BIM uses for deconstruction: an activity-theoretical perspective on reorganising end-of-life practices

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ABSTRACT

Despite that Building Information Modelling (BIM) is often praised as a whole life-cycle methodology, possibilities for deconstruction are consistently overlooked. This study demonstrates what those possibilities may be. Previous studies showed that: deconstruction practices pose several site-based challenges; BIM implementations may help practitioners to address such challenges; and activity theory offers a framework to understand BIM implementations. We aimed to explore how deconstruction practices can be reorganised with BIM by applying an activity-theoretical perspective to a rather unique case-study. The selected case concerned the deconstruction of a nursing home so that many of its elements could be reused to construct a school. During this project, we implemented BIM in three essential activities: analysing existing conditions, labelling of reusable elements and planning deconstruction. The implementations resolved initial problems related with the use of traditional drawings, schedules and instructions. They nevertheless also triggered several additional problems that we attempted to address in successive steps. The organisation of the activities so evolved, which culminated in the formation of three new BIM uses for deconstruction: “3D existing conditions analysis”, “4D deconstruction simulation”. These concepts complement existing BIM use taxonomies and can be appropriated in future deconstruction projects.

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Introduction

Building Information Modelling (BIM) is hardly ever used in deconstruction, even though it is commonly hailed as a whole life-cycle methodology. BIM has received a lot of interest in construction research and practice due to promising benefits of the “ideal of having a complete, coherent, true digital representation of buildings” (Turk 2016, p. 274). Such a digital representation, or model, could be analysed, priced, interpreted, procured or used in some other way by distinct organisations over different life-cycle stages (Succar 2009, Eastman et al. 2011). Penn State’s taxonomy of such use cases defines a BIM use as “a method of applying Building Information Modeling during a facility’s lifecycle to achieve one or more specific objectives” (Kreider and Messner 2013, p. 2). Surprisingly, none of the 25 BIM uses identified in this taxonomy pertain to the end-of-life phase. A review on BIM potentials for construction and demolition waste management listed a similar number of BIM uses for planning, design, construction and operation phases, but also no “specific BIM uses that can be implemented in the demolition phase” (Won and Cheng 2017, p. 8). Even though many studies are pervaded with “technocratic optimism” and claim that BIM could bring benefits throughout the entire life-cycle (Dainty et al. 2017, p. 696), potential uses during deconstruction appear constantly overlooked.

Such new possibilities for deconstruction could support the imperative change towards reuse-oriented activities. Kibert (2016, p. 480) describes deconstruction as “construction in reverse” in which a building is disassembled for the purpose of reusing its elements. This presents an emergent alternative for conventional demolition, the complete elimination of all parts of a building (Thomsen et al. 2011). Deconstruction has been advocated for its environmental benefits as it prevents the extraction of virgin materials, cuts the associated release of greenhouse gases, saves energy and water consumption and avoids solid waste disposal (Cooper and Gutowski 2015, Diyamandoglu and Fortuna 2015). It may also provide more financial
benefits than demolition, but comes with increased complexity and risks that deter demolition contractors from its adoption (Pun et al. 2006). The shift towards reuse will nevertheless become increasingly necessary and politically mandated to cut the construction industry’s excessive waste production on the one hand (Cheshire 2016) and its strain on natural resources on the other hand (lacovidou and Purnell 2016). Expanding BIM usage to deconstruction contexts may support this shift. This warrants examining possible changes to end-of-life activities through a practice-oriented theory.

This study therefore adopts an activity-theoretical perspective to explore BIM uses for deconstruction. It starts with a review of recent literature on BIM usage and deconstruction challenges and introduces activity theory as a framework to understand and reorganise practice. We then elaborate on our involvement in an open-ended and expansive process of implementing BIM in a unique, real-world deconstruction project. The results section unpacks how three BIM implementations unfolded in this case: the BIM uses changed practices in deconstruction and vice versa. We finally discuss the implications of our study in relation to other recent works that try to rethink conventional (de)construction practices and conclude with possibility knowledge.

**Literature overview**

This section elaborates the following arguments: deconstruction covers emergent yet challenging end-of-life practices; BIM approaches to support these practices are overlooked; and activity theory offers a framework to (re)organise practices.

**Deconstruction: emergent yet challenging practices**

The construction industry is increasingly pressured to adopt working practices that enable the reuse of building elements. The industry is the largest consumer of natural resources and thus has a great share in the alarming forthcoming global resource scarcity of materials (lacovidou and Purnell 2016, Sanchez et al. 2020). The industry also generates one of the heaviest and most voluminous waste streams worldwide (Chini and Bruening 2003, Poon et al. 2004). In Europe, for example, around 820 million tons of construction and demolition waste is generated on a yearly basis, which amounts up to around 46% of the total waste (Gálvez-Martos et al. 2018). Most of this waste is caused by traditional demolition activities (Schultmann and Sunke 2007, Cheshire 2016). The waste is rather heterogeneous as it comprises various building materials depending on the construction’s original function and location (Lansink 2017). The costs of treating and recycling such waste can be very high due to material screening and reprocessing steps (Ghaffar et al. 2020). It is, however, increasingly recognised that building materials have their own specific life cycles that interact dynamically in space and time (Pomponi and Moncaster 2017). Some of the materials may, accordingly, have reuse potential. Those could substitute raw materials during the construction of new buildings (Van Den Berg et al. 2020b). This demands an alternative building removal method that strives for maximum recovered materials reuse and recycling: deconstruction. This underexamined practice is a precondition for closing material flows and complies with ambitions to implement circularity in construction (see e.g. Joensuu et al. 2020).

The practice is nevertheless subject to several challenges. Recent reviews conceptualised those challenges as information deficiencies and showed that timely and accurate information is vital for the effectiveness of deconstruction (Jayasinghe et al. 2019, Wijewickrama et al. 2021). Deconstruction projects are characterised by uncertainties stemming from the building, workflow and environment, all of which a demolition contractor needs to cope with (Van Den Berg et al. 2020a). Deconstruction is also more labour intensive and takes longer in comparison with demolition. As a direct consequence, labour costs can be up to six times higher for the same building (Coelho and De Brito 2011) and total costs can be 17–25% higher (Dantata et al. 2005). That is mainly because the ease and speed of deconstruction are hindered by (possibly unknown) design choices and techniques used during construction. The use of chemical connections between building elements (e.g. in-situ cast concrete joints) instead of mechanical ones (e.g. screws or bolts), for example, increases costs and limits the feasibility of deconstruction. This becomes particularly challenging when the project is under time pressure from landowners (Allwood et al. 2011, Cooper and Gutowski 2015), like when it is part of constructing a new structure. Furthermore, the very long lifespan of buildings with potentially changing ownership and differences in deterioration rates generally results in significant uncertainty regarding the actual material composition of buildings (Schultmann and Sunke 2007, Hosseini et al. 2015). It appears also very difficult to coordinate the supply of recovered elements with...
demand (Gorgolewski 2008). Other previously identified challenges associated with deconstruction and reuse include: a lack of support from legislations and regulations; the existence of hazardous substances in buildings (e.g. asbestos); and consumer preferences, taste and perceptions (Hosseini et al. 2014, Agrawal et al. 2015).

**BIM approaches to support deconstruction**

BIM is hypothesised as “an excellent platform” to deal with challenges in deconstruction and reuse (Wijewickrama et al. 2021, p. 11). Evidence of BIM use within deconstruction projects is virtually absent though. Instead, most previous BIM-based deconstruction studies can be categorised under one of two approaches. The first approach focuses on BIM for waste management. For example, Akbarnezhad et al. (2014) proposed a framework to evaluate and compare the economic and environmental impacts of various deconstruction strategies. Other exemplary studies developed a BIM-based framework to estimate and plan waste (Cheng and Ma 2013) or used a reconstructed BIM model to create a deconstruction waste management system (Ge et al. 2017). The second approach focuses on BIM to assess deconstructability during the design. For example, Akanbi et al. (2019) developed an analytics system to assess how well a certain building design would enable materials recovery. Related studies proposed a BIM-based deconstructability assessment scoring methodology for building designs (Akinade et al. 2015) or specifically for the design of steel structures (Basta et al. 2020). These two approaches, however, overlook the possibilities of BIM to support demolition contractors during deconstruction projects. It can actually be very troublesome to implement BIM in projects. Whyte and Hartmann (2017) characterise BIM implementation as an ongoing process of adaptation and change. BIM has long been glorified as a means through which the construction industry is expected to improve productivity and interorganisational collaboration, but in practice the “great leap forward is proving to be a long march” (Rowlinson 2017, p. 45). While some studies indeed report benefits associated with BIM uses (see e.g. Bryde et al. 2013), Fox (2014) argues that hype about BIM underplays many inter-related causal factors. BIM adoption and implementation appear nothing trivial. Simply mandating BIM use, for example, could result in unintended power asymmetries that are deeply troubling for firms who lack the resources to embrace it (Dainty et al. 2017). Implementation involves carefully adapting BIM-based methods to existing work practices or vice versa (Hartmann et al. 2012). Neither of those two are well-understood for deconstruction contexts. The influential BIM Handbook (see Eastman et al. 2011, Sacks et al. 2018) does not even consider the demolition contractor as a potential user of BIM, nor do popular BIM maturity models (see e.g. Sebastian and Van Berlo 2010, Siebelink et al. 2018). Demolition contractors have, accordingly, rarely implemented BIM due to additional challenges related with high modelling efforts, updating of information in models and handling of uncertain data (Volk et al. 2014). That is, updating of building information seems to end during the construction phase already (Miettinen and Paavola 2014) as maintaining it thereafter is typically not considered sensible (Korpela et al. 2015). Deconstruction activities are thus rarely organised with BIM.

**Activity theory as framework to (re)organise practices**

Activity theory offers an epistemological framework to understand work activities (Engeström 2000, Engeström 2001, Engeström et al. 2007). The theory stems from the work of Vygotsky during the 1920s and 1930s. He developed a thought tradition based on Karl Marx’ holistic view of work (Roth and Lee 2007). A central idea is that humans never interact with their environment directly, but that their relationship is always mediated by some ideational and material tools (Vygotsky 1978). Leont’ev (1978) subsequently conceptualised activities as hierarchically structured and object-oriented systems. Engeström (1987) captured this system-ness with a well-known triangular graphic (Figure 1). It shows that activity is realised through actions, which are embedded in, and result from, a socially constructed and historically grown context of collective practice (Engeström 2000). The top displays how a subject (actor that is directly engaged in the activity) uses tools (mediating artefacts) to transform an object (purpose of the activity) into an outcome (materialisation of the object). This action exists only in relation to elements at the bottom of the triangle: actors are members of a community (context with other involved actors) whose interactions are guided and constrained by rules (conventions, norms and rules governing the activity) and a particular division of labour (relational and hierarchical structure of the activity). Activity theorists maintain that practice can only be understood by uncovering actions as successive, momentary
instantiations of this wider and more stable system of human “doing” (Engeström 2000).

Evolving contradictions in and between the activity systems offer possibilities to reorganise practice. Activities are never static, but instead constantly work through tensions within and between their elements (Engeström 2001). When one element changes, such as with the adoption of a new tool, it clashes with other, previously established elements. These clashes are called contradictions and may manifest themselves as disturbances or performance problems for which solutions need to be found (Cole 1998). Contradictions come in four types. Primary contradictions arise within an element of an activity system; secondary contradictions emerge between elements; tertiary contradictions occur between an existing activity and a more advanced one; and quaternary contradictions arise between an activity and a neighbouring one (Engeström 1987). The problems and issues originating from such contradictions need to be resolved so that they do not interfere with the desired outcome. Activity theory considers intervening with experimental solutions a central way of learning and developing new practice (Miettinen et al. 2012).

Scholars adopting an activity theory perspective have explained change and development through their active involvement in the dynamics of focal activities (Sannino and Engeström 2017). This “innovative perspective on the understanding of practice” (Nicolini 2012, p. 117) has been applied mainly in the fields of education, healthcare and organisational learning. For our field, Miettinen and Paavola (2014) suggested that BIM implementation studies would benefit from an activity-theoretical and evolutionary view. Several researches responded with such an activity theory perspective: Mäki and Kerosuo (2015) studied the use of BIM in construction site management; Gade et al. (2019) analysed a BIM-mediated building design process; and Akintola et al. (2020) explained how professional work practices evolved with the introduction of BIM. Other construction management issues that have been explained through an activity theory perspective include the anticipation of user activity development in design (Van Amstel et al. 2015), the emergence of partnering in a road maintenance contract (Hartmann and Bresnen 2011) and a company’s journey towards servitisation (Robinson et al. 2016). Thus, through capturing contradictions as an activity evolves, an activity-theoretical perspective can help to explain how BIM implementations can reorganise (or remediate) practice.

Research design

A case-study was adopted to explore how deconstruction practices can be reorganised with BIM uses. This section introduces the real-world case, explains how an activity-theoretical perspective was applied and elaborates on our data collection and analysis procedures.

Case-study

Our case-study focuses on the deconstruction of a nursing home in the Netherlands – a country with advanced BIM maturity levels and abundant bottom-up industry initiatives yet few government-imposed
policies for diffusing BIM (Papadonikolaki 2018). Case studies are most suitable to study complex phenomena in their real-world contexts (Yin 2009). The rationale behind the selected case is that the project is rather unique. That is, many of the nursing home’s building elements were planned to be reused for the construction of a school in another city. The nursing home had a total gross floor area of approximately 2400 m² and consisted of two stories with mostly individual bedrooms and some shared bathrooms and kitchens/living rooms. It had been built by a system developer that specialised in modular and prefabricated buildings. Like most of the buildings that this firm constructs, the nursing home served a temporary function and had a relatively short service life (5–6 years). The system builder planned to take back and reuse almost all elements belonging to the “skin” and “structure” building layers (Brand 1994, p. 13), like façades, floors, columns, roofs and wind bracings. The firm therefore tasked a partner demolition contractor to deconstruct the nursing home and supply the new site with those building elements. This study focuses on the reuse-enabling deconstruction activities of that demolition contractor. The intended reuse of so many building elements is still uncommon in construction (see e.g. Thomsen and Van Der Flier 2009, Wassenberg 2011). Insights from an exceptional case like this one can therefore serve as “the force of example” (Flyvbjerg 2006, p. 228) and lead to transformative action elsewhere (Engeström et al. 2007).

**Formative interventions**

The case-study uses activity theory as a theoretical lens and approach to show how the use of BIM changed deconstruction activities and vice versa. Activity theorists have formalised the principles to understand change and development in the methodology of formative interventions (Engeström 2011, Sannino and Engeström 2017). This variant of action research is based on the notion of double stimulation (Vygotsky 1978). It suggests that interventions need to be developed in response to contradictions in an existing activity system. Those contradictions serve as a first stimulus for change and development. They manifest themselves as problematic situations within vital work activities, which can be identified through ethnography-inspired observations (see e.g. Löwstedt 2015). To deal with any identified contradiction, a new tool is then created together with the involved practitioners. This mediating tool serves as the second stimulus and must be embedded and contextualised in the practitioners’ activity. Both stimuli typically go through multiple reformulations during such an intervention. This ultimately leads to a new concept that may be used in other settings as frames for the design of locally appropriate new solutions (Engeström 2011). In line with the tenets of activity theory, we applied the methodology of formative interventions by implementing BIM in deconstruction activities and examining how those implementations addressed existing contradictions and stirred up new ones.

**Data collection and analysis**

Several data collection methods were deployed. Site-based participant observations for about 250 hours were the primary source of data. The first researcher sought to understand contradictions in deconstruction activities by observing as an “active participant” (Spradley 1980, p. 60) or, in other words, by engaging in and with practices. As such, the researcher worked among the site workers to participate in the regular deconstruction actions, including: removing panels, sorting materials, cutting cables and rigging loads. He simultaneously retained an analytical position for being able to observe manifestations of both the existing contradictions (i.e. the first stimulus that could potentially be resolved with BIM-based methods) and emerging new ones (i.e. those caused by implementing a BIM-based method as the second stimulus). The development of the BIM-based methods was also logged, since – unlike with linear interventions – the contents of such interventions were unknown beforehand and shaped together with the practitioners (see e.g. Engeström 2011). The researcher assisted with the BIM implementations and audio-recorded (and transcribed) the practitioners’ agentic actions in order to discern how they reorganised their activities (i.e. the resulting new concept). During this work on site, he made notes in a diary and took over 800 pictures and movie clips – as Pink et al. (2010) recommended for fieldwork. Furthermore, the researcher collected important project documents, like the (original) construction drawings and deconstruction schedules. All the data was stored in a database as a procedure to increase reliability (Yin 2009).

Data analysis consisted of coding and theoretical redescription. This started during and partly overlapped with data collection, following the “layered character” of formative interventions (Engeström 2011, p. 620). Using qualitative data analysis software, the aforementioned researcher divided the data into smaller chunks and linked those to the characteristic
elements of activity systems and their contradictions “in order to consolidate meaning and develop explanation” (Saldana 2016, p. 9). That is, codes derived from the framework of Engeström (1987) – like subject, tool, object, etc. – were assigned to parts of the data. Deconstruction problems and disturbances were thereby seen as (manifestations of) contradictions. The identified empirical findings were subsequently interpreted from an activity theory perspective. This method, known as theoretical redescription, raises the level of theoretical engagement beyond thick description (Fletcher 2017). Changes in the organisation of deconstruction activities were, for example, ascribed to the implementation of new BIM-based methods. Researcher triangulation was applied during this process (Boeije 2009): all authors regularly discussed the interpretive analyses to reduce bias. The analyses were also sharpened with feedback from an involved director, site manager and project leader (collected during a workshop) and with comments from the editor and anonymous reviewers of this article. This ultimately resulted in an activity-theoretical redescription of the ways in which BIM implementations dynamically help addressing and give rise to contradictions in deconstruction activities.

Results

Deconstruction activities unlock the reuse potentials of building elements. The focal nursing home had to be “constructed in reverse” by a demolition contractor so the system builder could construct a school with (most of) the elements. The demolition contractor organised this project with the same site management as similar (completed) projects: a site manager, foreman and operative (referred to as the unofficial “second foreman” by the other two). Through engaging with these practitioners – and the other labourers – we identified contradictions in three essential deconstruction activities that we attempted to resolve with new BIM-based methods. This eventually resulted in three BIM uses, which are elaborated upon below: “3D existing conditions analysis,” “reusable elements labelling” and “4D deconstruction simulation”.

BIM use I: 3D existing conditions analysis

One key deconstruction activity concerns analysing existing building conditions to secure proper handling of reusable elements. Participant observations revealed that site management (subject) instructed deconstruction labourers which elements were planned to be reused and which ones not. This was, for example, done through spraying graffiti on the nursing home’s metal-stud interior walls that (likely) contained reusable wind bracings. “Damage to them must be prevented,” explained the site manager the project contract (rule) that regulated his action. The graffiti informed the deconstruction labourers (community), and in particular the mini excavator operators, about which walls required special care during mechanical demolition. Later observations (and pictures) revealed not all floors and façades had been modularised but that there were some “specials” for which a different deconstruction method had to be conceived. For analysing such existing conditions, the site manager and foremen used paper-based construction drawings (tools). This appeared to be troublesome.

Contradictions arose from the instrumentality used in analysing existing conditions. The drawings were often incomplete or difficult to interpret. For instance, the floor plans that were used to understand the exact locations of wind bracings only showed the building’s structural system (including wind bracings) and not the non-bearing walls. This made it difficult for the subjects to understand which walls actually contained those wind bracings. The site manager solved this exemplary problem by spraying question marks on those walls that could not be properly assessed with the help of the drawings. Other deconstruction workers considered that “a practical solution” for signalling them about the potential presence of building elements with reuse value. It nonetheless highlighted a secondary contradiction between the tools (2D representations of as-built information) and the object (analysis of existing building conditions) of the deconstruction activity.

A 3D model of the existing situation was iteratively developed in response to this contradiction. The system builder had not yet fully adopted BIM at the time that the firm designed and built the nursing home. The building’s design was thus mainly represented through 2D drawings, but a few discipline-specific 3D models had also been archived. These models needed to be upgraded to a newer file format before they could be viewed and manipulated. They appeared to contain (only) parts of the foundations, floors, roofs, columns and wind braces. The researcher integrated these separate models into one and modelled the façade as well (using instances of the system builder’s façade object library). Particular attention was thereby paid to correct locations, connections and shapes of reusable elements. Site management saw little point in adding more detail to the model as deconstruction
was well underway by then and “existing conditions” continued to evolve.

The 3D model was implemented as instrument for resolving the identified contradiction (Figure 2(a)). This model had to be shown on the researcher’s laptop, since the directors of the demolition contractors previously declined repetitive requests to equip the foremen with a laptop or tablet. During a first implementation of the 3D model, the (first) foreman noticed that a certain part of the roof structure “is different than usual, because it contains an additional beam.” He agreed with the site manager that some building parts, like the wind bracings, could be distinguished better in 3D. “With 2D we also find our way, but in 3D it works a bit nicer.” The foreman consequently requested to check out the so-called destination model of the school building in which certain elements would be reused. However, it appeared that both men were not familiar with the 3D modelling software’s interface and could not view or manipulate the models themselves. This highlighted a (secondary) contradiction between the subjects (management with limited 3D BIM competencies) and the tool (emergent 3D BIM competencies). The contradiction, as depicted in Figure 2(b), called for another response.

The activity subsequently evolved with the researcher introducing a new BIM role to the division of labour (Figure 2(c)). He assisted the site manager and foremen by showing the model from any desired angle during deconstructability analyses on site. This enabled them to deduce deconstruction sequences. “You can simply see it over there,” pointed the site manager to the laptop screen during a discussion about two floors connected with a staircase (Figure 3). Unlike the 2D drawings (without staircase), the 3D model showed that the upper floor had a recess, but the lower one not. “So the staircase is just assembled on top of that one,” noticed the site manager. Together with the foreman, he concluded that the lower floor then “for sure” had to be deconstructed for reuse in the school building and that the destination of the upper one (i.e. storage or disposal) had to be discussed with the system builder.

Further expansion of the deconstruction activity requires efforts directed to resolving two more (quaternary) contradictions. The new BIM role could be abandoned if site managers and foremen would be trained in the use of BIM. The schooling of site management, a neighbouring activity, then needs to change in order to equip them with BIM knowledge.
and skills. This is essentially a change in the subject-producing activity (Figure 2(d)). The neighbouring activity that creates the mediating tools similarly needs to change (Figure 2(e)). Some 3D BIM models had only been used during construction – making them unfit for the focal activity. Resolving this contradiction implies that 3D models must also be prepared for usage in a deconstruction context.

In sum, secondary contradictions stemming from the use of 2D construction drawings to analyse existing building conditions (the first stimulus) and the implementation of 3D BIM models as remediating tools (the second stimulus) have transformed the deconstruction activity that aims to secure proper handling of reusable building elements. This resulted in an embedded and contextualised BIM use (the new concept) that we propose to call “3D existing conditions analysis”.

**BIM use II: reusable elements labelling**

Another essential deconstruction activity is labelling of reusable building elements to organise reverse logistics. “This type of projects is more strategic,” explained one of the deconstruction workers (community) the complexities associated with the intended reuse of many building elements. Unlike traditional demolition projects, the site manager emphasised here to “perform soft-stripping carefully to prevent damage” to the façade. That consisted of modular elements that needed to be labelled according to certain specifications given by the system builder (rules). This way, the builder could plan and control which façade element would be assembled where in the new school building (or elsewhere). It implied that the demolition firm’s site management (subjects) needed to ensure that certain codes from a disassembly drawing (tool) would be written on the façade elements (object). “Sometimes we also need to do that for other elements, such as the columns,” clarified the foreman, but in this project labelling was limited to the façades.

The activity contained a contradiction between the tool and the object. The use of disassembly drawings for labelling appeared error-prone. The disassembly drawing for the façade, for example, displayed four exterior views of the building with hand-written codes above or below each façade element. These codes needed to be written on (temporal) pieces of tape in visible areas of the façades. That would “normally” be done by three persons, explained the site supervisor the division of labour: “somebody holds the drawing, [another] walks around with a roll of tape and [a third person] writes down the numbers.” But “we are always labelling the elements from the inside of the building,” told the foreman. The four-digit code on the far left of the drawing must then be written on the element on the far right. “We must [thus] think in mirror image,” complemented the site manager. This could be confusing, particularly when other building elements needed to be coded as well and one would “need to walk around with multiple drawings.”

A virtual environment was developed to deal with the challenge of this secondary contradiction. The researcher used the nursing home’s BIM model (that
he prepared earlier) and added the required codes as 3D texts to the façades – initially using the demolition contractor’s house style colour. The model was exported and prepared for usage into a navigable model viewer, the “virtual environment”. The foreman later requested to update the colours so as to (also) provide insight into different destinations of the façades. Colour coding appeared important to organise reverse logistics. The colour green indicated that an element was reserved for the school, blue that it needed to go to the system builder’s storage and red that it was classified as waste. The navigable virtual environment was updated accordingly.

This tool was implemented to resolve the identified contradiction (Figure 4(a)). During a first trial, it was quickly observed that it was impractical to simultaneously carry the laptop, navigate in the virtual environment and label the façade elements – especially with rainy weather conditions. This can be seen as a primary contradiction within the tool (poor handleability on site). In the hands-on spirit the researcher had observed earlier among the other deconstruction workers – “there is a solution for everything” – he found a warehouse cart and a couple of crates that he used to create some sort of walkable desk. The researcher put the laptop (with the virtual environment) on top of this and used a bag to protect it against the rainwater that was then pouring into the partly deconstructed (and thus open) building. This response was appropriate for the new contradiction (Figure 4(b)).

Mounting the laptop with virtual environment on wheels also affected the division of labour. The site manager did not feel completely confident about using the new tool as he described himself as “not a computer kind of person.” He initially proposed to resolve the contradiction with another role: the researcher controlling the avatar so he could focus on writing down the codes. But the site manager quickly discovered that the virtual environment was actually pretty easy to use. When the foreman came by to check out the new tool, he exclaimed “this works great!” The foreman agreed, even though he had accidentally pressed a key that reset the avatar’s position, which caused some confusion.

The site manager eventually continued labelling all façade elements without the researcher’s help in navigating within the virtual environment (Figure 5). Reflecting on the activity’s outcome, he argued that the tool helped him to get “a quick overview” of the

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**Figure 4.** Challenges and responses in labelling reusable elements: (a) resolved tool vs. object [secondary] contradiction, (b) resolved tool vs. tool [primary] contradiction, (c) resolved division of labour vs. division of labour [primary] contradiction, (d) unresolved tool-generating activity vs. tool [quaternary] contradiction.
building and that “it worked easier than a drawing.” The different colours allowed him to see where the façade elements would need to be transported to. “I find it all quite nice. I had not expected this.” The division of labour had also changed again. That is, the site manager no longer needed assistance from two more workers in the activity, but could navigate, tape and number the reusable façades by himself (Figure 4(c)).

The reconfigured activity also stirred up a new (quaternary) contradiction between the tool and the tool-generating activity. For BIM to substitute the disassembly drawings in future deconstruction projects, the system builder (instead of the researcher) needs to set up a virtual environment with labelling instructions (Figure 4(d)). The demolition contractor’s site manager said that the firm could simply insert the codes into their existing model and mail it to him. “I think that saves some time.” He also suggested that it would be useful for the firm to “add two letters for indicating whether a façade element has a left-swinging or right-swinging window.” However, the system builder’s as-built models do not contain such labelling information yet.

Thus, secondary contradictions existing in the use of paper-based disassembly drawings to label reusable elements (the first stimulus) and the implementation of a BIM-based virtual environment as a response (the second stimulus) have transformed the deconstruction activity that tries to organise reverse logistics. A BIM use (the new concept) emerged out of the interplay of these two stimuli that we propose to call “reusable elements labelling”.

**BIM use III: 4D deconstruction simulation**

One more important activity concerns deconstruction planning to ensure the timely handover of deconstructed elements. Any deconstruction delay would impact the construction project that needed to be supplied with reusable floors, roofs, façades and other elements. A project contract between system builder and demolition contractor thus stipulated the delivery of reusable elements in due time (rules). The demolition contractor’s site management (subject) needed to plan accordingly (object). This was, for example, evidenced by the introduction of two new labourers to the workforce (community) to bring the project back on track. “The pink-coloured parts are already finished,” referred the site manager to two large floor plans (tools) that he used to mark progress. He then led “the new guys” to the partly deconstructed nursing home to allocate them to an urgent remaining task (division of labour): cleaning up the roofs.

A secondary contradiction between the tools and object of this deconstruction activity manifested itself through challenges in allocating tasks. That is, frequent mismatches were observed between the actual situation outside and the one represented on floor plans and schedules – making it difficult to use the tools for planning decisions. The planning information was also distributed over several drawings and...
documents and thus required interpretation. The drawings consisted of 2D views, which not all workers seemed to fully understand. The site manager consequently preferred to give instructions at the site itself – “outside, in 3D!” – so that he could refer deconstruction workers to the actual elements that needed to be deconstructed. This suggests a tool (distributed and often outdated documents) versus object (deconstruction monitoring and task allocation) contradiction.

Responding to this (secondary) contradiction, a 4D model was developed by linking a project schedule to the 3D (BIM) model. The researcher initially decided to link the (previously created) model to one upcoming task: hoisting of the façade. He split this task into many sub-tasks (one for each element) to visualise the sequenced deconstruction of the façade. But the deconstruction workers showed agency during a lunch break presentation of the new 4D model and requested to revise it. The foreman described the second foreman as “the director of the roof. If [he] decides: we go left, then we will go to the left. And if he goes to the right, we will go in that direction.” In other words, the simulation assumed a certain hoisting sequence that did not take this role into account. The subjects were furthermore curious to see the different destinations of deconstructed façade elements. The researcher responded by realigning the tool’s level of detail (by modelling more building elements yet linking them to abstracter tasks) and by colour-coding the different destinations (Figure 6).

Implementing the final 4D model intended to resolve the identified contradiction (Figure 7(a)). The new tool visualised the sequenced deconstruction of the nursing home in 3D over time. The subjects thought the simulation looked nice, but were not sure how to use it as they had “only ever heard of a 4D model” before engaging with the researcher. In other words, the mismatch between required and available (4D) BIM competencies became apparent. This tool versus subject contradiction – depicted in Figure 7(b) – was aggravated by the fact that the foreman did not have laptop access to run the deconstruction simulation. This disturbance particularly came to the surface near the end of the project when the site manager (with laptop) was assigned to a new project.

A new BIM role emerged as a response to this contradiction. That is, the researcher started collaborating with the site manager and/or foreman to control and interpret the deconstruction simulation (using his own laptop). For example, he changed 3D viewing settings and played and stopped the simulation on request. Site management could monitor progress and allocate tasks based on such input. The latter can be seen as an answer to another emerging contradiction between the subject (management requiring 4D BIM assistance) and the division of labour (new 4D BIM role), as shown in Figure 7(c). Few decisions were based on this new tool though.

A tertiary contradiction emerged when more sophisticated simulation actions became available in the activity (Figure 7(d)). The object of activity had partly expanded with model visualisation and manipulation possibilities that 4D simulations provide. A senior worker saw potential in using these to inform new workers. The site manager similarly found the simulation “very funny to see how things are being deconstructed and … to show the office people of [the system builder] how deconstruction progresses in...
practice.” But he was also very critical about the rigidity of the 4D model, commenting that “it is not correct any longer if something is delayed” and that the (traditional) paper-based schedule on the wall “could be adapted easier.” This difference between the previous object of activity (planning deconstruction) and the technologically more advanced form (simulating deconstruction) suggests a tertiary contraction that was left unresolved.

Two more quaternary contradictions manifested themselves that could also not be resolved. The subjects’ limited BIM knowledge and skills prevented them to further experiment with and learn from the 4D model. “Oh dear,” the site manager spoke after seeing the simulation play for the first time: “in practice, we will never benefit from this.” This suggests that he had learned that he could do his job just fine without such advanced technologies (Figure 7(e)). Changes are also needed in the tool-generating activity for the focal activity to expand. The system builder needs to prepare a complete as-is BIM model for the demolition contractor (Figure 7(f)), for example by grouping similar elements together so the latter firm can easily link them to a schedule.

Summarising, secondary contradictions originating from using scattered (and sometimes outdated) 2D drawings and schedules to monitor progress and allocate tasks (the first stimulus) and the implementation of 4D BIM models as remediating instruments (the second stimulus) have changed the deconstruction activity that aims to handover deconstructed elements in time. This resulted in an embedded and contextualised BIM use (the new concept) that we propose to call “4D deconstruction simulation”.

**Discussion**

Deconstruction practices can be reorganised with BIM uses. This study explains how actual activities changed with the implementation of BIM-based methods and vice versa. We applied an activity-theoretical perspective to a case-study of a rather unique deconstruction project. That project concerned the systematic disassembly of a nursing home so that many of its building elements could be reused to construct a school. During this project, we implemented three BIM-based methods in an open-ended, expansive process. This resulted in three new concepts – BIM uses for
deconstruction — that we interpret and discuss here. We also acknowledge the limitations of our work and derive suggestions for further research.

**Contributions: reorganised end-of-life practices**

The results show that the implementation of BIM-based methods changed the organisation (or system-ness) of three deconstruction activities: analysing existing conditions, labelling reusable elements and planning deconstruction. We identified inefficiencies and performance issues in each of these activities due to the use of traditional drawings, schedules and instructions. These secondary contradictions (between the tool and object) motivated the development of three BIM-based methods. As such, we recreated a BIM model – using pre-existing construction drawings, object libraries and incomplete models – that we adapted to the subjects’ needs in the three activities. This resulted in, respectively, a 3D model, a virtual environment and a 4D model. These new tools mediated the focal activities: they resolved the identified secondary contradictions, but also stirred up several new primary, secondary, tertiary and/or quaternary contradictions.

Only some of those emerging contradictions could be resolved during the implementation processes. For example, the analyses illustrate that site management (subject) found it difficult to use the new BIM-based methods (tools) in the first and third activity. These secondary contradictions were not resolved. Instead, the two activities evolved when the researcher started to assist site management (emergence of another [subject vs. division of labour] contradiction) and the subjects accepted the supportive role (resolution of that contradiction). Another important (quaternary) contradiction concerns the mismatches between the as-built documentation that had been delivered and the BIM-based methods needed in the activities (i.e. between the tool-producing activity and the new tools). In other words, BIM development and implementation possibilities were restricted by the lack of a complete and accurate BIM model of the nursing home. It can furthermore be noted that some elements (like rules and community) were not affected in any of the evolved end-of-life practices.

The open-ended implementations eventually generated three new concepts. Both the contents and the course of the three BIM-based interventions were not known beforehand. This corresponds with formative interventions, but contrasts with linear ones (Engeström 2011). The results, accordingly, characterise the three activity transformations as series of remediatory actions. In other words, the initial problem (contradiction) and the proposed solution (BIM-based method) expanded during the implementation processes as new problems arose and solutions were found in other activity system elements as well. For example, a new labelling procedure was embedded in the second activity (affecting the division of labour). Actions like these refraged the activities. This culminated in the formation of three new concepts (BIM uses) that could be appropriated in future deconstruction projects: “3D existing conditions analysis,” “reusable elements labelling” and “4D deconstruction simulation”.

**Theoretical and practical implications**

The new BIM uses have several implications for end-of-life practices. They foremost open up a wider horizon of possibilities for the use of BIM. Previous works have consistently overlooked demolition contractors as potential users of the digital life-cycle methodology (see e.g. Succar 2009, Sacks et al. 2018). Several literature reviews reaffirm that very few BIM studies concentrated on the end-of-life phase (Volk et al. 2014, Wong and Zhou 2015). Penn State’s taxonomy of BIM uses, a central point of departure for our work, structures 25 BIM uses along the plan, design, construct and operate life-cycle stages and, again, ignores the end-of-life phase (Kreider and Messner 2013). To that end, this work provides important (counter)evidence: it pioneers three actual implementations of BIM during deconstruction. The resulting new BIM uses hence complement the existing taxonomies. Through showing that demolition contractors can use BIM to organise their site activities, we also uncover possibilities for BIM software vendors, training centres and maturity modellers to expand their scope to a new discipline.

This can gradually lead to more digital technology-oriented demolition contractor roles. A recent multiple-case study characterised three emergent roles for demolition contractors with the metaphors of “separator,” “mover” and “salesman” (Van Den Berg et al. 2020a). We suggest that those roles will continue to evolve with the adoption of BIM and related digital technologies. Sebastian (2011) similarly illustrated how traditional roles of clients, architects and contractors changed through BIM. Our study shows that the site management’s lack of BIM knowledge prompted the creation of new BIM roles for some deconstruction activities. Akintola et al. (2017) explained that the ones taking such roles derive legitimacy and authority to
act because of a BIM knowledge resource advantage over core professionals. Those new BIM roles are thus transitory (see also Hosseini et al. 2018). They lose their relevance when site managers (and other core professionals) gain more BIM knowledge – as also observed in the reusable elements labelling activity. Given that digital information becomes increasingly pervasive in construction (Whyte 2019), demolition contractors are thus likely to slowly absorb BIM-induced changes through temporary BIM roles.

The analyses similarly illustrate new possibilities to move towards a circular built environment. Circular economy principles are increasingly mandated by governments to reduce the pressure of our lifestyles on the environment (Korhonen et al. 2018). The Netherlands, for example, strives to realise a fully circular economy in 2050 and set a 50% reduction in virgin materials usage as an intermediate target for 2030 (Dijksma and Kamp 2016). Previous studies conceptualised that managing (digital) information plays a crucial role to realise such targets in construction (see e.g. Jayasinghe et al. 2019). We provide the empirical evidence. Our case-study results highlight three information-intensive end-of-life practices that enable (circular) reuse – and show that BIM-based methods can support those activities. Given that the BIM implementation process in the second activity – labelling of reusable elements – triggered fewer contradictions than in the other two activities (primarily because of the tool’s ease of use), we suggest that that BIM use holds most upscaling potential. But the analyses also point to contradictions that need to be resolved before demolition contractors can capture possible benefits of this – and other – BIM uses: as-is BIM models need to become readily available before deconstruction; demolition contractors need to acquire or develop BIM expertise; and site management needs to be equipped with the required hardware and software. These systemic issues must be addressed by practitioners and policy makers who seek to realise circularity targets through expanded BIM use.

**Limitations and further expansion**

The unresolved contradictions point to limitations of our work and future research directions. This study merely provides “possibility knowledge” (Sannino and Engestrom 2017, p. 80) by outlining what forms BIM-mediated deconstruction activity systems might take. It cannot answer whether the resolved contradictions outweigh the emerging new ones. The benefits that can be attributed to the new BIM uses remain unclear, since those were not isolated from other contextual factors. Our detailed account on the new problems and bottlenecks nevertheless reinforces the previous finding that BIM implementation is difficult and can unfold in unpredictable ways (Sackey et al. 2014). In that regard, it can be noted that the outcomes of the three activities remained largely the same, even though their methods changed with the introduction of BIM. Future studies can thus adopt a comparative research design to measure the relative benefits of the developed BIM uses. More research is also needed to address the lack of accurate BIM models prior to deconstruction. In our study, the first researcher provoked change in three activities with recreated BIM models and methods. It seems, however, more efficient to use a model that has been kept up-to-date throughout the building’s life-cycle instead – although previous studies suggest that updating the model after the construction stage may not be worthwhile (Korpela et al. 2015). Costs and benefits of these different approaches must thus be studied. Finally, this research is limited to our interpretive analyses of data collected in one case. Other activity-theoretical studies may discover more BIM uses or experiment with any of the other ones that were recently hypothesised by Charef and Emmitt (2020) as catalysts for a circular economy approach. The BIM uses presented here are no fixed solutions, but concepts that need to be adjusted to contextual peculiarities upon implementation in other deconstruction projects. Even though the benefits cannot be fully predicted yet, further expansion of BIM uses for deconstruction seems both possible and valuable.

**Conclusions**

Despite widespread optimism around the use of BIM as a whole life-cycle methodology, possibilities for deconstruction are consistently neglected. This study demonstrates what those possibilities may be. We sought to explore how deconstruction practices can be reorganised with BIM uses through applying an activity-theoretical perspective to a rather unique case-study project in the Netherlands. This project concerned the deconstruction of a nursing home in such a way that most of the building elements could be reused to construct a school. During this project, the first researcher actively participated in the site work and collaborated with practitioners to identify contradictions in (information-intensive) activities. Inefficiencies and performance issues – arising from the use of traditional drawings, schedules and
instructions – were observed in three activities: analysing existing conditions, labelling of reusable elements and planning deconstruction. We developed BIM-based methods as tools to remediate these activities. Implementing the tools resolved the identified contradiction in each of the three activities, but also stirred up several new ones. Our theoretical redescriptions demonstrate how those new ones were successively addressed by reorganising entire activity systems. For example, the division of labour changed with another labelling procedure in the second activity and with additional BIM roles in the first and third. Three embedded and contextualised BIM uses so emerged: “3D existing conditions analysis,” “reusable elements labelling” and “4D deconstruction simulation”. These new concepts expand existing BIM use taxonomies and provide possibility knowledge for reorganising end-of-life practices.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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