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Recovering building elements for reuse (or not) – Ethnographic insights into selective demolition practices

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ABSTRACT

The construction industry faces growing socio-environmental pressures to close its material loops. Reuse of building elements can, accordingly, reduce both new production and waste. Before any element can be reused, demolition contractors first need to recover it. Previous research has not yet explored why such firms opt to recover some elements and destruct other ones. This research therefore attempts to understand the (socio-technical) conditions which lead to the recovery of a building element for reuse. Data collection consisted of approximately 250 h of (ethnographic) participant observations during the course of a partial selective demolition project in the Netherlands, complemented with semi-structured interviews and project documentation. An analytic induction method was adopted to analyze the data collected. This resulted in a proposition strongly grounded in the data: a building element will be recovered for reuse only when the demolition contractor: (1) identifies an economic demand for the element; (2) distinguishes appropriate routines to disassemble it; and (3) can control the performance until integration in a new building. In-depth insights and practical strategies are provided for each of the three recovery conditions that this proposition captures. Together, this could guide building practice to promote element reuse and lead to cleaner demolition processes.

1. Introduction

Growing socio-environmental pressures to close its material loops stimulate the construction industry to consider reuse. Construction and demolition activities generate worldwide one of the heaviest and most voluminous waste streams, of which the majority ends up in landfills (Llatas, 2011). The industry is also responsible for more than half of the total global natural resources consumed annually and for more than a third of the total global energy use and associated greenhouse gas emissions (Iacovidou and Purnell, 2016; Ness et al., 2015). These practices have severe impacts on the environment, including natural resources depletion, global warming, risks to public health, biodiversity loss and pollution of air, surface water and underground water (Cooper and Gutowski, 2015; Mahpour, 2018). Acknowledging the importance and urgency of these problems, societal emphasis on 'circular' models of production is growing, particularly in Europe and China (Jin et al., 2017; McDowall et al., 2017). Policy-makers accordingly strive to incentivize reuse because of the intuitive belief that it reduces both new production and waste (Silva et al., 2017). A scientific knowledge base then helps to develop effective strategies for closing material loops.

For reuse to occur, it is essential that demolition contractors shift their attention from destructing building parts to recovering them. The life-cycle expectation of a building generally does not exceed 50–60 years, after which the property owner must make a decision about its future (Laefer and Manke, 2008). When adaptive reuse of the building through renovation or upgrading (see e.g. Conejos et al., 2016; Remøy and van der Voordt, 2014) is not feasible, the owner can select a demolition contractor to demolish the building. That firm adopts any of three demolition methods: conventional demolition, in which the building is converted into waste; complete selective demolition (also called deconstruction), in which construction steps are reversed so as to recover as many materials as possible; or partial selective demolition, which is a combination of the other two (Kourmpanis et al., 2008). These methods differ in the number of elements that is recovered, i.e. the amount of material that is diverted from landfills or incinerators to replace natural resources in material flows (Kibert, 2016). While

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previous studies have revealed some generic challenges for reuse like regulatory barriers, economic constraints and a lack of public acceptance (Kibert et al., 2001), they are deficient in explaining when demolition contractors opt for recovery and when not. To further reuse practices, this lack of in-depth knowledge about demolition contractors' recovery decisions must be addressed.

This research hence seeks to understand the conditions which lead to the recovery of a building element for reuse. It does not quantify the environmental or economic impacts of different deconstruction strategies, nor does it classify self-reported barriers or enablers for recovery; instead, our qualitative work conceptualizes recovery decisions (in terms of conditions) primarily based on participant observations during an actual demolition project. It starts from the premise that a demolition contractor needs to decide for each and every element in a building whether to recover that element or not. We define an element here as any physical part of a building that can be handled separately. Elements can be found in all "layers" (Brand, 1994, p.13) of a building: a lamp, ceiling tile, wiring, façade and column are all examples of elements. A building, in this view, constitutes (only) of elements that are all somehow connected to each other. In demolishing a building, a demolition contractor then faces two options for each element: recovery or destruction. Selecting the first option implies that the firm disassembles an element with the aim to offer it for future reuse; the second option implies that it treats the element as waste. When an element is destructed, the resulting waste may or may not be recycled: that is typically determined by a waste processing firm rather than demolition contractor (hence irrelevant here). Taking a qualitative approach, we develop a general proposition for predicting whether a demolition contractor recovers an element or not.

This paper is structured as follows. We start with a literature review on building element recovery and reuse in a circular economy. In the subsequent research design section, we present how we attempted to acquire detailed insights into actual demolition practices through unique participant observations and analytic induction. We then turn to presenting the results of that work: a proposition strongly grounded in the data about the demolition contractor's (binary) decision to recover or destruct any building element. The paper ends with deriving suggestions for strategies that target element recovery.

2. Literature review – building element recovery and reuse in a circular economy

A literature review on reuse predictability suggests three knowledge gaps, here sorted from the abstract to the concrete. First, circular economy research tends to overlook the potentials to close material loops through reusing building elements. Second, building research concerned with reuse insufficiently considers recovery issues. Third, research dealing with element recovery has neglected the demolition contractor's point of view.

2.1. Circular economy research for buildings

The concept of a circular economy is recently gaining momentum as a way to overcome current production and consumption patterns that put a significant burden on our planet and its environmental capacity. The economic model that still dominates society is based on a simple, linear process: take, make, use and dispose, with little or no consideration for the waste generated at each step. However, the world has finite boundaries and the wastes generated during production and consumption "come around to haunt us as pollution as they eventually end up either in a landfill or are dispersed in ways that contaminate our environment" (Sauvé et al., 2016, p.53). Negative environmental effects threaten the stability of economies and the integrity of natural ecosystems essential for humanity's survival (Ghisellini et al., 2016). As an alternative, the circular economy model proposes a restorative or regenerative industrial production system through: circulating materials as long as possible with minimal loss of quality, shifting towards the use of renewable energy and eliminating toxic chemicals (Ellen MacArthur Foundation, 2013). This is most frequently depicted as a combination of reduce, reuse and recycle activities (Kirchherr et al., 2017). The concept is rooted in several schools of thought such as cradle-to-cradle approaches, which consider waste as a value-producing resource (McDonough and Braungart, 2010; McDonough et al., 2003), biomimicry, which looks to nature for sustainable solutions to design challenges (Benyus, 1997) and industrial symbiosis, where waste from one industry replaces raw material in another (Graedel and Allenby, 2010). The main contribution of the circular economy is that it decouples economic growth from resource depletion. That is, it poses that consumption of goods and services is possible without extraction of virgin resources through incentives that ensure post-consumption products get reintegrated in upstream manufacturing processes (Kjaer et al., 2019; Sauvé et al., 2016).

Framed from a circularity perspective, building research has focused more on energy rather than material flows. Even though the construction industry is the most resource intensive industry in the world (Iacovidou and Purnell, 2016), much of the recent circularity thinking has been on short- and medium-lived consumer products instead (Adams et al., 2017). Construction research that aims to contribute to a more sustainable built environment is still mostly concerned with energy consumption and carbon emission issues (Hossain and Ng, 2018; Pomponi and Moncaster, 2016). Recent studies include, for example, an analysis of the embodied energy use of China's construction industry through a multi-regional input-output model (Hong et al., 2016) or a case-study approach to evaluate and assess the energy efficiency of buildings (De Lieto Vollaro et al., 2015). Although important, research that focuses only on energy tends to overlook other environmental impacts associated with winning and processing of raw materials, such as scarcity or the impact on biodiversity of mining or drilling operations (Cheshire, 2016). To secure that actual environmental impacts of circular economy work towards sustainability, many of their advocates accordingly argue that more research is needed into closing material loops on a building level (Leising et al., 2018; Pomponi and Moncaster, 2017).

2.2. Buildings and reuse potentials

The main strategy to close material loops for buildings at the end of their useful life is reuse. The waste hierarchy (also called Lansink's Ladder) indicates an order of preference for the latter part of an element's life-cycle: prevention, minimization, reuse, recycling, energy recovery and disposal (Parto et al., 2007). The circular economy model similarly prioritizes strategies that require less changes to an element because of potential savings on the shares of material, labor, and embedded capital and on the associated externalities (Ellen MacArthur Foundation, 2013). For buildings, this implies that refitting and refurbishment are prioritized over demolition and rebuild, but other strategies at a (more detailed) element level need to be considered when that is impossible. A preferable option is then reuse, in which an element is used again either for its original purpose or for a familiar purpose, without significantly altering the physical form of it. Recycling involves reprocessing salvaged elements with a manufacturing process and making it into a (component for a) final element again (Kibert, 2016). Even though much policy is oriented towards recycling

(Allwood et al., 2011), the strategy is less preferable because it typically reduces the element's quality, potential for future uses and economic value – which is why it is sometimes also called downcycling (Chini, 2007). Concrete elements, for example, could be turned into secondary aggregates and solid timber may be reduced to particle boards. Disposal (through landfilling) and energy recovery (through incineration) are common strategies, but least preferred as they waste material resources out of the loop forever. From a material efficiency perspective, element reuse is hence the most preferred strategy for buildings that are nominated to be demolished.

That insight has fostered research into reuse potentials. Design researchers have been studying how a building's design can be optimized to allow for adaptations on one hand and the recovery of elements for reuse on the other hand (Crowther, 1999, 2018; Durmisevic, 2006). The design philosophy they put forward, called design for disassembly, aims to design-out waste through careful consideration at the early design stage. Buildings are reinterpreted as collections of valuable material resources that must be preserved over different life-cycles. Great inspiration for this work is the conceptualization of a building as – "six S's" – layers with different longevities by Brand (1994, p.13): stuff, space plan, services, skin, structure and site. Because of the (expected) different rates of change of the elements belonging to these layers, the main principle of design for disassembly is that elements must be easily recoverable. Guidelines derived from that principle include (i) the use of reversible building connections; (ii) allowing their accessibility; and (iii) minimizing the number of connections (Akinade et al., 2017; Crowther, 1999; Durmisevic, 2006; Guy et al., 2006). Reuse potential is then a – theoretical – measure of an element's ability to retain its functionality after the end of its primary life (Iacovidou and Purnell, 2016). Akinade et al. (2015), for example, used a building design's bill of quantity to capture the design's disassemble-ability in a mathematical score. Remarkably, research into reuse potentials tends to focus on new buildings with new elements and, consequently, has limited impact for the existing building stock. To bring about circularity in buildings, it is thus necessary to look at the challenges associated with recovering elements from salvaged buildings (Koutamanis et al., 2018).

2.3. Reuse enabling recovery practices

Recovering building elements is essential to realize cleaner processes in demolition projects. Research into recovery issues has started with identifying and prioritizing abstract drivers and barriers for the construction industry as a whole. Mahpour (2018), for example, used quantitative surveys to rank potential barriers in moving towards more circular construction and demolition waste management practices. One of the conclusions is that "sorting, transporting, and recovering processes" is among the most important barriers, a generic insight that does not explain how or why certain elements may or may not be recovered. Other studies have similarly identified critical success factors for recovery (Akinade et al., 2017), factors impacting demolition waste generation (Chen and Lu, 2017), benefits and constraints of deconstruction (Iacovidou and Purnell, 2016), circularity challenges and solutions (Van den Berg et al., 2019) and drivers and/or barriers for reverse logistics in construction – sometimes substantiated with (some) empirical data (Chileshe et al., 2016, 2018) and sometimes limited to existing literature (Hosseini et al., 2014, 2015). Aiming for more in-depth insights, Gorgolewski (2008), alternatively, used case studies to reveal "some challenges" for designers working with recovered building elements, like complexities due to the timing and availability of materials and the lack of a coordinated supply chain. An important shared insight from these studies is that element recovery is not only challenging because of project-specific uncertainties, but also because of the socio-technical organization of the (selective) demolition process.

Research has nevertheless neglected reuse enabling recovery practices from the demolition contractor's point of view. Even though a building owner or municipality may mandate the recovery of some elements in a demolition project (Chini and Goyal, 2011), the demolition contractor – here viewed as an autonomous decision-maker – must still opt to actually engage in either recovery or destruction practices for every (other) building element. To assist in such recovery decisions, previous studies have compared different demolition methods. This includes evaluations of the economic (Coelho and De Brito, 2011) and environmental (Coelho and De Brito, 2012; Diyamandoglu and Fortuna, 2015; Wang et al., 2018) implications of different demolition strategies. Other studies could build on that by developing decision-making models, for example to compare costs, energy use and carbon emissions with data from a building information model (Akbarnezhad et al., 2014). In practice, however, reliable building information is often absent at the end-of-life phase (Volk et al., 2014). Practitioners also appear to rely heavily on experience and implicit knowledge (Addis, 2016; Phelps and Horman, 2009) when taking recovery decisions. Few writers have been able to draw on those pragmatic realities. Previous research has not clearly explained why demolition contractors opt to recover some elements and destruct other ones. More in-depth research is thus needed to understand the recovery decisions from the demolition contractor's point of view.

3. Research design

This research seeks to understand the conditions which lead to the recovery of a building element for reuse. One partial selective demolition project was chosen to obtain ethnographic insights because of its *revelatory* nature (Yin, 2009, p.48): (i) recovery and reuse of building elements is still uncommon and (ii) those practices are also typically inaccessible to study due to health and safety (entry) regulations for site-based research. We got the rare opportunity to not only closely observe but also participate in an exemplar demolition project. Through systematically recording the participant observations and complementary interviews and documents, we gained detailed ethnographic insights of actual recovery and destruction practices. Using analytic induction, we then iteratively developed a proposition that accounts for demolition contractors' recovery decisions.

3.1. Participant observations with complementary interviews and documents

Because we aimed to develop a proposition that is strongly grounded in the data, we opted to conduct – first and foremost – participant observations. This method provides an unusual opportunity "to gain access to events or groups that are otherwise inaccessible to a study" (Yin, 2009, p.112). It has emerged as the principal method for ethnographic research, which is concerned with the study and systematic recording of social environments (Creswell and Poth, 2017). Ethnography has traditionally been adopted by anthropologists to describe a human culture from a native's point of view (Spradley, 1979, 1980). It considers both observing and participating in the lives of a group of individuals essential for building a rich understanding of complex phenomena that occur within specific social environments. Participant observations, accordingly, involve fieldwork during which a researcher takes part in the daily activities, rituals, interactions and events of a group of people (Musante and DeWalt, 2010). Ethnographic methods (like this one) have more widely been used in social sciences in general, but rarely for (cleaner) construction research (Phelps and Horman, 2009). Pink et al. (2010, p.658) nevertheless argue that ethnographic methods enable researchers to benefit from “the luxury of time (with the workers), the ethnographer’s eye, and the ear of management and the industry” and conclude that they are therefore “compatible with … the nature of the material and social contexts of the construction site.” Some of the (rare) ethnographic studies in construction include works on the adoption of interorganizational information and communication technology (Adriaanse et al., 2010), planning and safety practices at construction sites (Löwstedt, 2015) and reflexive thinking processes during a professional conflict (Grosse, 2019).

In this study, participant observations focused on recovery and destruction practices on a construction site. The first step in any ethnographic study is to get access to a site (Leedy and Ormrod, 2010). This implied here that the first mentioned author needed to pass an official health and safety exam and to verify insurance coverage for personal accidents on site. After gaining entry to the site, the researcher engaged in participant observations for about 250 h, visiting the site on a nearly daily basis for the entire project duration. Throughout this fieldwork, the researcher was not merely a passive observer of demolition practices, but actively participated with demolition workers and in their activities. This type of participation “begins with observations, but as knowledge of what others do grows, the ethnographer tries to learn the same behavior” (Spradley, 1980, p.60). In other words, the (first) researcher sought to do what demolition workers were doing. As such, he actively participated in a wide range of demolition activities, including: installing construction fencing, removing ceiling tiles, cutting electric wires, moving things around, sorting waste materials, and rigging heavy loads. His active participation in such activities provided unusual opportunities to study demolition practices and to “perceive reality from the viewpoint of someone ‘inside’” (Yin, 2009, p.112). He noted down his observations and experiences in a field diary. The notes were taken immediately after the researcher’s participation in demolition activities, as recommended by Bernard and Ryan (2010). They initially described a wide range of issues, but gradually became more specific and focused (together with a sharpening of the research question) – which is in line with sound ethnographic research methods (see e.g. Musante and DeWalt, 2010; Spradley, 1980). The field record eventually listed the building elements that were recovered and the ones that were destructed, together with any (socio-technical) characteristics that the researcher had observed or experienced in the particular demolition practices. Moreover, the researcher took over 800 pictures and videos of those practices, which corresponds with “recent innovative approaches to doing ethnography” (Pink et al., 2010, p.649). He also audio-recorded a few key discussions about recovery issues (with the consent of the workers involved in them).

Next to this fieldwork, this study was informed by semi-structured interviews and project documentation. Creswell and Poth (2017) suggest that the use of additional data sources is an essential strategy for validating (ethnographic) data. The first author therefore conducted five interviews with decision-makers that were recognized as ‘experts’ in distinct parts of the focal recovery-reuse process (i.e. one site supervisor, one designer, two project leaders and one warehouse manager). These persons were identified through what is called a “snowball sampling” technique (Bernard and Ryan, 2010, p.367): they were introduced to this study by one key informant with whom the researchers had previously established contact. A semi-structured interview format was chosen to make comparisons across interviews possible and simultaneously offer flexibility in the order and detail of how topics are covered (Leedy and Ormrod, 2010). This implies that the researcher used a fixed set of questions (about the relationship between demolition and subsequent reuse activities in projects like the focal one) with some individually tailored questions to get clarification or to probe a person’s reasoning. All of these interviews were audio-recorded. One key informant also sent relevant project documents, like the original construction drawings and a framework contract. Other project documentation was collected from the site office’s archive (including schedules and project plans). These complementary data sources helped to strengthen this study’s validity as the “richness of the [ethnographic] data provides an ideal environment for understanding the same phenomenon by different means (i.e., triangulation)” (Phelps and Horman, 2009, p.61). To build an understanding about the focal recovery decisions, the participant observations were thus complemented with other data collection methods.

3.2. Analytic induction

A qualitative method called analytic induction was adopted to analyze the data collected. This method is particularly useful to build up causal explanations of phenomena “with none of the wishy-washy tendencies and associations that are the product of statistical analysis” (Bernard and Ryan, 2010, p.328). The idea is to iteratively develop a proposition that explains a certain phenomenon through first formulating a preliminary hypothesis that accounts for just one unit of analysis and then refining that hypothesis through adding and testing more units of analysis (Robinson, 1951). The process is stopped when the evolving theory explains every new unit of analysis one adds; the end result is thus a proposition. The analytic induction method has recently been deployed to develop causal explanations for cleaner production topics such as the link between sustainable public procurement and business models (Witjes and Lozano, 2016), the sustainability of humanitarian supply chain management (Kunz and Gold, 2017), the conditions under which stakeholders see through firms’ sustainability claims (Crilly et al., 2016) and the transition from traditional business models to business models for sustainability (Long et al., 2018).

The analytic induction process here started with preparing the data. The first author digitized the field diary, transcribed the audio recordings verbatim, sent summaries of the interviews to the informants for verification purposes and – in line with a strategy to strengthen the study’s reliability (Yin, 2009) – organized the pictures, videos and project documents in a database. Using qualitative data analysis software (ATLAS.ti), the researcher then read, marked and named small chunks of the field diary and the interview transcripts one by one. This so-called initial or open coding is “appropriate for virtually all qualitative studies, but particularly for … ethnographies” (Saldaña, 2016, p.115) as it creates a starting point to make sense of and assign meaning to the data. A total of 83 different codes were applied to the data during the first round of coding (like ‘demand’, ‘speed’ and ‘reverse logistics’). This helped to identify potentially useful concepts to explain why some building elements were recovered for reuse and others not. Based on the initial coding scheme, the researcher formulated a hypothetical explanation for one unit of analysis, namely the demolition contractor’s recovery decision for a specific building element. In line with analytic induction (Robinson, 1951), he then continued by studying other recovery decisions and determining whether the hypothesis fit those units of analysis as well. The researcher thereby “triangulated data sources” by comparing pictures, videos and project documents with his field notes to verify whether the demolition contractor had opted to recover a building element or not (Miles and Huberman, 1994; Yin, 2009). He constantly revised the hypothesis with every recovery decision that the evolving theory incorrectly explained. The intermediate versions of the theory were also discussed among all three authors, which is an essential step to ensure rigor: multiple researchers can foster a higher level of conceptual thinking than individuals working alone and can reduce bias because of incorporating control of each other's interpretations (Boeije, 2009). The first author furthermore presented an early version of the evolving theory to three demolition experts during a workshop (a site supervisor, project leader and director) to be able to incorporate their feedback. Such discussions and feedback subsequently led to modifications to the coding scheme and the evolving theory. In line with the analysis method (Bernard and Ryan, 2010; Robinson, 1951), we finally declared the hypothesis stable when it correctly 'predicted' the outcome of a recovery decision for each element that we examined (and in all building layers).

3.3. Project: demolition of a nursing home

The focal project concerns the partial selective demolition of a temporary nursing home located in the Netherlands. It was strategically selected because many (but not all) building elements were planned to be reused, which is exceptional − even though the Netherlands has one of the highest recycling rates of Europe (Gálvez-Martos et al., 2018). The nursing home was a two-story building with a gross floor area of approximately 2400 m^2. It was constructed by a system builder that had adopted a modular construction method aligned with a standardized structural grid and associated products. The structure consisted of precast concrete slabs that were supported by a steel frame (columns and wind bracings) and covered with a flat timber roof. The façade was made up of distinct prefabricated elements that contained (among others) cladding, glazing, insulation and plasterwork. Precast concrete piles and ground beams were used for the foundation. Plumbing and heating systems were installed on site. Metal-stud walls were too: they enclosed 40 bedrooms, 11 bathrooms, 5 living rooms, 1 elevator and some other rooms (like offices or storage spaces). Demolition of this building was foreseen after a service life of approximately five years: the system builder was then asked to demolish it accordingly. This firm, in turn, subcontracted a demolition contractor with which it has a long-term partnership for the actual selective demolition works. It handed over a nearly empty building that was disconnected from water, gas and electricity. While the system builder obviously expected the demolition contractor to act in line with their mutual contract, it was the latter firm that had to decide upon recovery or destruction for all individual building elements it encountered during the project. Flyvbjerg (2006, p.228) explained that one such a project can contribute to "scientific development via generalization" because it may serve as a powerful example for understanding circular demolition practices.

4. Results − conditions for element recovery

Before any building element can be reused, it first needs to be recovered. Here, we attempt to arrive at a general statement of the necessary conditions which have always been present when a demolition contractor recovers a building element for reuse. Only when all conditions outlined below are met will a building element be recovered for reuse rather than be destructed (Table 1).

4.1. Condition I - identify economic demand

A demolition contractor does not typically attempt to recover a building element for reuse. The firm's focus is, by default, on establishing a quick and cost-efficient waste stream during the destruction of a building. It is thereby financially attractive to separate materials per type, since landfilling and recycling firms apply different market prices. The demolition firm transports the waste to the waste processing firm with the best financial quotation, normally the cheapest one. The demolition contractor only starts to shift its attention from destructing to recovering when it realizes that there is an economic demand for an element, that is, when enabling reuse may be more profitable than the alternative.

The demand for most of the focal building's structural and façade elements was clear right from the start of the project. The builder of the nursing home had already secured the right to demolish the building during the construction phase. That would enable this system builder to take back its 'own' modularized and industrialized building elements and to reuse those in other projects. Here, the system builder planned to directly reuse many of the nursing home's structural and façade elements for the construction of a school building, a project it had recently been selected for. Exemplary elements planned for reuse include floor, column, roof and façade elements. "Those are the components that we are interested in [to reuse]," said one of the system builder's project leaders. "Because these are modularized products, the designer knows what the building constitutes of. So he will design a new building with resources from the old building." Structural elements or façades that cannot be reused directly, can be temporarily stored in a facility of the system builder first. The intended direct or indirect reuse of such elements creates a demand to recover those elements from the nursing home.

The demolition contractor identified those demands from several documents and working practices. The firm, to whom the system builder outsourced the deconstruction works, is a fixed partner of the system builder. "If we plan to disassemble [one of our buildings], we will do that together with [that demolition contractor]," explained a project leader. "He understands our buildings and how we think." The demolition contractor's site supervisor confirmed: "[the system builder] is interested in getting the building shell back." That interest was evidenced by disassembly drawings that he had received from the system builder. Those drawings represent floor plans and cross-sections of the building with numbers and colors indicating which floor, roof or façade elements the system builder plans to reuse and where. Almost all floor slabs, for example, were necessary for the construction of the aforementioned school. One ground level floor and two first story floor slabs, however, were classified as waste. A closer examination revealed that those three slabs, located near the elevator shaft, had non-standard shapes (e.g. L-shapes) and sizes than the other floors. Since that would make it more difficult to reuse them, the system builder had not requested them back. That firm wanted to store five other slabs with different (yet not uncommon) sizes though, as it expected to be able to use those in some other project in the future. The system builder thus used drawings and other (contract) documents to request the recovery of certain structural and façade elements for reuse.

While the demand is less obvious for most other building elements, the demolition contractor appeared to have a fine understanding about what recovery practices are profitable and what not. The site supervisor and the foreman of the project frequently used the phrase that "you can [or cannot] make money with that" when referring to groups of building elements. The toilets in the nursing home were not recovered for reuse, for example, because the firm believed nobody would be interested in a used toilet. The lighting systems were also considered outdated. Contrastingly, the demolition contractor believed that it could make money with reselling (among others) door closers, faucets and refrigerators to traders because "there is a demand for such second-hand elements." One early morning, the latter also became painfully clear when the

Table 1
Exemplary building elements that were either recovered for reuse or not.

Layer	Recovered for reuse	Not recovered for reuse (destructed)
Stuff	Microwaves; Refrigerators; Hot plates; Ovens; Flowerpots; Curtains; Sun screens	Mirrors; Lamps
Space plan	Staircases; Banisters; Door fittings	Interior walls; Doors; Ceiling tiles; Linoleum; Floor plinths; Cable ducts
Services	Sinks; Air conditioning units; Sockets; Door closers; Faucets; Fire hose reels; Meter cupboard	Radiators; Toilets; Luminaires; Electrical wiring; Plumbing; Elevator; Countertops
Skin	Façades; Timber coverings; Foundation plinths	(Non-standard) façades; Sliding entrance doors
Structure	Floor slabs; Columns; Roofs; Wind bracings; Lift pit	(Non-standard) floor slabs; Foundations
Site[a]	Brick pavement; Hedges; Fencing	–

[a] We reinterpret this layer as consisting of elements belonging to the outdoor space rather than the "eternal" legally defined lot.

ethnographic researcher and two other demolition workers discovered that thieves had managed to enter the building and taken away some disassembled bathroom appliances. The (legal) interest in reusable elements was furthermore evidenced by three other events that the researcher witnessed. A woman living opposite of the nursing home expressed her "cheeky" interest in two large flowerpots outside the nursing home, two other passersby asked whether they could have a look at the kitchen appliances (eventually buying a kitchen cabinet, hot plate, microwave and refrigerator) and another man living in the neighborhood wanted to buy 14 large timber beams that formed an architectural feature of the façade. The site supervisor explained that such events were financially interesting because some money could be earned and landfill disposal costs would be saved.

For all building elements that were recovered for reuse, the demolition contractor expected that it could make some money with them. A building element was destructed when no potential buyer was identified through, for example, professional documents/contracts, direct on-site meetings or indirect sales channels. One necessary condition to recover an element for reuse is thus that the demolition contractor identifies an economic demand for that element.

4.2. Condition II – distinguish disassembly routines

Even after a demolition contractor realizes that a demand for a particular building element justifies its disassembly, recovery of the element may not take place. The potential reapplication of an element requires more skillful and disciplined disassembly routines than the reduction of that same element to (recyclable) demolition waste. As our participant observations and interviews suggest, the decision to recover an element is also influenced by the demolition contractor's ability and willingness to adopt those routines.

Disassembly routines depend on the type, accessibility and number of connections a building element has with other elements. Even though the nursing home was designed as a reversible structure, some of its elements had irreversible or inaccessible connections. Recovery of the linoleum floor covering, for example, was impossible because a strong glue had been used to attach it to the concrete floor slabs. The metal-stud interior walls could not be disassembled as distinct parts since its gypsum plates and glass wool insulation made its connections to floors and ceilings inaccessible (Fig. 1). Cables and pipes had too many connections with walls, ceilings and other elements and their tangled arrangement made it difficult to get an overview of each of them. For many other elements, however, the series of activities needed to disassemble them with minimal damage was more straightforward. The nursing home's flowerpots, curtains and ceiling tiles, for example, had a connection with other building elements based on gravitational forces. They could be accessed easily and the number of disassembly steps is limited: one demolition worker could simply lift these elements. A refrigerator or microwave likewise only needed to be unplugged. Kitchen and bathroom elements, like faucets and sinks, had fastener-based connections (e.g. bolt-nuts or screws) that could be loosened with standard tools.

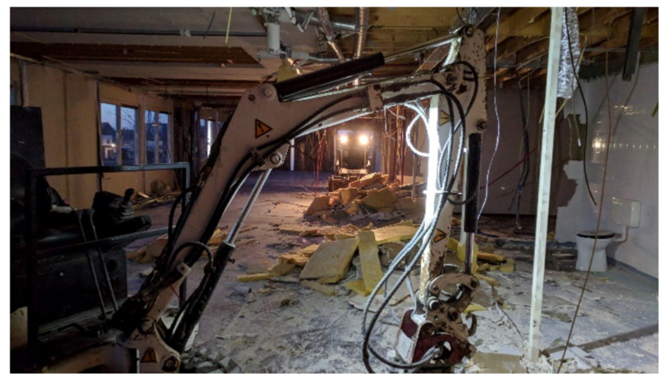

Fig. 1. Example of the destruction of an interior wall (belonging to the 'space plan' building layer).

But also for larger building elements, the demolition contractor had established specific disassembly routines. As such, the ethnographic researcher participated in the recovery of the modular façade (as distinct elements). That started with one (other) demolition worker removing three screws at the bottom of an element to partly detach a façade element from the concrete floor it was attached to. A demolition worker on the roof attached two chains, hanging from a crane hook, to two rope lifting loops on the top left and top right side of the façade element. He then completely detached the façade by removing the three remaining screws on the top of the façade element. The crane operator subsequently put the (then vertically hanging) façade element on the ground and let it slowly topple to one side. "The façade must be rotated a quarter because it would otherwise be too high for transportation," explained one of the demolition workers. He detached one of the two chains and attached it to a third rope lifting loop at the bottom of the element; he then also screwed a timber bar to the element for protection (Fig. 2). The crane operator lifted the (then horizontally hanging) element again and finally put it into a lifting yoke with the help of one more demolition worker and the researcher.

Disassembly routines like these also extend to more thoughtful handling of adjacent elements and the skillful adoption of specific tools. To illustrate that, the aforementioned linoleum floor covering was removed with special equipment in order to recover the concrete floors. But removing pieces of linoleum near the edge of a floor could, in turn, lead to damage to the façade. Bumping into the façade with that equipment could not be completely prevented. The foreman explained that they thus tried to reduce the risk of damage by unscrewing the bottom part of a façade element first: "if [the machine operator] then hits the façade, he will push it a bit outward instead of making a hole in the wall." Here, the recovery of

Fig. 2. Example of the recovery of a façade element (belonging to the 'skin' building layer).

one element depends on the demolition contractor's skills to carefully demolish other elements. The site supervisor revealed this: "[a few employees of the system builder] taught us, like, this is how you need to pay attention to the façades." He then added that they gradually tried to get their own speed in those routines, particularly through developing specific supportive tools. For example, demolition workers found a solution for a recurring practical problem in hoisting floor slabs, which was later praised by the system builder as "real craftsmanship." It had been difficult to precisely locate the position of the four hoisting rings in a concrete slab since those rings were poured over with mortar after assembly. Demolition workers discovered that a strong magnet is attracted to those rings (i.e. more than to rebar) and could thus be used to locate the positions of the rings. Other inventions include a sharp tool to cut through the roof covering material from below so as to separate two roof elements and a custom-made extension for a drilling machine that made it easier to loosen bolts above the head. All of these offer technical possibilities to efficiently disassemble building elements.

That must be complemented with the commitment to actually recover those elements. Many demolition workers found it "interesting" to know that an element would be reused. Throughout the project, the site supervisor and/or the foreman instructed the ethnographic researcher and other demolition workers why careful handling was expected for some elements and not for others. One worker who was, in the opinion of the site supervisor, not committed enough to carefully disassemble certain elements, was replaced and sent to another demolition project where "he can just destruct things." The site supervisor repetitively told the ethnographic researcher and other workers that he "enjoyed it a lot to try making money" with reusable building elements, like the kitchen appliances. Demolition workers also seemed to be committed to enable reuse with minimal damage for most large elements. As such, "this is what I really like doing," said one of the workers when he removed the last screws with which a façade element was still attached to a floor slab and then gave a 'hoisting' signal to a crane operator. Interviews furthermore suggested that the demolition workers prefer cleaner disassembly tasks. Destructing the metal-stud interior walls with machinery, for example, generated a lot of dust and dirt. "When it is a system wall type, … I prefer disassembling it manually rather than with a crane," argued the site supervisor. "Why? Because in terms of speed, when you do it manually, it is almost as fast yet much cleaner." The possibilities to assign committed workers to disassembly routines, accordingly, affect recovery decisions.

The demolition contractor distinguished appropriate disassembly routines for all building elements that were recovered for reuse. When the element's connections were irreversible, inaccessible or innumerable so that skillful and disciplined disassembly routines were practically not available, the building element was destructed. A second condition to recover an element for reuse is thus that the demolition contractor distinguishes appropriate routines to disassemble that element.

4.3. *Condition III — control future performance*

One more condition needs to be satisfied for a building element to be recovered for reuse. From the demolition contractor's perspective, it only makes sense to disassemble an element from a salvaged building when that element can (eventually) also be integrated in a new building again. The integration is limited though when it cannot be recovered properly (in due time) or when storage and/or reparation is impractical. As outlined here, this implies that the practical possibilities of a demolition contractor to control the performance of an element until future reintegration also influence that firm's decision to recover an element for subsequent reuse or not.

Sufficient time is needed to disassemble an element without diminishing its performance. For some elements, applying a disassembly routine takes about the same time as destructing it. "I think the doors are a nice example," said one (system builder's) project leader to the site supervisor. "Actually, you just take them out [of their frames] … even though you cannot make any money with them." The doors are disassembled (and then thrown away) simply because that is cleaner and can be done in the same time. For almost all other elements, recovery through careful disassembly and handling takes more time to be able to control their future performance. Two demolition workers who cleaned the bottom side of the roof, for example, told the ethnographic researcher that their job was very time consuming because they had "to remove all kinds of small things, like hooks and nails." Referring to another project context, one of the workers said that "a building like this will be demolished within a few weeks. But nothing is [recovered] then." That corresponds with regular lunch break stories about supermarket renovations that other demolition workers shared with the ethnographic researcher. They argued that there is a lot of time pressure in those projects, with employees working day and night shifts, as management typically wants to reopen the supermarket as fast as possible. A remarkable difference, according to them, is that in those demolition works "nothing" is recovered for reuse (yet materials are separated for recycling). Those time pressures were less high in the focal project and, consequently, did not limit demolition workers in following specific disassembly routines.

A reusable element also needs to be stored for a shorter or longer period of time. When an element can be integrated in a new building directly, storage time is minimal. The ethnographic researcher, for example, moved some large flowerpots to another building where they were directly functional again. The system builders' project leaders argued that some storage time is, however, usually necessary even when direct reuse is possible, such as when a building owner wants to relocate an entire building: the first elements needed at the new location are then the foundation piles and beams, but those are disassembled last. Here, almost all of the nursing home's floor, roof, column, wind bracing and staircase elements were planned to be reused directly. Similar to the façade, these elements were shortly stored on site for the time between disassembly and transportation. Most façade elements were, however, transported to a storage and reparation facility of the system builder first for a quick paint job (before transporting them to the same new site). For all of these elements, the demolition contractor could control their (short) storage with ease: the elements are weather-resistant and there was enough space on the site.

With indirect reuse, storage becomes a greater source of concern for the demolition contractor. The nursing home's air conditioners, sinks, fire hose reels and other smaller elements were all piled up on pallets after they had been disassembled. Planks separated the elements from each other, while plastic foil somehow protected the elements against dust and dirt. The façade and the interior walls also (initially) helped to protect these elements against wind and rain. Near the end of the project, before disassembling of the structural elements commenced, these elements were transported to a storage hall of the demolition contractor for later resales. The ceiling panels represented, however, a group of elements for which the demolition contractor could not ensure that they would maintain their physical and/or structural properties over an indefinite storage time. The site supervisor and one of the system builder's project leaders argued that they quickly deteriorate when they get wet, which is (more) likely with indirect reuse. If they were to be reused, they would need to be stored in a dry and warm place. The site supervisor and project leader both considered that "too expensive" and one added that a buyer will likely reject a whole package of recovered ceiling panels "if only one little hook or something … remains behind." Another project leader illustrated this problem for the radiators: "when you disassemble a radiator from a wall, you must store it …, so you clean it, it is transported, it is sealed, at the next project it is unpacked again, it must be cleaned again, you have to let water run through it otherwise it even freezes. … It is green to reuse … but actually no money is earned with it." Another project leader hypothesized: "doors, for example, if you put those in a hall for half a year, [then] you can forget it! … But if you only have them for a short while … then you can do a lot more with them [in terms of reuse]." The demolition contractor's possibilities to temporarily store an element for future reuse hence affect the recovery decision.

In line with that, reparation of disassembled (and stored) building elements may be necessary to guarantee their functional qualities. For the façades and the structural elements, the system builder operates a storage and reparation facility. The demolition contractor reported and sent a roof element to this facility for a detailed technical inspection after that element had fallen from the crane during an incident on site. More regular reparations with which the value of recovered elements can be guaranteed are painting (e.g. to fix discolored parts) and coating (e.g. to comply with fire regulations) jobs. For other elements, the demolition contractor reacted itself to (unexpected) damages. A crane had, for example, leaked a considerable amount of oil on the brick pavement. Apart from cleaning up the oil, the demolition contractor responded by washing those bricks to ensure their reusability. Conversely, the demolition contractor could not control that many service elements would maintain their functionality. The sliding doors of the main entrance, for example, had a sensor and electronic mechanism that the firm considered very fragile. The site supervisor explained that those electronic components would oxidize after disassembly and that "you will [then] get hitches and malfunctions if you reuse those doors." These doors, as well as many other service elements, subsequently ended up in a waste container.

For all building elements that were recovered for reuse, the demolition contractor could control the performance until they would be integrated in a new building again. The demolition contractor had sufficient time for careful disassembly and could ensure that the elements maintain their physical and structural properties for shorter (on-site) or longer (off-site) storage times and/or could respond to damages with necessary reparations. Building elements were destructed when the demolition contractor could not ensure their performance until future reuse. A third necessary condition to recover an element for reuse is thus that the demolition contractor can control its performance until it is integrated in a new building.

5. Discussion

This research revealed three conditions which together lead to the recovery of a building element for reuse. We embraced the rare opportunity to conduct (ethnographic) participant observations for the entire duration of a partial selective demolition project. This allowed us to examine the responsible demolition contractor's recovery decisions for many building elements in all layers of the focal nursing home. The participant observations, together with complementary interviews and project documentation, were recorded and analyzed with a method called analytic induction. From this, we derived a proposition strongly grounded in the data: a building element will be recovered for reuse only when the demolition contractor: (1) identifies an economic demand for the element; (2) distinguishes appropriate routines to disassemble it; and (3) can control the performance until integration in a new building.

5.1. Recovery — if all conditions are satisfied

For all building elements that the demolition contractor recovered, all three conditions were satisfied. The nursing home's flowerpots, staircases and columns have in common that the demolition contractor considered recovering them profitable (condition one), distinguished routines to disassemble them (condition two) and could control their performance until integration in a new building (condition three). For these (and many other) elements, the demolition contractor opted for recovery: they were disassembled for subsequent reuse. Next to these striking similarities, a closer examination of the results also suggests differences in the way in which the three conditions can be fulfilled, depending on the type of elements.

The first condition is that the demolition contractor identifies an economic demand for the element. That is, there must be a demand for the element, recovering is considered profitable and the demand is identified in the first place. For many large building elements like floors, roofs and façades, the demolition contractor is aware of the intended reuse not only because of formal contract documents and drawings but also because it understands the business processes of the system builder (as fixed partner for demolition works). The planned reuse of other elements was not governed with contract documents. Some elements, like door closers and air conditioners, could be sold through indirect sales channels like traders or online marketplaces, since the demolition contractor identified a mature market for such second-hand elements. Other elements, like timber beams and some kitchen appliances, were recovered only after the demolition contractor recognized that a passersby was interested in buying them. Had such a person not seen the demolition works and enquired for something that he/she needed, then the demolition contractor would not be aware that person would be willing to pay for a particular element. Hence, the demolition contractor can identify an economic demand through formal contracts and documents, indirect sales channels or meetings on site.

The second condition is that the demolition contractor distinguishes appropriate routines to disassemble an element. This implies that the element can technically be disconnected from other elements and that the demolition contractor is also skilled and disciplined to do so. As we discussed, the nursing home was designed and built as a reversible structure through the use of mostly modular and prefabricated elements with reversible, accessible and limited connections with other elements. Recovering those elements was only possible by strictly following a specific order of disassembly steps and with the use of heavy equipment, in particular a crane. Other elements, like sun screens and faucets, were easier to handle due to their (smaller) size and (lower) weight and thus only required simple tools and steps for disassembly. Depending on the type of element, the demolition contractor hence needs to distinguish different steps, skills and tools/equipment for appropriate disassembly.

The third condition is that the demolition contractor can control the element's performance until integration in a new building. This means that there needs to be sufficient time available for proper disassembly and that the demolition contractor can ensure that the element maintains its physical and structural properties during storing and subsequent handling. Elements differ in the number and type of measures with which the demolition contractor can ensure the value until future reuse. The floors, roofs, columns and other system elements maintain their qualities when shortly stored outside, at the site. Other elements, like air conditioners and microwaves, needed to be wrapped into foil and could only be stored inside, in an enclosed space, to protect them against weather influences, other demolition activities and petty criminals. Likewise, we discussed differences in the possibilities to conduct reparations so as to restore and ensure the performance of elements with, for example, a fully functional storage and reparation center in place for the system elements. The demolition contractor can thus control an element's performance in a new building with different combinations of protective and reactive measures aimed at value protection.

5.2. Destruction − if any conditions are false

For all building elements that were destructed, one or more of the hypothesized conditions were not satisfied. The firm did not engage in recovering mirrors that were left behind in the nursing home, because it did not identify any potential buyers (condition one). Linoleum floor covering was not recovered since the firm was unable to disassemble that appropriately (condition two), particularly because of the used glue. The main entrance's sliding doors were not recovered, because the firm could not ensure that they would still work as supposed at some unknown time in the future (condition three). The mirrors, linoleum floor covering and sliding doors, like many other elements, all ended up in one of the waste containers. Though a waste processor may (or may not) recycle materials of the destructed elements, their functional lives all ended at the examined site. Irrespective of the building layer, if one or more of the three conditions were false for an element, the result was destruction.

5.3. Implications and limitations of proposition

The three conditions for element recovery are captured in one proposition that could guide construction practice towards reuse. The *a posteriori* fit of the proposition with the examined data suggests that recovery decisions are governed by a set of rules. On the surface, it may look like an experienced site supervisor or foreman simply "knows" whether it is best to either recover or destruct a building element. We argue that we explicated some of that tacit knowledge here: the demolition contractor will only engage in recovering a building element when three conditions are met. That is, the firm must answer "Yes" to the following three element-related questions: "do we recognize an economic demand?", "are we sufficiently skilled and disciplined for disassembly?" and "can we control the performance until future integration in a new building?" The evidence makes clear that element recovery only takes place when the firm can answer affirmatively to these three questions (consciously or not) and will not occur when that is not the case. The overall proposition, accordingly, accounts for recovery decisions about any type of building element.

Those insights provide a strong basis to propose strategies for promoting element recovery. We argue that such strategies must focus on increasing the likeliness that a demolition contractor (1) identifies economic demands, (2) distinguishes disassembly routines and (3) can control future performance. Since previous studies have argued that *system wide* changes are necessary to move towards a circular economy (Ghisellini et al., 2016; Kalmykova et al., 2018; Silva et al., 2017), we accordingly deduced strategies for firms across the entire construction supply chain that link with the discovered conditions (Table 2). A manufacturer could, for example, change its business model so as to take back manufactured elements that reached the end of their technical service lives. This strategy makes it more likely that a demolition contractor identifies an economic demand for those specific elements (hence targets condition one). Builders could assemble building elements with reversible, accessible and limited connections during construction to ease disassembly (targeting condition two). Designers and architects could design small scale and lightweight elements to facilitate repeated handling and transport (targeting condition three). These exemplary strategies each try to increase the likeliness that a condition is satisfied whenever a demolition contractor takes a recovery decision. The proposition, accordingly, opens up possibilities with which (other) construction firms can direct recovery practices.

Some caution is necessary though. This *theory building* study is limited to data collected from just one project. This was justified on the grounds of its revelatory nature (Flyvbjerg, 2006; Yin, 2009), because partial selective demolition projects are still uncommon and researchers' access to construction sites is typically restricted due to health and safety regulations. More fieldwork is nevertheless needed to determine whether the developed proposition holds in other contexts. We have followed several strategies to that end, like examining many repeated recovery decisions (i.e. units of analysis) in the focal project, having multiple researchers in the same study and using more than one data collection method. These are recommended strategies to deal with the problem of generalizability (or reliability) in qualitative research (Creswell and Poth, 2017; Miles and Huberman, 1994). To deal with validity, another major problem, we have carefully followed several strategies put forward by the same authors: triangulating the different data sources, spending significant time on site and determining the accuracy of preliminary findings in a workshop with practitioners. We furthermore strived for adequate validity and reliability by providing a "rich thick description" of the findings, since this can both "convince others that the [demolition practice] has been sufficiently understood" and "provide enough context and nuance that others will understand what aspects of the unique situation are generalizable to similar situations" (Phelps and Horman, 2009, p.62). Our proposition might be invalid or incomplete though if a demolition contractor decides to 'destruct' any building element while the three recovery conditions revealed here are satisfied. Follow-up *theory testing* studies thus need to contrast actual and predicted outcomes of recovery decisions in other projects and (types of) salvaged buildings.

This relates to another important limitation pertaining the analytic induction method adopted here. This method accounts for *necessary* and not *sufficient* conditions for a certain phenomenon (Robinson, 1951). We revealed three heretofore unknown conditions for building element recovery to occur. It is, however, possible

Table 2
Exemplary strategies to promote building element recovery through targeting three conditions.

Actor in supply chain	Condition for demolition contractor		
	Identify economic demand	Distinguish disassembly routines	Control future performance
Manufacturer	Take back manufactured elements at end of life-cycle	Produce elements with reversible, accessible and limited connections Dimension elements in accordance with a modular size to ease repeated (dis)assembly Archive element detail (connection) information to share with future demolition contractor	Use materials that have a long technical service life and high impact resistance for repeated assembly and disassembly Detail elements so they are easily maintainable Provide reparation services
Designer/ architect	Investigate demolition projects nearby new site for valuable elements (sourcing) Incorporate (to be) recovered elements in design proposal	Ease (dis)assembly by ensuring reversible, accessible and limited connections between elements Separate elements in building layers with different service lives (pace-layering) Archive building (dis)assembly information to share with future demolition contractor	Integrate durable elements that are easy to maintain and have materials with a long technical service life Design small scale and lightweight elements to ease repeated handling and transport Align elements along a dimensional standard to enable interchangeability
Builder	Source/purchase elements from salvaged buildings Publish element needs for projects in near future online Pursue long-term collaborations with demolition contractor	Assemble elements with reversible, accessible and limited connections Apply modular and prefabricated elements to ease (dis)assembly Archive building sequencing information to share with future demolition contractor	Deploy storage and reparation facilities Create flexibility in transport movements to (new) site to accommodate supply of recovered elements
Building owner	Request the use of recovered elements in new buildings Request recovery of elements for salvaged buildings	Share existing conditions information with demolition contractor	Keep elements well-maintained to lengthen technical service lives Allow sufficient time and space for demolition works
Demolition contractor	Invite potential buyers to site (e.g. open house) Share information about reusable elements (online)	Train demolition workers in disassembly skills Share best disassembly practices	Deploy storage and reparation facilities Formalize warrantees on recovered elements

that there are one or more other conditions that must be satisfied before an element is recovered for subsequent reuse. Such conditions could, in principle, be present in both positive and negative cases, i.e. with elements for which the demolition contractor opted recovery respectively destruction, which makes it impossible to discover them. Investigating more recovery decisions for more building elements and in other projects could generally increase the confidence in the robustness of the proposition, but there is no way to completely eliminate this inherent drawback of the method. Bernard and Ryan (2010, p.332) nevertheless argue that the resulting proposition "allows us to make strong predictions about uncollected cases yet to come" and that "it can do as well as statistical induction" if data collection and analysis were performed systematically. We have therefore purposefully investigated recovery decisions for elements in all six building layers of Brand (1994) and stated the evolving hypothesis in universal terms so that negative cases could be discovered and used to revise it. More research is recommended to further substantiate and refine the resulting proposition, but can also elucidate the different mechanisms through which separate conditions can be satisfied.

6. Conclusion

This study has used a fieldwork-based approach to develop a proposition for cleaner demolition processes: a building element will be recovered for reuse only when the demolition contractor: (1) identifies an economic demand for the element; (2) distinguishes appropriate routines to disassemble it; and (3) can control the performance until integration in a new building. This general proposition links together three conditions in a "classic formal statement" of expected relationship (Miles and Huberman, 1994, p.271). We predict that a demolition contractor will decide to recover a building element if all three conditions are satisfied (or destruct it otherwise). This (if-then) prediction advances previous studies that were limited to describing recovery issues, for example in terms of barriers (e.g. Agrawal et al., 2015; Iacovidou and Purnell, 2016), and did not link them together in one testable proposition. Such studies suggested generic barriers, like "buildings are not designed for easy dismantling" (Hosseini et al., 2015, p.508), that we have refined here. That is, we demonstrated that a demolition contractor can take different recovery decisions for distinct elements – even for buildings that were originally designed for easy dismantling (like the focal one here). Another surprising insight is that there are different mechanisms to satisfy the three discovered conditions. A demolition contractor can, for example, identify economic demand through a contractual document, a meeting with a potential buyer on site or an indirect sales channel (e.g. online marketplace). It seems that those mechanisms depend on the type of building element – and, hence, its respective layer (Brand, 1994) – but more research is needed to better understand such underlying relationships. Like Chileshe et al. (2018), we also did not find evidence for the popular belief that "going green" is an important motivation to recover building elements. We speculate that this is because we examined actual instead of self-reported recovery decisions. Changes to building codes, an important barrier for implementing reuse (Gorgolewski, 2008; Hosseini et al., 2015; Kibert et al., 2001), played likewise an unimportant role here – most probably because the focal building was only five years old. We argue that our proposition is robust enough to deal with this potential barrier in other cases, since (in)compliance with a new building code impacts the economic demand for an element (i.e. the first condition). Finally, through linking the proposition to different construction supply chain actors, this study complements previous research with new, targeted strategies with which manufacturers, designers/architects, builders, building owners and demolition contractors could promote element recovery and subsequent reuse.

Thus, based on extensive fieldwork, this study revealed necessary conditions, in-depth insights into and practical strategies for an essential step towards a circular built environment: recovering building elements for reuse.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT authorship contribution statement

Marc van den Berg: Conceptualization, Formal analysis, Investigation, Writing - original draft. **Hans Voordijk:** Conceptualization, Writing - review & editing, Supervision. **Arjen Adriaanse:** Conceptualization, Writing - review & editing, Supervision.

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