Chapter 11
Digital Technology Use Cases for Deconstruction and Reverse Logistics

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Abstract The transition towards a circular built environment challenges dismantling firms to revisit their practices. These firms traditionally demolish buildings with crushing force, essentially creating poorly recyclable waste. This practice leads to a loss of economic value and has several negative social and environmental consequences. Deconstruction, defined as construction in reverse, represents an alternative practice in which as many materials are recovered as possible. Deconstruction is particularly challenging because responsible firms need to process more information to organise various reverse logistics options efficiently. This chapter, therefore, reviews reverse supply chain practices in construction and illustrates how digital technologies could support dismantling firms and their partners during essential deconstruction activities. Through evidence-based insights and examples from practice, the chapter presents a state-of-the-art overview of digital deconstruction technology use cases for identifying, harvesting, and distributing reusable building elements. It shows that digital technologies have been developed for separate deconstruction activities but are rarely used in an integrated manner. Further integration through aligning the digital technologies with practitioners' information needs will, accordingly, unlock new opportunities for closed-loop material flows.

Keywords Circular Economy · Deconstruction · Digital Technologies · Information Needs · Reverse Logistics · Reuse

11.1 Introduction

The transition towards a circular built environment challenges the construction industry to rethink and reorganise building end-of-life practices. The fate of almost every obsolete building is conventional demolition, during which dismantling firms essentially convert it into waste (Thomsen et al. 2011). Dismantling firms typically

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use heavy equipment and crushing force to efficiently tear down buildings at the end of their service life. These demolition practices generate huge amounts of waste. It is estimated that demolition waste, together with waste generated during construction and renovation, accounts for approximately 30–40% of all solid waste (Cheshire 2016; Li et al. 2020). The sheer volume of construction and demolition waste has high environmental impacts, particularly associated with its logistics and land occupation (Gálvez-Martos et al. 2018). Traditional landfilling of the waste can also cause space problems in densely populated areas and may lead to contamination of nearby water bodies (Cooper and Gutowski 2015). These problems thus call for novel end-of-life approaches.

New approaches require rethinking materials hidden in the built environment as attractive alternatives for raw ones. Andersson and Buser (2022, p.488), for instance, illustrated how dismantling firms started renaming the materials generated during their dismantling practices as "products" or "resources" and how they viewed waste only as "a state in a never-ending transformation." Buildings can, likewise, be seen as material banks where materials are only temporarily stored (Debacker and Manshoven 2016). A building can, in this view, be used to mine resources for new constructions (Koutamanis et al. 2018). Gorgolewski (2018, p.1), likewise, envisioned how "new urban vernacular may emerge if we focus on previously used materials and components that come from the local area." This "urban mining" is an important circularity strategy for the construction industry as it can offer significant economic savings and reuse benefits (Arora et al. 2021).

The circularity strategy also calls for reorganising end-of-life practices. Conventional demolition typically marks the end-of-life phase of a building and its parts. Yet to enable reuse, dismantling firms must embrace an alternative dismantling method, called deconstruction, that is oriented towards retaining the value of building materials. Deconstruction has been described as "construction in reverse in which the building and its components are dismantled for the purpose of reusing them or enhancing recycling" (Kibert 2016, p.480). It is the first stage in reverse logistics, which is concerned with the movement of materials from the building dismantling point to the point of new construction (Hosseini et al. 2015b). Reverse logistics is nonetheless complicated in construction due to particular uncertainties, information deficiencies, and uncoordinated material flows (Tennakoon et al. 2022). Digital technologies seem particularly promising to that end as these enable data collection, integration, and analysis (Çetin et al. 2022).

This chapter describes how digital technologies could support deconstruction and reverse logistics. It first discusses challenges and information needs in reverse construction supply chains. The next section then presents an overview of how digital technologies can be used to support three essential deconstruction activities, namely: identifying, harvesting, and distributing reusable building elements. The chapter ends with an in-depth discussion of remaining technology adoption challenges and an outlook on future developments.

11.2 Reverse Supply Chains in Construction

Reverse logistics can become an effective sustainable practice with many benefits to the construction industry. This potential is not yet fully exploited though. Reverse logistics deals with products at the end of their life cycle. A general definition – originally formulated for manufacturers, wholesalers, retailers, and service firms – is that reverse logistics concerns “the process of planning, implementing, and controlling the efficient, cost effective flow of raw materials, in-process inventory, finished goods, and related information from the point of consumption to the point of origin for the purpose of recapturing value or proper disposal” (Rogers and Tibben-Lembke 1999, p. 2). These reverse flows differ in maturity per industry, but are generally quite well-developed in the manufacturing industries while often overlooked in construction (Hosseini et al. 2014). Instead, researchers and practitioners have devoted much of their attention to the classical, forward supply chain approach that “does not feel any responsibility for end-of-life” products (Govindan and Soleimani 2017, p.371). Connecting both forward and reverse supply chains into closed-loop material flows has, consequently, become at the forefront of much strategy- and policymaking (Ghaffar et al. 2020).

Closed-loop construction industries direct materials from deconstruction sites towards new construction sites, either directly or indirectly. A building owner or principal contractor usually selects a firm specialised in dismantling once a decision is made to deconstruct or renovate. That firm then initiates a range of collection, separation, sorting, treatment, reuse, and recycling activities aimed at removing a building or parts of it (Brandão et al. 2021). The end-of-life strategy can differ per individual building element, such as doors, floors, or installations. Reuse entails that an element is transferred to another location where a principal contractor assembles it again in a new construction without structurally changing it (Allwood et al. 2011). This may be achieved directly, without an intermediate party, but often reuse is indirect. It is then temporarily stored at a storage facility that serves as a buffer between reverse and forward material flows. Sometimes small repairs are also conducted at such storage facilities. Recycling entails the structural reduction of an element to its constituent materials. This is typically done by specialised waste processors, although some materials can also be recycled on site (like crushing of concrete). Suppliers can, subsequently, replace virgin materials with these recycled materials to produce new building elements. Reverse logistics practices thus represent different ways in which materials are brought back into the loop.

Possible benefits of reverse logistics practices include economic, social, and environmental aspects. Economic benefits could be achieved by cost savings offered by reusing salvaged elements instead of virgin materials (Hosseini et al. 2015b). While revenue can be made with recovered materials, the practice also saves landfill disposal costs (Diyamandoglu and Fortuna 2015). Since deconstruction is generally more labour-intensive than demolition, this can furthermore generate many new jobs. Other social benefits are the mitigation of noise, dust and compaction (Iacovidou and Purnell 2016) and an improved “green” image and reputation of the companies involved (Chileshe et al. 2018). Environmental benefits mainly include a reduction in both the use of virgin materials and in the waste generated (Del Río Merino et al. 2010). Since this reduces associated emissions and environmental impacts, reverse logistics finally represents a major climate mitigation strategy (Arora et al. 2021).

Yet compared with forward supply chains, reverse supply chains are more complex and affected by a wide range of uncertainties (Tennakoon et al. 2022). Buildings consist of heterogeneous materials and are typically immobile and not designed for deconstruction (Schultmann and Sunke 2007). The quality and size of reclaimed building elements varies widely (Iacovidou and Purnell 2016). Specifications may also be unclear, which can prompt the need to recertify them. Deconstruction thereby appears, on average, financially less attractive than conventional demolition, particularly because of the higher associated costs (Dantata et al. 2005; Coelho and De Brito 2011). Recovery facilities, infrastructure, and second-hand material markets are simultaneously underdeveloped, particularly in comparison with the manufacturing industries (Hosseini et al. 2014). Sourcing of reusable building elements therefore often requires individual searching and negotiation (Allwood 2014). Moreover, updates to rules and standards can limit the reuse potential of existing elements. A principal problem with reuse thus concerns matching supply with demand, as reclaimed materials may not show up at the right time, in the right amount, or with the right dimensions (Gorgolewski 2008).

The lack of information is a root cause of these challenges (Hosseini et al. 2015a; Chileshe et al. 2019; Wu et al. 2022). Uncertainty has been defined as a lack of information required to make a project decision (Winch 2015). Reverse supply chain operations need to deal with uncertainties related to the building, workflow, and environment (Van den Berg et al. 2020a). A typical building-related uncertainty that dismantling firms often face concerns the lack of information about the current conditions of any elements that potentially can be reused. It may, for example, be unclear which manufacturer produced a certain element, under what conditions, and according to which quality standards. Yet also any later damage or wear and tear of the elements may not have been documented well. Information, or the lack thereof, thus plays a crucial role in determining the actual conditions of building elements. But information must also be processed during a wide range of other organisational activities, such as coordinating site work or maintaining interorganisational relationships. Reverse material flows must thus be supported with sound information flows (Jayasinghe et al. 2019).

These information flows nonetheless appear to be hampered due to the complex, fragmented, cross-functional, and multi-disciplinary nature of reverse supply chains (Wijewickrama et al. 2021a). There are many actors involved in reuse and recycling processes. Their activities are typically dispersed and disordered. Information could strengthen the coordination among these activities, but is often poorly shared between different actors (Chileshe et al. 2019). Systemic information-sharing gaps were identified at links between the forward and reverse supply chains (Wijewickrama et al. 2021b). This was explained because of limited collaboration and connections between key actors involved in building operation and end-of-life stages. According to Wu et al. (2022), the most important barriers for sharing information are a lack of certainty in market environments, limited trust among actors, and a lack of government support. Poorly connected information flows consequently hinder the successful implementation of circularity in the built environment.

Digitalisation efforts across the sector are nevertheless opening new possibilities to support reverse supply chain practices. Innovative solutions are needed to address the various wicked barriers. To that end, information and communication technologies (ICT) are increasingly recognised and prioritised as critical circularity enablers (Demestichas and Daskalakis 2020). Yu et al. (2022), as such, mapped the readiness and effectiveness of ICT-based decision support tools throughout the building life cycle. They related end-of-life research with ICT solutions based on building information modelling (BIM), geographic information systems (GIS), radio-frequency identification (RFID), modelling and simulation (MS), and big data analytics (BDA). Such solutions are still rarely implemented during deconstruction and reverse logistics though. The evidence base of potential digital technology usages has thus far remained limited.

11.3 Digital Deconstruction Technology Use Cases

This section illustrates circularity-oriented use cases of digital technologies that support deconstruction and reverse logistics. These usages are structured along activities that dismantling firms and their partners follow: identifying, harvesting, and distributing reusable building elements.

11.3.1 Identify Reusable Building Elements

One of the first activities in any deconstruction project is identifying reusable materials. Wassenberg (2011) listed several reasons for dismantling a building, such as physical decay, a surplus of similar buildings, changed needs or expectations, quality-of-life problems, or social engineering processes. These different reasons suggest that at least some of the building elements may still be reusable. When there is a demand for such elements, it can be attractive to recover and resell those (Van den Berg et al. 2020b). A dismantling firm will therefore analyse existing building conditions to identify any such reusable building elements. Building owners may also stimulate this by mandating that the selected dismantling firm ensures the reuse and/or recycling of a certain number of elements.

Dismantling firms need information to make sense of existing building conditions. Basic project information about the building type, floor area, and primary materials used provides input for quick waste estimations based on waste rates per unit, like kg/m^2 or m^3/m^2 (Mah et al. 2016). Waste audits, site visits, dismantling contracts, and as-built or construction drawings fulfil most of these information needs (Tennakoon et al. 2022). However, more accurate building information is warranted to determine the reuse potentials of distinct elements – and that is most often incomplete, obsolete, or fragmented for many existing buildings (Volk et al. 2014). Dismantling firms will want to know about the material composition and the aesthetic and structural performance of distinct elements. Information about the number, type, and accessibility of the way those elements are connected to other elements is needed to assess whether any such elements can be reclaimed without damaging them or not. Furthermore, relevant market information from waste processors and material suppliers is needed to become aware which elements are demanded in secondary markets.

Several types of building capture and auditing technologies have emerged in response to as-is information needs. Such technologies aim to provide accurate insights into the geometric dimensions and other material properties of existing building elements (Han et al. 2021). BIM-based representations can, for example, be used to review how constructions were built (Van den Berg et al. 2020a). Inventory methods that combine photography with digital forms to record relevant characteristics of building elements and to assess their reuse potentials are also used more and more often by dismantling firms (see Wahlström et al. 2019) – or by partnering firms to which such activities may be outsourced (like Rotor or Sloopcheck). Honic et al. (2021, p. 1) demonstrate that material passports also provide "an outstanding advantage" to that end. Material passports essentially give elements an identity by digitally describing their characteristics, location, history, and ownership status (Luscuere 2017; Çetin et al. 2021). Such passports could inform dismantling firms about reuse potentials and enable them to extract exact quantities, but they are mainly being developed for new buildings rather than existing ones (Chap. 5 on Material Passports by Honic et al.).

More automated digital modelling methods have also emerged, though these still demand significant effort and cause high costs (Rašković et al. 2020). Laser scanners can capture dense 3D measurements of any building's as-is conditions, and the resulting point cloud can be processed to create a BIM that reflects the current situation (Tang et al. 2010). Using geometry as a foundation, modellers then attempt to augment the building representation with object metadata (semantics) related to any facet of the built environment. Since this can be a time-consuming and error-prone process, much research has been devoted to automating parts of it (Fathi et al. 2015; Che et al. 2019). As such, object recognition algorithms have been developed for walls (see Ochmann et al. 2016) and some other common building elements. Such algorithms are still infrequently combined into scalable and contextualised methods (Czerniawski and Leite 2020). Further advances in scan-to-BIM techniques that rely on low-cost, accessible hardware can nevertheless promise "a logistical base for complex reuse analyses" (Gordon et al. 2023, p.14).

Digital technologies are also used to support waste management decision-making. Having acquired insight into the as-is conditions of a to-be-deconstructed building, dismantling firms need to estimate how much waste will be generated. Lifetime analyses, which are based on a mass balance principle, assume that waste can be quantified based on the initial mass of constructed buildings and reasonable projections of material life cycles (Wu et al. 2014). Alternatively, more recent approaches attempt to quantify waste and its associated impacts based on BIM (Cheng and Ma 2013; Ge et al. 2017). For example, Kang et al. (2022) developed a conceptual framework that integrated BIM with advanced technologies, such as Internet of Things (IoT), to assist in planning alternative reuse and recycling scenarios; Su et al. (2021) combined BIM, GIS, and life cycle assessment (LCA) to develop a waste estimation and evaluation system. Works like these attempt to promote more informed waste management decisions and help to identify which building elements could be reused through closed material loops.

11.3.2 Harvest Reusable Building Elements

The next deconstruction activity concerns harvesting those building elements that were identified as reusable. The Dutch architectural firm Superuse Studios coined the term "harvesting" in reference to the practice of reclaiming valuable elements from the existing built environment – with the aim to reuse those in new buildings (Jongert et al. 2011). Dismantling firms typically do not reuse building elements themselves: they enable reuse through this harvesting. The intention to reuse implies that damage to selected elements must be minimised. Harvesting (or reclaiming) those elements hence usually requires non-destructive techniques and more skilled labour over a longer duration (Coelho and De Brito 2013). This implicates that the site work must be reorganised accordingly.

Information needs for harvesting building elements originate mainly from the workflow on site. The sequence and time allocated for deconstruction tasks are essential variables that dismantling firms need to control (Chileshe et al. 2019). Site work starts with disconnecting services and removing any present hazardous materials, like asbestos. Reusable elements can then be disassembled and (temporarily) stored somewhere on- or off-site. Dismantling firms process planning information (e.g., Gantt charts or timetables) and other project management documentation to coordinate these interdependent tasks (Van den Berg et al. 2020a). To ensure compliance with regulatory frameworks, the firms thereby need information regarding government planning requirements, health and safety guidelines, and waste handling procedures (Tennakoon et al. 2022). Information is furthermore needed to sort and prepare transportation of any harvested building elements to the next destination.

Digital technologies can support coordinating deconstruction workflows. BIM is particularly suited to facilitate the planning and organisation of site work. It can, at the outset, provide input for handling instructions and procedures to minimise possible damage during disassembly. Information may be retrieved regarding, for instance, the thickness of the cover concrete of an embedded steel connection to be removed (Akbarnezhad et al. 2014). BIM could also be used to analyse and visualise deconstruction sequencing. It is crucial to understand interdependencies and physical relationships between different elements. To that end, Marzouk and Elmaraghy (2021) used a BIM plugin to illustrate how mechanical, electrical, and plumbing

(MEP) elements intersect with walls (embedded, ending, or passing). Such insights can be used to determine in which order the elements need to be disassembled. Other existing BIM functionalities related to spatiotemporal site analyses could support managing where and when specific tasks, such as crane operations (Tak et al. 2021) or storage of deconstructed elements, need to be done. Evidence of dismantling firms using BIM for purposes like the above is nevertheless still scarce though.

Robotic technologies are likewise only occasionally used on deconstruction sites. These technologies are being developed with the intention to perform deconstruction more efficiently and precisely (Bademosi and Issa 2022). For example, Lee et al. (2015) presented a prototyping process for automated and robotised disassembly of high-rise buildings. As another example, Chen et al. (2022) described a compact robot prototype for automatic waste recycling. Robotic technologies like these are much more common in industrialised construction settings though. In end-of-life contexts, they may prove particularly suitable for repetitive deconstruction tasks. However, a general downside from a sustainability perspective is that they require the additional consumption of a significant amount of energy for operating tasks.

Other digital technologies prepare for future use. Dismantling firms will need to generate or update reusability information about the selected elements, for example, through a material passports platform. That information can then be made available to other actors in the reverse supply chain (see Wijewickrama et al. 2021b). Information systems may furthermore be needed to label harvested building elements so that those can then be tracked to new construction sites or intermediate storage facilities. The technologies can, accordingly, lead to more informative harvesting practices.

11.3.3 Distribute Reusable Building Elements

Deconstruction ends with activity regarding distributing the harvested building elements. Dismantling firms organise the diverging movements of materials away from a site. They can do this on their own or together with a transportation partner. Destinations for the different building elements typically differ. Depending on the planned end-of-life strategies, elements are transported to a new construction site (for direct reuse), an intermediate warehouse/hub (for indirect reuse), a reprocessing facility (for recycling), or a landfill site (for disposal/incineration). Dismantling projects, accordingly, lead to a large number of transport movements and associated environmental impacts, which is a primary reason that construction and demolition waste is a priority for most environmental programmes around the world (Gálvez-Martos et al. 2018).

Distribution activities depend on information to facilitate matchmaking between the supply and demand for reusable building elements (Van den Berg et al. 2020a). When a dismantling firm is contracted, that firm usually obtains ownership of the focal building and will attempt to resale reusable elements to contractors or other potential buyers. This triggers information needs. Dismantling firms need information about the current market conditions, such as prevailing prices and price volatility (Wijewickrama et al. 2021a). Buyers also need information about reusable elements, such as where and when certain elements are (or will become) available. Information is furthermore used to organise logistics or, in other words, to make sure that harvested elements arrive at the right destination at the right time (Chap. 2 by Tsui et al. on GIS). For organising closed-loop material flows, it is thus essential that material flows are accompanied with supportive information flows (Jayasinghe et al. 2019).

Various e-commerce initiatives have emerged that aim to connect supply and demand for harvested building elements. Online marketplaces for local or global trade in salvaged construction materials are growing rapidly (Caldera et al. 2020). Most dismantling firms in the Netherlands, for example, maintain their own online stores on which they showcase reclaimed building elements for sale. Common elements that can be found on such online stores include doors, timber beams, windows, insulation materials, furniture, and heating systems. Elements are typically accompanied with a picture and some information about relevant characteristics (e.g., type and dimensions), including indications of any wear or damage. Some of that information could also be retrieved from an accurate BIM. As such, Jayasinghe and Waldmann (2020) demonstrated a web-based tool that links elements to their digital counterparts in BIM. An additional benefit from linking an online store to BIM would be that the deconstruction sequencing could be automatically updated based on the demand for elements (Marzouk and Elmaraghy 2021).

Other e-commerce initiatives attempt to move beyond the project level to benefit from the advantages of scale. A particular type of online marketplace was pioneered by Jongert et al. (2011, p.56). They created (and later sold) a “harvest map,” which highlights the geographic locations of reclaimed elements by plotting those on a map. This map supports resource-based design practices. It aims to serve as a regional material catalogue that a design firm can use to locate the available supply of materials in the vicinity of a new building project. Another example is the initiative “Insert,” which was founded by several collaborating dismantling firms in the Netherlands. Their online platform bundles elements that were harvested by its partnering firms. The initiative also offers hubs where elements can be stored for indirect reuse and small repairs are conducted.

Digital technologies can furthermore support distribution with tracking methods. Several technologies were identified for tracking elements from an obsolete building to a new one. Van den Berg et al. (2021) experimented with a BIM-based method where site personnel simply wrote down numbers on pieces of tape attached to reusable facade elements. More advanced methods also make use of technologies to identify and index information of physical elements, such as RFID. This is a technology that uses tags and readers to make wireless communication possible (Yu et al. 2022). The technology has been coupled with BIM in efforts to develop various digital tracking systems, such as for steel components specifically (Ness et al. 2015). Xing et al. (2020) integrated RFID with a cloud-based BIM platform to allow bidirectional data exchange between physical building elements and their virtual counterparts. The general idea of such systems is that they allow the exact status (e.g., ownership or location) of individual elements to be checked and updated over time. Blockchain technologies, which save and link data records using cryptography, thereby appear promising as they offer transparency in tracing back status changes over time (Shojaei et al. 2021) (Chap. 12 by Shojaei and Naderi on blockchain technology). Actual implementations of tracking systems in reverse logistics still remain fairly limited though.

11.4 Discussion

This chapter presented a state-of-the-art overview of digital technology use cases for supporting deconstruction and reverse logistics. To realise circularity targets in the built environment, it is essential to rethink demolition waste as resources and to reorganise traditional end-of-life practices. Digitalisation advancements provide dismantling firms and their partners new possibilities to that end. With evidence-based insights and examples from practice, the present chapter illustrated how digital technologies can be used in identifying, harvesting, and distributing reusable building elements. The implications are profound, but several challenges and future perspectives remain.

The illustrated digital deconstruction technology use cases imply that reverse logistics could benefit from more informed practices. Deconstruction is an exciting life cycle stage: it can be seen as a restart rather than an end in closed-loop material flows. The practice thereby reduces the demand for raw materials. Circularity measures can be taken during design, construction, or operation stages, but these are often intended to pay off only during deconstruction. Exemplary measures listed by Benachio et al. (2020, p. 7) include “design for disassembly of building structures” (during design), “off-site construction” (during construction), and “minimise recuperative maintenance with preventive maintenance” (during operation). Measures like these merely promote reuse; actual reuse prerequires that end-of-life activities are organised accordingly. Those practices appear to be information intensive. That is, dismantling firms need information to organise reverse logistics and to realise reuse. Digital technologies have emerged with the potential to inform those practices.

Various technologies are so becoming available to dismantling firms and their partners. BIM technologies seem most prevalent: evidence of (pioneering) uses was found for identifying, harvesting, and distributing reusable elements. This may nevertheless be surprising given that dismantling firms are not acknowledged as potential BIM users in established handbooks (Eastman et al. 2011) and taxonomies (Kreider and Messner 2013). BIM models are also not available for most existing buildings (Volk et al. 2014), although that is likely to change as the methodology becomes increasingly widespread in the industry. Advances in scanning and automated digital modelling methods can thereby speed up the process of recreating accurate as-is models for existing buildings. More possibilities are also likely to emerge through ongoing efforts to develop low-cost scan-to-BIM solutions (Gordon et al. 2023) and to establish real-time connections between BIM and IoT applications into digital twins (see Deng et al. 2021). These BIM developments seem well aligned with circularity trends to replace demolition with a deconstruction alternative.

Other digital technologies can support specific tasks in deconstruction. Robotic solutions are most suitable to replace heavy and repetitive manual labour. Material passports seem particularly useful in understanding both present conditions and past history of potentially reusable building elements (Debacker and Manshoven 2016; Honic et al. 2021). These passports can inform dismantling firms during activity to identify reusable elements. They could also be linked to GIS systems and blockchain technologies, which would enable tracing building elements across space and over time (Xing et al. 2020). A particular challenge for developing any such tracing systems concerns the relatively long lifespan of building elements, which implies that robustness and future-proofness need to be taken into account. Simpler labelling solutions, such as those described by Van den Berg et al. (2021), can therefore be a pragmatic choice for distribution activities in the near future. Online stores and other e-commerce initiatives are essential to inform designers and general contractors about the (direct) supply of harvested materials, although their misalignment with demand remains a challenge (Çetin et al. 2022). Indirect reuse, where building elements are brought to and from a storage point, could improve supply predictability and create advantages of scale.

Several challenges persist that limit the uptake of digital technologies in circular end-of-life contexts though. Information is poorly shared between actors due to the fragmented, unorganised, cross-functional, and multi-disciplinary nature of reverse supply chains (Wijewickrama et al. 2021a). The industry is furthermore characterised by limited trust and governmental support (Wu et al. 2022). Dismantling firms typically face significant building uncertainty. Moreover, it is often still too costly or time-consuming to recreate (BIM) models that accurately represent as-is conditions (Czerniawski and Leite 2020). Actors may also lack the knowledge or skills to adopt certain technologies, like BIM. Other technologies, such as material passports, are only started to get standardised in the industry (see Platform CB'23 2022) and require changes in the way certain work activities are organised. Challenges in adopting digital technologies are closely related to general barriers in adopting digital technology and specific barriers that emerge from organising circular material flows (Jayasinghe et al. 2019; Çetin et al. 2022).

11.5 Outlook

Digital technologies can support dismantling firms and their partners with deconstruction and reverse logistics practices. Potential use cases for various technologies have been pioneered during information-intensive tasks in identifying, harvesting, and distributing reusable elements. Material passports and building capture and auditing technologies, most of which use an existing or recreated BIM model, can be used to identify reusable building elements. The planning and organisation of site work focuses on harvesting such elements, which can be supported with BIM, robotic technologies, and labelling methods. Distribution activities can make use of various types of e-commerce initiatives, BIM, and tracking technologies. Most of these technologies are not yet widely adopted in circular end-of-life contexts due to persistent industry and reverse supply chain challenges. Implementation of any digital technology hence requires adaptation of the technology to local project routines and vice versa. More research and development efforts are necessary to meet both practitioners' information needs and the potentials of illustrated digital technologies for promoting circular closed-loop material flows.

11.6 Key Takeaways

- Reverse logistics intends to close material loops, starting from the point of deconstruction.
- Deconstruction challenges dismantling firms to process more information for organising reverse logistics.
- Dismantling firms can use digital technologies in identifying, harvesting, and distributing reusable building elements.
- Reverse material flows remain poorly supported with information flows, as digital technologies tend to focus on separate activities only.
- Aligning digital technology use cases with practitioners' information needs could unlock new circularity opportunities.

References

Akbarnezhad A, Ong KCG, Chandra LR (2014) Economic and environmental assessment of deconstruction strategies using Building Information Modeling. Autom Constr 37:131–144

Allwood JM (2014) Squaring the circular economy: the role of recycling within a hierarchy of material management strategies. In: Worrell E, Reuter MA (eds) Handbook of recycling. Elsevier, Boston, pp 445–477

Allwood JM, Ashby MF, Gutowski TG, Worrell E (2011) Material efficiency: a white paper. Resour Conserv Recycl 55:362–381. https://doi.org/10.1016/j.resconrec.2010.11.002

Andersson R, Buser M (2022) From waste to resource management? Construction and demolition waste management through the lens of institutional work. Constr Manag Econ 40:477–496. https://doi.org/10.1080/01446193.2022.2081989

Arora M, Raspall F, Fearnley L, Silva A (2021) Urban mining in buildings for a circular economy: planning, process and feasibility prospects. Resour Conserv Recycl 174:105754. https://doi.org/10.1016/j.resconrec.2021.105754

Bademosi FM, Issa RRA (2022) Automation and robotics technologies deployment trends in construction. In: Jebelli H, Habibnezhad M, Shayesteh S, Asadi S, Lee S (eds) Automation and robotics in the architecture, engineering, and construction industry. Springer, pp 1–30

Benachio GLF, do Carmo Duarte Freitas M, Tavares SF (2020) Circular economy in the construction industry: a systematic literature review. J Clean Prod 260:121046. https://doi.org/10.1016/j.jclepro.2020.121046

Brandão R, Edwards DJ, Hosseini MR, Silva Melo AC, Macêdo AN (2021) Reverse supply chain conceptual model for construction and demolition waste. Waste Manag Res 39:1341–1355. https://doi.org/10.1177/0734242x21998730

Caldera S, Ryley T, Zatyko N (2020) Enablers and barriers for creating a marketplace for construction and demolition waste: a systematic literature review. Sustainability 12:9931. https://doi.org/10.3390/su12239931

Çetin S, De Wolf C, Bocken N (2021) Circular digital built environment: an emerging framework. Sustainability 13:6348. https://doi.org/10.3390/su13116348

Çetin S, Gruis V, Straub A (2022) Digitalization for a circular economy in the building industry: multiple-case study of Dutch social housing organizations. Resourc Cons Recyc Adv 15: 200110. https://doi.org/10.1016/j.rcradv.2022.200110

Che E, Jung J, Olsen MJ (2019) Object recognition, segmentation, and classification of mobile laser scanning point clouds: a state of the art review. Sensors 19:810. https://doi.org/10.3390/s19040810

Chen X, Huang H, Liu Y, Li J, Liu M (2022) Robot for automatic waste sorting on construction sites. Autom Constr 141:104387. https://doi.org/10.1016/j.autcon.2022.104387

Cheng JCP, Ma LYH (2013) A BIM-based system for demolition and renovation waste estimation and planning. Waste Manag 33:1539–1551. https://doi.org/10.1016/j.wasman.2013.01.001

Cheshire D (2016) Building revolutions: applying the circular economy to the built environment. RIBA Publishing, Newcastle upon Tyne

Chileshe N, Rameezdeen R, Hosseini MR, Martek I, Li HX, Panjehbashi-Aghdam P (2018) Factors driving the implementation of reverse logistics: a quantified model for the construction industry. Waste Manag 79:48–57. https://doi.org/10.1016/j.wasman.2018.07.013

Chileshe N, Jayasinghe RS, Rameezdeen R (2019) Information flow-centric approach for reverse logistics supply chains. Autom Constr 106:102858. https://doi.org/10.1016/j.autcon.2019.102858

Coelho A, De Brito J (2011) Economic analysis of conventional versus selective demolition—a case study. Resour Conserv Recycl 55:382–392. https://doi.org/10.1016/j.resconrec.2010.11.003

Coelho A, De Brito J (2013) Conventional demolition versus deconstruction techniques in managing construction and demolition waste (CDW), Handbook of recycled concrete and demolition waste. Woodhead Publishing, pp 141–185

Cooper DR, Gutowski TG (2015) The environmental impacts of reuse: a review. J Ind Ecol 21:38–56. https://doi.org/10.1111/jiec.12388

Czerniawski T, Leite F (2020) Automated digital modeling of existing buildings: a review of visual object recognition methods. Autom Constr 113:103131. https://doi.org/10.1016/j.autcon.2020.103131

Dantata N, Touran A, Wang J (2005) An analysis of cost and duration for deconstruction and demolition of residential buildings in Massachusetts. Resour Conserv Recycl 44:1–15. https://doi.org/10.1016/j.resconrec.2004.09.001

Debacker W, Manshoven S (2016) Synthesis of the state-of-the-art: key barriers and opportunities for materials passports and reversible building design in the current system. Buildings As Material Banks

Del Río Merino M, Izquierdo Gracia P, Weis Azevedo IS (2010) Sustainable construction: construction and demolition waste reconsidered. Waste Manag Res 28:118–129. https://doi.org/10.1177/0734242x09103841

Demestichas K, Daskalakis E (2020) Information and communication technology solutions for the circular economy. Sustainability 12:7272. https://doi.org/10.3390/su12187272

Deng M, Menassa CC, Kamat VR (2021) From BIM to digital twins: a systematic review of the evolution of intelligent building representations in the AEC-FM industry. J Inf Technol Construct 26:58–83

Diyamandoglu V, Fortuna LM (2015) Deconstruction of wood-framed houses: material recovery and environmental impact. Resour Conserv Recycl 100:21–30. https://doi.org/10.1016/j.resconrec.2015.04.006

Eastman C, Teicholz P, Sacks R, Liston K (2011) BIM handbook: a guide to building information modeling for owners, managers, designers, engineers, and contractors. Wiley, Hoboken

Fathi H, Dai F, Lourakis M (2015) Automated as-built 3D reconstruction of civil infrastructure using computer vision: achievements, opportunities, and challenges. Adv Eng Inform 29:149–161. https://doi.org/10.1016/j.aei.2015.01.012

Gálvez-Martos JL, Styles D, Schoenberger H, Zeschmar-Lahl B (2018) Construction and demolition waste best management practice in Europe. Resour Conserv Recycl 136:166–178. https://doi.org/10.1016/j.resconrec.2018.04.016

Ge XJ, Livesey P, Wang J, Huang SH, He X, Zhang C (2017) Deconstruction waste management through 3d reconstruction and bim: a case study. Vis Eng 5:13. https://doi.org/10.1186/s40327-017-0050-5

Ghaffar SH, Burman M, Braimah N (2020) Pathways to circular construction: an integrated management of construction and demolition waste for resource recovery. J Clean Prod 244: 118710. https://doi.org/10.1016/j.jclepro.2019.118710

Gordon M, Batallé A, De Wolf C, Sollazzo A, Dubor A, Wang T (2023) Automating building element detection for deconstruction planning and material reuse: a case study. Autom Constr 146:104697. https://doi.org/10.1016/j.autcon.2022.104697

Gorgolewski M (2008) Designing with reused building components: some challenges. Build Res Inf 36:175–188. https://doi.org/10.1080/09613210701559499

Gorgolewski M (2018) Resource salvation: the architecture of reuse. Wiley, Hoboken

Govindan K, Soleimani H (2017) A review of reverse logistics and closed-loop supply chains: a Journal of Cleaner Production focus. J Clean Prod 142(Part 1):371–384. https://doi.org/10.1016/j.jclepro.2016.03.126

Han D, Kalantari M, Rajabifard A (2021) Building Information Modeling (BIM) for construction and demolition waste management in Australia: a research agenda. Sustainability 13:12983. https://doi.org/10.3390/su132312983

Honic M, Kovacic I, Aschenbrenner P, Ragossnig A (2021) Material passports for the end-of-life stage of buildings: challenges and potentials. J Clean Prod 319:128702. https://doi.org/10.1016/j.jclepro.2021.128702

Hosseini MR, Chileshe N, Rameezdeen R, Lehmann S (2014) Reverse logistics for the construction industry: lessons from the manufacturing context. Int J Constr Eng Manag 3:75–90. https://doi.org/10.5923/j.ijcem.20140303.01

Hosseini MR, Chileshe N, Rameezdeen R, Lehmann S (2015a) Integration of design for reverse logistics and harvesting of information: a research agenda. Int J Logist Syst Manag 20:480–515. https://doi.org/10.1504/IJLSM.2015.068490

Hosseini MR, Rameezdeen R, Chileshe N, Lehmann S (2015b) Reverse logistics in the construction industry. Waste Manag Res 33:499–514. https://doi.org/10.1177/0734242X1558484

Iacovidou E, Purnell P (2016) Mining the physical infrastructure: opportunities, barriers and interventions in promoting structural components reuse. Sci Total Environ 557:791–807. https://doi.org/10.1016/j.scitotenv.2016.03.098

Jayasinghe LB, Waldmann D (2020) Development of a BIM-based web tool as a material and component bank for a sustainable construction industry. Sustainability 12:1766. https://doi.org/10.3390/su12051766

Jayasinghe RS, Rameezdeen R, Chileshe N (2019) Exploring sustainable post-end-of-life of building operations: a systematic literature review. Eng Constr Archit Manag 26:689–722. https://doi.org/10.1108/ECAM-08-2017-0148

Jongert J, Nelson N, Goosens F (2011) Recyclicity: a toolbox for resource-based design. Archit Design 81:54–61. https://doi.org/10.1002/ad.1320

Kang K, Besklubova S, Dai Y, Zhong RY (2022) Building demolition waste management through smart BIM: a case study in Hong Kong. Waste Manag 143:69–83. https://doi.org/10.1016/j.wasman.2022.02.027

Kibert CJ (2016) Sustainable construction: green building design and delivery. Wiley

Koutamanis A, van Reijn B, van Bueren E (2018) Urban mining and buildings: a review of possibilities and limitations. Resour Conserv Recycl 138:32–39. https://doi.org/10.1016/j.resconrec.2018.06.024

Kreider RG, Messner JI (2013) The uses of BIM: classifying and selecting BIM uses. The Pennsylvania State University, University Park

Lee S, Pan W, Linner T, Bock T (2015) A framework for robot assisted deconstruction: process, sub-systems and modelling. In: 32nd ISARC: proceedings of the international symposium on automation and robotics in construction, Oulu, Finland

Li CZ, Zhao Y, Xiao B, Yu B, Tam VWY, Chen Z, Ya Y (2020) Research trend of the application of information technologies in construction and demolition waste management. J Clean Prod 263:121458. https://doi.org/10.1016/j.jclepro.2020.121458

Luscuere LM (2017) Materials passports: optimising value recovery from materials. Proc Inst Civil Eng Waste Resour Manage 170:25–28. https://doi.org/10.1680/jwarm.16.00016

Mah CM, Fujiwara T, Ho CS (2016) Construction and demolition waste generation rates for high-rise buildings in Malaysia. Waste Manag Res 34:1224–1230. https://doi.org/10.1177/0734242x16666944

Marzouk M, Elmaraghy A (2021) Design for deconstruction using integrated lean principles and BIM approach. Sustainability 13:7856. https://doi.org/10.3390/su13147856

Ness D, Swift J, Ranasinghe DC, Xing K, Soebarto V (2015) Smart steel: new paradigms for the reuse of steel enabled by digital tracking and modelling. J Clean Prod 98:292–303

Ochmann S, Vock R, Wessel R, Klein R (2016) Automatic reconstruction of parametric building models from indoor point clouds. Comput Graph 54:94–103. https://doi.org/10.1016/j.cag.2015.07.008

Platform CB'23 (2022) Leidraad paspoorten voor de bouw deel 1+2: Werkafspraken en onderbouwing voor paspoorten in een circulaire bouwsector. https://platformcb23.nl/images/downloads/2022/final/Leidraad_Paspoorten-voor-de-bouw-3.pdf

Rašković M, Ragossnig AM, Kondracki K, Ragossnig-Angst M (2020) Clean construction and demolition waste material cycles through optimised pre-demolition waste audit documentation: a review on building material assessment tools. Waste Manag Res 38:923–941. https://doi.org/10.1177/0734242x20936763

Rogers DS, Tibben-Lembke RS (1999) Going backwards: reverse logistics trends and practices. Reverse Logistics Executive Council, Pittsburgh

Schultmann F, Sunke N (2007) Energy-oriented deconstruction and recovery planning. Build Res Inf 35:602–615. https://doi.org/10.1080/09613210701431210

Shojaei A, Ketabi R, Razkenari M, Hakim H, Wang J (2021) Enabling a circular economy in the built environment sector through blockchain technology. J Clean Prod 294:126352. https://doi.org/10.1016/j.jclepro.2021.126352

Su S, Li S, Ju J, Wang Q, Xu Z (2021) A building information modeling-based tool for estimating building demolition waste and evaluating its environmental impacts. Waste Manag 134:159–169. https://doi.org/10.1016/j.wasman.2021.07.025

Tak AN, Taghaddos H, Mousaei A, Bolourani A, Hermann U (2021) BIM-based 4D mobile crane simulation and onsite operation management. Autom Constr 128:103766. https://doi.org/10.1016/j.autcon.2021.103766

Tang P, Huber D, Akinci B, Lipman R, Lytle A (2010) Automatic reconstruction of as-built building information models from laser-scanned point clouds: a review of related techniques. Autom Constr 19:829–843. https://doi.org/10.1016/j.autcon.2010.06.007

Tennakoon GA, Rameezdeen R, Chileshe N (2022) Diverting demolition waste toward secondary markets through integrated reverse logistics supply chains: a systematic literature review. Waste Manag Res 40:274–293. https://doi.org/10.1177/0734242X211021478

Thomsen A, Schultmann F, Kohler N (2011) Deconstruction, demolition and destruction. Build Res Inf 39:327–332. https://doi.org/10.1080/09613218.2011.585785

Van den Berg M, Voordijk H, Adriaanse A (2020a) Information processing for end-of-life coordination: a multiple-case study. Constr Innov 20:647–671. https://doi.org/10.1108/CI-06-2019-0054

Van den Berg M, Voordijk H, Adriaanse A (2020b) Recovering building elements for reuse (or not) – ethnographic insights into selective demolition practices. J Clean Prod 256:120332. https://doi.org/10.1016/j.jclepro.2020.120332

Van den Berg M, Voordijk H, Adriaanse A (2021) BIM uses for deconstruction: an activity-theoretical perspective on reorganising end-of-life practices. Constr Manag Econ 39:323–339. https://doi.org/10.1080/01446193.2021.1876894

Volk R, Stengel J, Schultmann F (2014) Building Information Modeling (BIM) for existing buildings — literature review and future needs. Autom Constr 38:109–127. https://doi.org/10.1016/j.autcon.2013.10.023

Wahlström M, Castell-Rüdenhausen MZ, Hradil P, Hauge-Smith K, Oberender A, Ahlm M, Götbring J, Hansen JB (2019) Improving quality of construction & demolition waste: requirements for pre-demolition audit. Nordic Council of Ministers

Wassenberg F (2011) Demolition in the Bijlmermeer: lessons from transforming a large housing estate. Build Res Inf 39:363–379. https://doi.org/10.1080/09613218.2011.585104

Wijewickrama MKCS, Chileshe N, Rameezdeen R, Ochoa JJ (2021a) Information sharing in reverse logistics supply chain of demolition waste: a systematic literature review. J Clean Prod 280:124359. https://doi.org/10.1016/j.jclepro.2020.124359

Wijewickrama MKCS, Rameezdeen R, Chileshe N (2021b) Information brokerage for circular economy in the construction industry: a systematic literature review. J Clean Prod 313:127938. https://doi.org/10.1016/j.jclepro.2021.127938

Winch GM (2015) Project organizing as a problem in information. Constr Manag Econ 33:106–116

Wu Z, Yu ATW, Shen L, Liu G (2014) Quantifying construction and demolition waste: an analytical review. Waste Manag Res 34:1683–1692. https://doi.org/10.1016/j.wasman.2014.05.010

Wu Z, Yang K, Xue H, Zuo J, Li S (2022) Major barriers to information sharing in reverse logistics of construction and demolition waste. J Clean Prod 350:131331. https://doi.org/10.1016/j.jclepro.2022.131331

Xing K, Kim KP, Ness D (2020) Cloud-BIM enabled cyber-physical data and service platforms for building component reuse. Sustainability 12:10329. https://doi.org/10.3390/su122410329

Yu Y, Yazan DM, Junjan V, Iacob ME (2022) Circular economy in the construction industry: a review of decision support tools based on Information & Communication Technologies. J Clean Prod 349:131335. https://doi.org/10.1016/j.jclepro.2022.131335

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