impossibilities of such activities influence the outcome of design decisions.

Hence, the workshop led to the identification of two types of circularity challenges that were exemplified and discussed during the workshop: on one hand is the move from new to recovered materials limited by quality variations, desired service levels, and expectations regarding the look and feel of materials and on the other hand is the move from waste to recovery for reuse limited by the ease of demolition, code compliance, certification issues, (the absence of) modular sizes and (the absence of) related design projects.

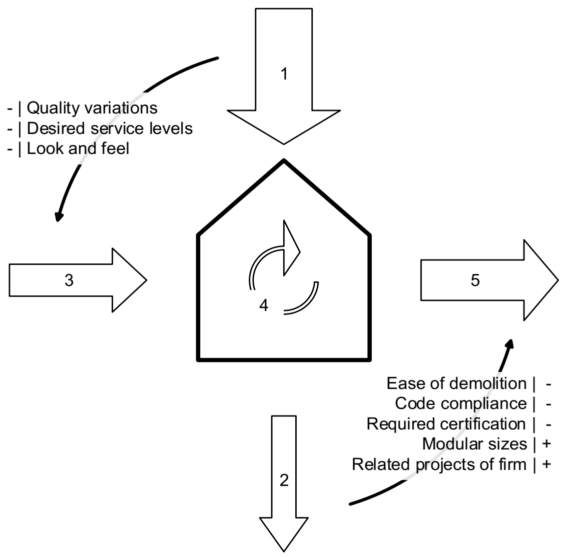

Figure 2: Workshop results structured along the Circular Project Model. Thickness of large arrows indicates the relative expected material volumes (average of collected forms). Identified circularity challenges (negative or positive) are positioned along smaller arrows

V - Specifying learning: Solutions for circularity challenges

The action research generated new scientific and practical knowledge for circularity thinking in design. The workshop was conducted in response to a need to better understand what design measures could be taken to make a project more circular. This yielded an overview of circularity challenges, from which new ideas were generated that tried to solve some of those challenges in the ongoing design project. The researchers thus acquired knowledge about the effects of using the newly developed Circular Project Model in a workshop format, while the practitioners gained insights to solve actual circularity challenges.

The first insight to solve circularity challenges was to assess the reuse potentials of materials in buildings. A BIM modeller suggested during the workshop that "one could make a checklist of the potentials for materials in [his/her] own project regarding reuse." His idea involved organizing information about the volumes and characteristics of materials that could potentially be reused. Parts of the school building's balconies, for example, could be disassembled with ease and may thus be reused in other projects. Another workshop participant built on the idea by suggesting that such a checklist could follow "a format like the Circular Project Model." After the workshop, the architectural design team leader praised the idea and said the firm would "definitely implement it." In the weeks after the workshop, the researchers observed that an intern was indeed tasked to quantify all material flows for the focal school building and visualize them in the model. This measure thus tries to make reuse potential information available for other, related projects of the firm so that they may reuse materials that can be recovered from the focal project.

The second insight to solve circularity challenges was to design with future disassembly and reuse in mind. According to several workshop participants, a key strategy is to design modular structures (with standardized sizes) which can be disassembled easily later. The MEP design team leader said that most installations can already be disassembled and speculated that the firm's challenge was thus simply "to call things differently." He also acknowledged that such a change does not guarantee reuse though; arguing that "after 20 years, I probably do not want to reuse the [photovoltaic] panels any longer." Other practitioners suggested different measures to increase the degree of circularity though. As such, a BIM modeller proposed to use "timber beams that are larger than necessary so they can be cut to size in a new project." Such design measures target circularity by making it easier to recover (valuable) materials during future demolition.

The third insight to solve circularity challenges was to promote commitment for circular design among clients and other stakeholders. During the workshop, the project's architect argued that "the new way of working" can only succeed if the client is also willing to change from linear to circular practice. Another workshop participant then suggested that client commitment must be formalized in the project brief. During one of the focal project's design meetings, for example, it was observed that one of the client representatives argued that "circularity is quite nice, but it should not increase our costs." Other workshop participants expected that clients who are more committed to circular construction practices would also be willing to pay a bit extra to realize circularity ambitions. One practical solution for moving to that situation is to inform clients about the circular economy concept beforehand and then to formalize commitment in the design brief. Designers in the focal project did so after the workshop by presenting cost estimations of several sustainable and circular design alternatives to client representatives and asking them to choose. Seeking commitment can help to overcome challenges related to the expectations regarding quality variations, service levels or the look and feel of recovered materials.

These three insights hence deal with circularity challenges in the ongoing design project. The workshop with the Circular Project Model helped design professionals to become more aware of expected material flows in the focal school building projects - and to reconsider them. While challenges related to building code compliance and certification issues could not be solved (yet), the action still yielded some concrete insights for taking measures with which design professionals can increase the level of circularity in a project.

DISCUSSION AND CONCLUSION

This paper explored circularity challenges and solutions with an action research approach. The construction industry currently faces the grand challenge to move from a resourceful and wasteful mode of production to a circular model. Such a production model tries to close material loops through a combination of reduce, reuse and recycling activities. The implications of circularity thinking for design projects are fundamental yet understudied. This study hence tried to provide new opportunities for understanding and solving circularity challenges.

It firstly contributes to literature by systematically reflecting on a new way to understand circularity challenges in design projects. Since the construction industry is globally only starting to implement the concept of a circular economy in its projects, documented reflections are scarce. Previous studies mainly depended on self-reported challenges (e.g. Adams *et al.,* 2017). The present work complements such studies with qualitative, in-depth insights of actual challenges. Substantiated with data collected over a six-month period, the authors explained how practitioners aimed to create a pioneering circular design for a school building yet struggled with realizing that ambition. The use of a Circular Project Model during a workshop setting provided a new way to understand challenges at hand. The model visually represented (expected) linear and circular material flows, which opened up discussions about (im)possibilities for change. Several challenges were, accordingly, identified and exemplified, including: building code compliance; complexity of buildings; and ease of demolition. This research thus illustrated such circularity challenges with real-world data and provided a new way to understand them.

The study secondly contributes with solutions for identified circularity challenges. Design professionals in the focal project were searching for more possibilities to implement circularity. They had initially only focused on developing new purposes for existing materials on site - and overlooked reuse possibilities in other projects. The proposed model and workshop opened up a new range of circularity solutions. It suggested on one hand that recovered materials from other demolition projects could be reused in the school building, and on the other hand that materials from the school building could be recovered and reused elsewhere. This concretized the idea that designers can close material loops by rethinking buildings as material banks which allow both giving and taking of valuable materials (Van den Berg, 2019). Three insights to solve some of the identified circularity solutions were developed accordingly: assessing reuse potentials of materials in existing buildings; designing with future disassembly and reuse in mind; and promoting commitment among clients and other stakeholders.

This action research study hence provided new opportunities to understand and solve circularity challenges in design projects. Since the study is limited to just one complete action research cycle, more research is recommended to increase the validity of the proposed model and workshop format. It is similarly unclear whether practitioners could acquire the same circularity knowledge in other, perhaps more efficient, ways than this study's action or intervention. Researchers can also further build on the suggested opportunities by developing new circularity solutions and refining the model. Practitioners can use the presented insights to systematically rethink their conventional design practices.

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