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De Wolf, Catherine; Çetin, Sultan; Bocken, Nancy

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Can Digital Matchmaking Boost Circular Construction? Lessons from Reusing the Glass of Centre Pompidou

Catherine De Wolf, Sultan Cetin, and Nancy Bocken

Abstract

Digitalization is driving innovation towards a circular economy in various industries—but the construction industry is lagging behind. The building industry, a growth sector due to increasing urbanization, is at the same time actively depleting our resources, generating waste, and emitting greenhouse gases at a tremendous scale and speed. This chapter argues that we must urgently shift from a linear take–make–waste model to a circular one whereby we utilize our resources wisely and keep them from becoming waste. The experience of reusing the glass from the Centre Pompidou in Paris, France, confronted the architects with the many challenges we face when renovating a building with circular principles. Finding architects to use the iconic bent glass instead of crushing it for recycling (or worse, for disposing it in a landfill) turned out to be a time-consuming task. Adopting artificial intelligence and digital information sharing to match materials for reuse with people who can reuse them is exactly what the construction industry needs for a paradigm shift towards circularity.

Keywords

Reuse · Centre Pompidou · Circular construction · Digital matchmaking

C. De Wolf (✉)
ETH Zurich, Department of Civil, Environmental and Geomatic Engineering, Zurich, Switzerland
e-mail: cdewolf@ethz.ch

S. Cetin
TU Delft, Faculty of Architecture and the Built Environment, Delft, Netherlands

N. Bocken
Maastricht University, Maastricht Sustainability Institute (MSI), Maastricht, Netherlands

1 Introduction

It is evident that the building industry is a growth sector due to increasing urbanization and yet, at the same time, one that is actively depleting our resources, generating waste, and emitting greenhouse gases at a tremendous scale and speed. This essay argues that we[1] must urgently shift from a linear take–make–waste model to a circular one whereby we rethink our resources wisely and keep them from becoming waste. Adopting digital innovation is exactly what the construction industry needs in order to achieve this shift (World Economic Forum 2022). This also responds to Sustainable Development Goals such as 'Industry, innovation and infrastructure', 'Sustainable cities and communities',

[1] By "we," I am referring to key actors of the construction sector: designers, architects, engineers, contractors, etc.

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'Responsible consumption and production', and 'Climate action'.

Today, we construct buildings using "linear economy" principles: we extract resources from the earth, produce construction materials, use them, and then dispose of them when we no longer need them. In the process, we deplete global resources such as sand (United Nations Environment Programme 2019). What's more, we produce a huge amount of waste: in 2018 and in the United States alone, we generated 600 million tons of construction and demolition waste (United States Environmental Protection Agency 2016). We also intensify the climate crisis: the building sector accounts for around 38% of our global greenhouse gas (GHG) emissions (United Nations Environment Programme 2020). Of course, we know this results in a loss of value and resources, but we clearly haven't sufficiently considered how to fix this costly problem. And it is getting worse. By 2060, we expect to add 2.4 trillion ft^2 (230 billion m^2) of floor area due to the growing population, urbanization, and higher demands—this is equivalent to constructing one New York City every month for 40 years (Architecture 2030). The question is, how do we break the pattern of resource depletion, waste generation, and pollution in the construction sector?

A shift to a "circular economy" model would yield maximum value from building materials by extending their service life through maintenance and repair and reusing them as new resources when they reach the end of their life. Yet, while pioneering circular projects have been promising, a static industry with little cross-sector communication impedes the practical implementation of circular construction on a large scale (Nußholz et al. 2020). This was not always the case: reuse was common until about a century ago, when, due to the high price of land in dense urban areas like Manhattan, we began demolishing buildings rather than disassembling them. Because of the time required to carefully disassemble buildings and reuse their materials, we have moved away from the circular construction model. But it doesn't have to be that way.

Digital technologies can help us disassemble and reuse much quicker, cheaper, and smarter than before. What if we used Building Information Modeling (BIM), to store information about materials available for reuse? What if we used artificial intelligence (AI) to match people wanting to design with reused building materials with people who have materials from demolition sites? How about we apply algorithms to find the right match between supply and demand? If we had better management tools, we could use *buildings* instead of the *earth* as a mine: the buildings would become depots and banks of materials.

The construction industry has been slow in adopting digital innovation, even though it is everywhere and growing: blockchain technology is now used by over 20% of traditional banks (Graffeo 2021), the Internet of Things is shaping smart cities in the making, and AI can be found everywhere from online marketplaces like Amazon to matchmaking platforms like Tinder. Though designers in these fields are taking considerable steps forward, the construction industry has not explored these technologies enough to solve its biggest current challenge: transitioning the built environment to a circular economy. The Excess Materials Exchange (EME) platform is an example of a digital marketplace that uses resource passports so companies can exchange excess materials with each other (Excess Materials Exchange 2022). This concept of digital matchmaking, plus exploring technologies such as AI and blockchain, needs to be extrapolated to the building industry.

The construction sector could use emerging digital technologies to make this transition happen. In academia and practice, new digital tools are being developed or used to manage circular construction. Take the Centre Pompidou[2] in Paris, France, for example (Fig. 1). The architects faced many challenges when renovating the structure's façade with circular principles. They needed to replace the bent glass due to changing

[2] The author's own experience is described in the documentary Samsara (Circular Engineering for Architecture and DiCE 2021).

Fig. 1 Renovation of façade and reuse of its glass from the centre Pompidou by maximum, Paris, France. ©Alexandre Attias and maximum architecture

security norms. The value chain in today's construction industry does not make it easy to reuse this glass. Often, it gets thrown away or, in the best-case scenario, recycled. Surely, there must be architects who dream of reusing such iconic bent glass instead of crushing it for recycling or, worse, disposing it in a landfill.

Spoiler: the architects were able to save the glass (as you can see on the right side of Fig. 1), but not without time, passion, and dogged persistence. Could digital technologies have helped these architects navigate this process more easily? This essay argues that we need digital innovation to match materials with users to make circular construction possible.

2 Transitioning to Circular Construction

Narrow, slow, close, regenerate. Let us start with the basics. What is a "circular economy"? It is a system that supports sustainable development to secure the resources to provide for current and future generations. This is achieved by applying four distinct strategies: narrowing, closing, slowing, and regenerating resource loops (Bocken et al. 2021). **Narrowing** the loop uses fewer resources per product, e.g., through structural optimization, so that fewer materials are needed. An example is the Guastavino vaulting system found in hundreds of buildings across the United States, which uses a uniquely thin layer of tiles (Ochsendorf 2010). **Slowing** the loop is about using buildings for longer, e.g., through adaptive reuse of building spaces. An example is Apple's reuse of a historic theatre building in Los Angeles, United States (Foster + Partners 2021). **Closing** the loop ensures that materials are used again, e.g., through reusing materials after demolition. An example is the reuse of window frames from all EU nations in Samyn and Partners' European Council building in Brussels, Belgium (Samyn and Partners 2016). **Regenerating** improves natural ecosystems in which materials exist, e.g., through green facades that help purify the air. An example is the Torre de Especialidades in Mexico City, Mexico, built with Made of Air technology sucking up air pollution (Made of Air 2022). Most of these strategies have been applied only in niche projects, but a collaboration, information sharing, and automation would enable building designers to take a more holistic, circular approach. In this essay, the case of Centre Pompidou's renovation shows how we can 'close' the loop by reusing the bent glass in Maximum Architecture's new project (Fig. 1), but we could also note how its structure already 'narrows' the loop by optimizing water-filled (for avoiding fire-protection) steel columns, how its renovation 'slows' the loop by keeping the building in use longer, and how its presence 'regenerates' the neighbourhood from a social perspective by hosting culture.

Monitor, Manage, Match. If we would like to automate circular construction, or automate the reuse of the bent glass from the Centre Pompidou, we need to: (a) collect and **monitor** data—we need to know what the materials in our buildings are, what resources we use, and their condition; (b) **manage** data—we need to know when these materials and resources become available and where we can store and distribute them; and (c) find the right **match** between supply and demand—we need to know who has materials to offer and who wants to turn them into resources. These monitoring, managing, and matching strategies are already being applied at the scale of an individual building in the Swiss Federal Laboratories for Materials Science and Technology's (EMPA) experimental NEST building, for example. This building is a full-scale experiment, showing the latest innovation in Swiss research and industry. Two particular NEST units demonstrate how circular strategies can be managed in construction: in the Urban Mining & Recycling (UMAR) unit, all resources are reusable, recyclable, or compostable; and in the Sprint unit, Covid-19 flexible offices were designed with largely reused materials (Swiss Federal Laboratories for Materials Science and Technology (EMPA) and Swiss Federal Institute of Aquatic Science and Technology (Eawag) 2018, 2021).

Today, the work of predicting recoverable materials is performed by a limited pool of experts who measure and collate data manually. In this field, efficiency is key, so it is important to understand the available components as quickly as possible in order to connect with potential end users. Today's matchmaking methods are manual and very time-consuming. For example, pioneering reuse practitioners in Switzerland such as Baubüro In Situ hire 'material hunters' who go around the country looking for poles indicating demolition sites[3] and then contact the building owners (De Wolf et al. 2020). There is not yet a feasible circular matchmaking strategy that can be broadly applied in construction practice, but digital technology could improve efficiency of the process.

3 Use Digital Technologies for More Efficient Matchmaking

Digital technologies could have better streamlined the reuse of the glass from the Centre Pompidou, especially for digital matchmaking, digital tracking, and creating online connections. Numerous digital technologies already exist that could support those endeavours. Learning from this reuse experience, laboratories[4] have been created to explore how digital innovation can foster a circular economy.

We need to connect the end-of-life of buildings with the start-of-life of other buildings making the reuse of building materials more effective, user-friendly, and widespread. Existing platforms list materials available for reuse, but in practice, the major challenge is finding the right match. Companies struggle to find architects who design with reused materials, construction sites in which the materials fit, contractors with the skills needed to reuse them, and so on. To solve this, we need to create a **'Tinder' for materials, buildings, and people**. Utilizing digital tools that have proven their feasibility and effectiveness in other sectors, we need to develop algorithms adapted to the construction sector to tackle the challenge of **matching supply and demand**,

[3] In Switzerland, construction sites must be staked out with poles to show how high a new construction will become.

[4] Examples are the Circular Engineering for Architecture (CEA—www.cea.ibi.ethz.ch) lab and the Digital Circular Economy (DiCE—www.dice-lab.com) lab.

acting as 'matchmakers' for owners, users, designers, suppliers, and workers across the entire value chain.

In the last several years, **Industry 4.0**, also known as the "fourth industrial revolution", has triggered a paradigm shift, particularly in the manufacturing sector, and has emerged as a promising technology framework used for integrating and extending manufacturing processes at both intra- and inter-organizational levels through the use of cyber-physical systems (Xu et al. 2018). Tracking devices even enable us to use the **Internet of Things (IoT)** to gather, store, and transmit data on the condition and availability of materials such as Centre Pompidou's glass using cloud computing and wireless sensor networks. The application of IoT in a circular economy is dispersed across various fields, covering topics from smart cities (Larson 2022) to sustainable product lifecycle management (Ingemarsdotter et al. 2019).

If **online platforms**[5] that list all the materials locally available for reuse were well known by all stakeholders in the supply chain, architects such as those at Centre Pompidou could list their glass on such a platform. By connecting supply and demand, digital sharing platforms and marketplaces create circular markets, thus facilitating communication and collaboration between value chain actors. Ideally, we need access to digital representations of a built asset, what we often call **Building Information Modeling (BIM)**. However, the use of BIM is not as widespread as the sector would have hoped today. Its use would help to create what we call a "**material passport**" that includes information about the components in a building such as material type and properties, dimensions and geometry, quantity, condition, location, etc. A material passport with digitally registered data describing a component's characteristics, location, history, and ownership status would serve to facilitate the sharing or selling of materials such as the glass from Centre Pompidou on a digital platform. The Madaster platform, which provides owners incentives to record their data and store the passports of buildings, is an example of such an initiative (Madaster 2022). Material passports can be connected to a digital twin, a virtual replica of the physical world, which is already commonly used in the automobile, aerospace, and process industries to simulate performance (Çetin et al. 2021). Such a connection can potentially extend the service life of building elements through predictive maintenance. Other platforms, such as Material Mapper, provide insight into all buildings about to be demolished, rebuilt, or newly built so that the type and quantity of materials available for reuse can be estimated (Material Mapper 2022). Many other platforms exist on the market, but we lack standardization on how to map materials and globally measure circularity so that these platforms may truly thrive.

To help facilitate resource and waste optimization by matchmaking materials available for reuse with designs from reused materials, we can use AI, and in particular **Machine Learning (ML)**, in combination with **Big Data Analytics**. ML trains algorithms to learn from data and identify patterns for decision-making. More specifically, deep learning, a subset of ML, is based on neural networks. While used regularly in other sectors, it has been recently applied to building demolition records' datasets (Akanbi et al. 2020). Though not a common use case in the field of **computer vision**, which trains computers to interpret and understand the visual world, some research has brought computer vision methodology to the construction site too. We can learn a lot from the many images that exist of the Centre Pompidou. For any building, even things like simple Google Street View images, social media images, historical archives, or national demolition records can enable us to map and match materials generated from deconstruction and demolition projects (Structural Xploration Lab 2018). Algorithms can indeed identify patterns in the data for building components' end-of-life treatments in order to make the right match (Raghu 2021). Companies such as FaSA (Facade Service Applicatie 2022) and Sportr.ai (Spotr 2022) use **AI** to predict the

[5] For example, www.useagain.ch/links/, www.rotordc.com/store/, or www.cycle-up.fr.

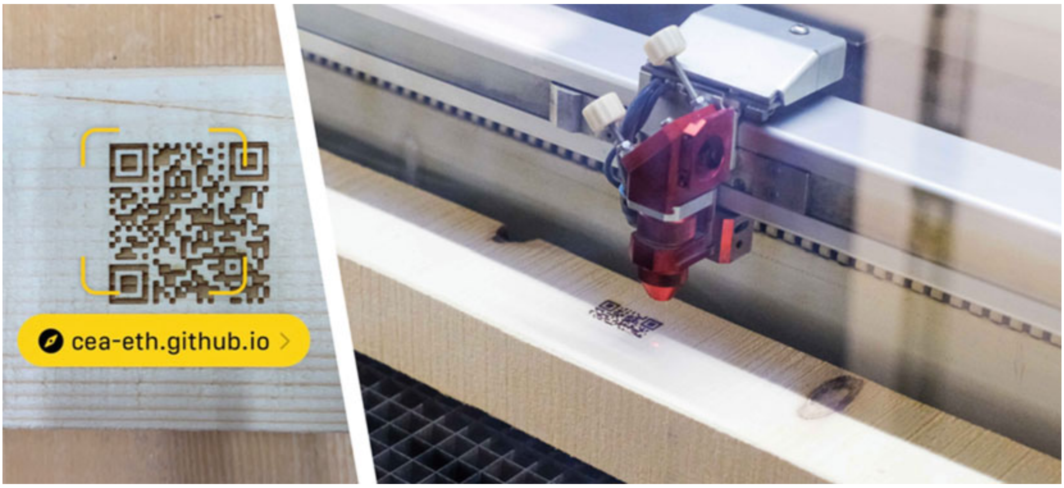

Fig. 2 QR code engraving in reused beams for tracking and tracing material passports for matchmaking. ©Anna Buser

need for façade maintenance. ZenRobotics uses AI to build smart sorting robots for recycling (ZenRobotics 2022). **Geographical Information Systems (GIS)** are often used as a data set to identify, map, and manage resources in building stocks for future reuse or recycling. This system is also used to support urban mining in the built environment. For example, GIS data of the city of Zurich is currently being used to identify the materials available in buildings (Raghu 2022). Using AI techniques, scenario modelling regarding future demolitions can help predict which materials will become available for reuse. For a further level of detail, drone imagery can be used in combination with AI; this is what businesses such as AeroScan offer to assess the condition of building assets (Aeroscan 2022).

Another challenge in reusing materials such as the glass from the Centre Pompidou is the transaction itself. The construction industry's supply chain is highly fragmented, and designers are reluctant to share information about their projects. Researchers are exploring **blockchain technology** (Tapscott and Vargas 2019; Hunhevicz et al. 2020; Li and Kassem 2021), a secure distributed peer-to-peer system that enables transparent value transactions without the need for central authorities and intermediaries, as a way to trace materials. Securely sharing data on where products have been and where they are shipped to along the supply chain is also what TradeLens, powered by IBM, is doing in the global trade and shipping industry (TradeLens 2022). Circulor also enables the traceability of supply chains through blockchain and tagging (Circulor 2022). Indeed, tagging technologies such as Quick Response (QR) codes, Near-Field Communication (NFC), and Radio Frequency Identification System (RFID) chips enable this transparent material tracking. In pilot projects that reuse building materials, such as Buildings As Material Banks (BAMB) (2022) or the ETH Reuse Dome (Gordon et al. 2022), QR codes are used to track and trace materials through different building life cycles (Fig. 2).

4 Collaborate and Be Critical

Complexity & interdependencies. Buildings are unique in the sense that they have a long lifespan, are composed of many parts (site, structure, façade, finishes, furniture), and use diverse resources (materials, land, energy, water, nutrients). Consequently, many stakeholders are involved, including architects, developers, designers, engineers, governments, occupants, clients, contractors, material suppliers, and demolishers. As a result, the industry is extremely compartmentalized. If it is going to transition to a circular model, construction designers need to collaborate with computer scientists, lawmakers, engineers, business developers, and others. Digital tools, such as BIM and IoT, could make it easier for designers to communicate, coordinate, fabricate, and visualize, but not in isolation. One digital technology is rarely used without another: e.g., Material Passports are created using BIM and can be connected to the IoT to sell reused elements on digital platforms.

New business models. Visionary actors in the construction sector know they must reinvent their business models to transition to a circular economy. European research project Circular X presents a series of business models as an inspiration for circular experimentation in construction, including buildings-as-a-service, movable housing solutions, and temporary material banks (Circular 2022). Buildings can be seen as trees by "supplying energy and raw materials for reuse" (Kraaijvanger 2022). The digital technologies discussed here enable these new circular business models. The Material@Hand service from construction materials multinational Saint-Gobain, for example, uses robotic measurements, BIM, and a tracking app to determine the exact material quantities needed for partitioning walls—avoiding the 15–25% waste created by the current industry's bulk package delivery of gypsum boards (Saint-Gobain 2022). The global design, engineering, and architecture firm Arup, the Ellen MacArthur Foundation, and the World Green Building Council recently introduced a Circular Building Design Toolkit at Glasgow's COP26 climate conference, to bring together tools for designing more circular buildings (España 2021).

Rebound effect. As we have seen many times in the past, technological innovations often unwittingly create one new problem while solving another. Designers should become aware of the actual net benefits for environmental, economic, and social sustainability, as well as potential trade-offs and rebound effects of implementing digital technologies. For example, we can't use blockchain technology to facilitate transactions of reused materials without thinking about the energy consumption of this Industry 4.0 technology.

As we have seen, digital technologies can help transition from a linear to a circular model in the built environment. Due to rapid urbanization, powerful driving forces will be needed to generate a fundamental paradigm shift from a linear to a circular model in construction. The digital technologies described here will help tackle urgent societal urbanization needs to ensure that buildings, not raw materials, are the resources for construction in the future. Architects of Centre Pompidou's renovation site were able to make the iconic glass available for reuse in a beautiful project by Maximum Architecture (2022). But digital technologies for matchmaking reused materials are essential for a happy—circular—ending.

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