JLFC Report
Series

Joint Lab on Future Cities (JLFC) Report

No. 4| OCTOBER
2024

Circular Construction: Opportunities and Challenges for Future Cities

AUTHOR
Ying Liu

CITATION
Liu, Ying (2024) *Circular Construction: Opportunities and Challenges for Future Cities*. Joint Lab on Future Cities (JLFC) Report No. 4. Hong Kong: JLFC.

Joint Lab on Future Cities (JLFC) Report No. 4 (October 2024)

Circular Construction: Opportunities and Challenges for Future Cities

Author:
Ying Liu

Citation:
Liu, Ying (2024) *Circular Construction: Opportunities and Challenges for Future Cities*. Joint Lab on Future Cities (JLFC) Report No. 4.
Hong Kong: JLFC.

Disclaimer:
The authors of JLFC Reports are solely responsible for the contents of each publication. If you find any error or problem in this publication, you may write to the JLFC Report Series Editor, Professor Becky P.Y. Loo, at bpyloo@hku.hk. JLFC welcomes any suggestion for improvement and will communicate with authors to take actions to correct any mistake and/or oversight.

About JLFC and the JLFC Report Series

The Joint Laboratory on Future Cities (JLFC) was set up jointly by the Faculty of Engineering and the Faculty of Social Sciences at the University of Hong Kong in July, 2019. It was founded by Dr. Keumseok (Peter) Koh, Mr Tong Leung, Professor Becky P.Y. Loo (Founding Co-Director), Professor Thomas S.T. Ng, Dr. Hayden So (Founding Co-Director), Ms. Rosana Wong, and Professor S.C. Wong. The main aim of JLFC is to establish a platform that facilitates studies on future cities: the people that live in them; the natural environment that they must coexist with; and the technologies that will enable these activities.

As urbanisation sets to become a global trend in the coming century, an increasing portion of the Earth's population are going to be migrating into cities on a global scale. Such massive increase in urban population not only put significantly stress on the existing infrastructure but also challenge every aspect of the human-environment relationship. To ensure the sustainability and resilience of future cities, there is a genuine imminent need to develop fundamentally innovative approaches of constructing and conceiving the ways in which future cities will operate. It is clear that any solutions to the challenges faced by future cities are going to require talents from a wide range of disciplines to innovate in an interdisciplinary environment.

The JLFC incubates such environment through a series of interdisciplinary projects, symposiums and workshops that involve academics, the industry, as well as the government. JLFC was made possible by the generous support by the Prosit Philosophiae Foundation. We also work in partnership with the Global Future Cities AI Lab.

The JLFC Report Series aim to provide state-of-the art reviews of key urban theories/concepts and real-life experiences. A particular focus is placed on the experience of Hong Kong as a high-density and compact city, and its relevancy to other metropolitan cities around the world. All reports in the JLFC Report Series are free for download by the general public. Comments and suggestions either on specific reports or the series may be directed to jlfc@hku.hk.

Table of Contents

1. Circular Economy and Circular Construction

The circular economy is expected to replace the linear economy (Manickam and Duraisamy, 2019). From a life cycle perspective, the linear economy encompasses only a single take-make-disposal process for products or services. In contrast, the circular economy adheres to the Reduce, Reuse, and Recycle (3Rs) principles to extend the life span or the number of life cycles of products or services (Nuñez-Cacho et al., 2018). Figure 1 illustrates the circular economy model as defined in Europe, which highlights the primary aims of reducing raw materials, waste, and emissions in both production and consumption. In recent years, circular construction has also garnered attention.

Figure 1: Circular Economy Model

Source: https://www.europarl.europa.eu/resources/library/images/20230927PHT05951/20230927PHT05951_original.png, accessed September 2024.

However, research and understanding of circular construction are still nascent compared to the circular economy. Figure 2 demonstrates the difference in popularity between the two concepts based on Google trends. Traditionally, architectural design follows a disposable or single-use method, with its lifespan determined by structural design years and social, policy, and market factors (Crowther, 2018; Salama, 2017). However, circular construction stresses that buildings are dynamic processes that can change with time or function requirements (Dams et al., 2021). This involves designing buildings that allow for disassembly and reuse after the end of the initial design cycle. A building's life cycle is more complex than other industrial products, comprising 16 significant phases and one post-demolition phase. Figure 3 shows the complexity of the circular construction framework. The primary objectives of circular construction align closely with the principles of the circular economy, which can be demonstrated in the following modern construction practices:

1. reducing emissions through the use of environmentally friendly materials (Akanbi et al., 2018; Herczeg et al., 2018);
2. minimising raw material inputs by promoting the reuse and recycling of materials(Ghisellini et al., 2018); and
3. managing waste generated during construction (Hossain and Ng, 2018).

However, it is essential to note that merely enhancing raw materials' economic benefits and durability offers limited value to the circular economy within the construction industry (Hossain et al., 2020). A more effective approach to promoting circular construction involves improving the reuse of construction materials. This can be achieved by extending the lifespan of building components and enhancing connection methods, thereby extending the overall life cycle of buildings (Eberhardt et al., 2019).

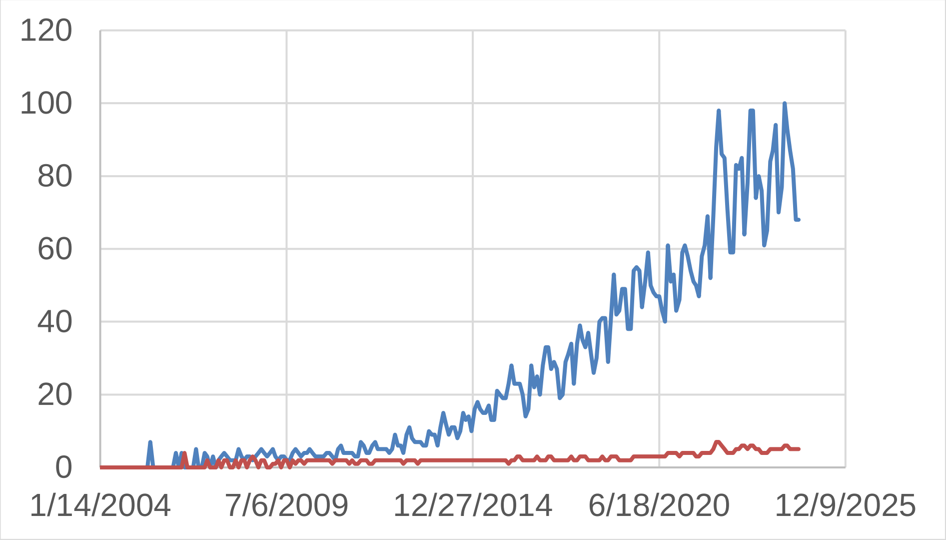

Figure 2: Global Trends of Circular Economy and Circular Construction in the Last Two Decades

Source: https://trends.google.com/trends/explore?date=all&q=circular%20economy&hl=zh-CN

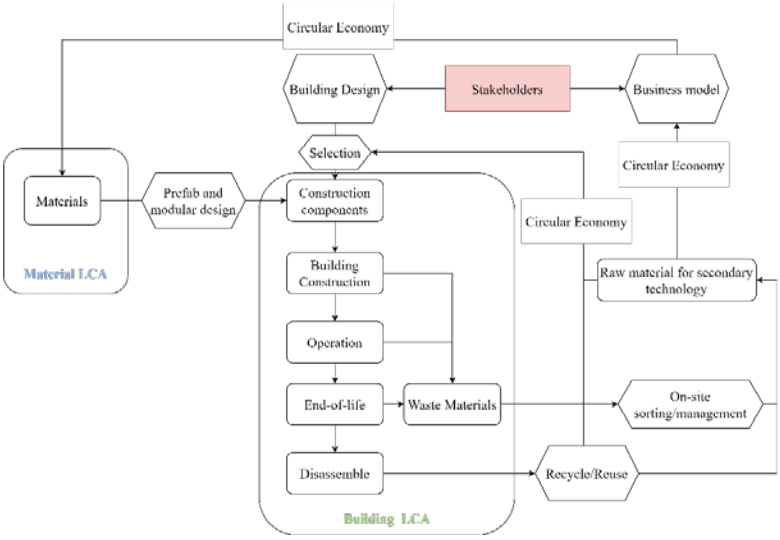

Figure 3: A Perspective Circular Construction Framework (Hossain et al., 2020)

2. Design for Manufacturing and Assembly (DfMA) and Design for Disassemble (DfD)

Changing the construction process is a way to increase productivity; hence, the DfMA is often combined with the prefabrication of building components to improve construction technology and to transfer the construction sector from labour-intensive to industry-intensive (Wasim et al., 2020). There will be further improvements in the DfMA technology as prefabrication becomes more mature and highly integrated. DfMA has two main objectives (Wasim et al., 2022):

1. to make the manufacture of building components simpler (DfM) and;
2. to simplify the installation of building components (DfA)

Since all types of buildings require a manufacturing phase, more research has been done on DfM than on DfA, specifically for prefabricated buildings (Lu et al., 2021). Studies have pointed out that DfMA facilitates the integration of all aspects of manufacturing and construction at the beginning of the project design to reduce negative environmental impact (Wasim et al., 2022).

DfD is another new concept in the construction industry (Salama, 2017). Like DfMA, it starts at the beginning of the project design stage. However, the disassembly design focuses on the building's end-of-life stages, a crucial step in transferring a linear life cycle to a circular life cycle assessment (Salama, 2017). The ultimate goal of DfD is to improve the reuse and recycling rate of building materials after their first life cycle (Crowther, 2005). Therefore, a key focus of DfD is considering how to maintain the status of the building components during disassembly, which is one reason that DfD is closely integrated with prefabrication and modular construction, where the connection methods between building components play a crucial role (Sturgess, 2012).

Since DfMA focuses on the conservation of raw materials and waste reduction (Vaz-Serra et al., 2021) and DfD emphasises the condition of materials after disassembly (Cai and Waldmann, 2019), combining these two approaches can cover critical phases of the building lifecycle and enhance sustainability. Therefore, researchers have proposed the DfX methods to further promote the circular economy in the construction industry by integrating DfMA and DfD (Charef et al., 2022). However, the progress now is mainly limited to theoretical discussion regarding the integration methods and their feasibility, with limited practical applications (Roxas et al., 2023).

3. Upcycling in Circular Construction

In addition to maintaining material performance to enhance component reuse rate, reducing raw material input, and minimising waste generated during construction and demolition, recycling construction waste is also a key focus of circular construction. Construction and demolition waste (CDW) accounts for approximately 30% of all waste generated in the European Union, making recycling a critical issue (Monsù Scolaro and De Medici, 2021). Recycling can be divided into upcycling and downcycling. Upcycling is a form of reuse that involves creating higher-quality or similar-quality products. In contrast, downcycling uses energy to produce lower-quality products from waste without new raw material inputs. Up and downcycling occur simultaneously in the construction industry or within a single building. Some cases demonstrate the potential of by-products from the building industry to be converted into high-value products in other industrial chains, such as using adhesive waste to produce composites for furniture manufacturing (Parece et al., 2022). Additionally, research has explored using demolished building materials to develop composite bricks for construction (Horvath et al., 2021). However, the upcycling of construction waste still faces a series of challenges, including logistics, cost, and safety regulations (Ghaffar et al., 2020).

4. Downcycling in Circular Construction

Downcycling is more common in recycling construction materials and waste (Kirchherr et al., 2017), with its primary significance being the extension of the raw materials' lifecycle, thus delaying their disposal in landfills. Researchers have indicated that the waste hierarchy is essential in improving downcycling efficiency (Kirchherr et al., 2017). Although this recycling mode is eventually regarded as not fully compliant with the requirements of the circular economy — since materials cannot continually re-enter the cycle — it does partially achieve the goals of circular construction, such as reducing the input of raw materials and saving costs (EU Demolition Association, 2022). For instance, in Hong Kong, after a building is demolished, construction waste is sorted and sent to two disposal sites: public fills and landfills (Figure 4). Materials in public fills, such as concrete, bricks, and stones, are reused. For instance, since 2007, materials from the public fills have been used for land reclamation in Mainland China (Figure 5).

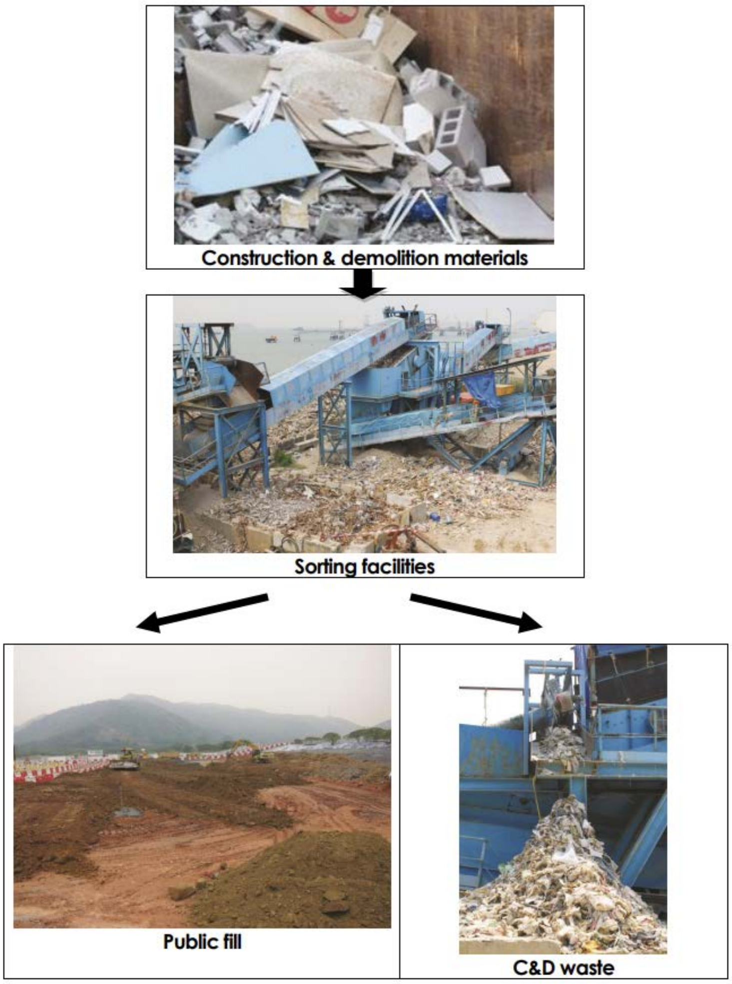

Figure 4: Construction Waste Management in Hong Kong

Source : https://www.cedd.gov.hk/filemanager/eng/content_954/Info_Sheet7.pdf, accessed September 2024

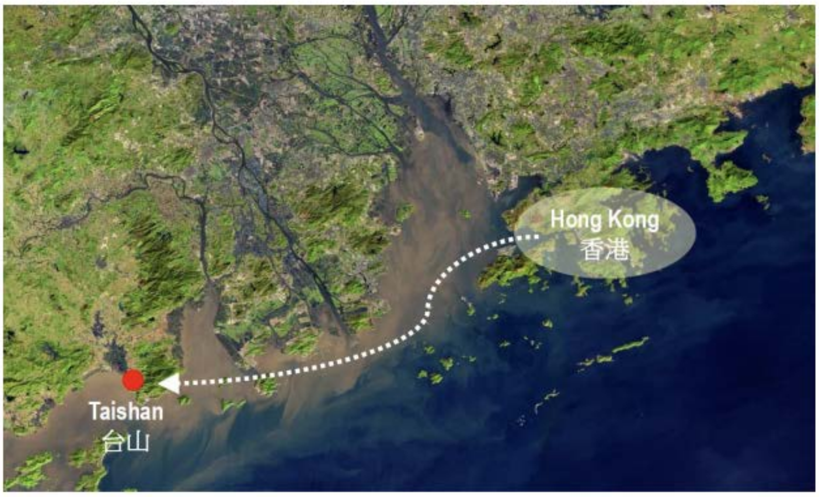

Figure 5: Use of Construction Waste for Land Reclamation in Mainland China

Source: https://www.cedd.gov.hk/filemanager/eng/content_954/Info_Sheet7.pdf, accessed September 2024

5. Opportunities and Challenges

The main advantage of circular construction is that it provides a new perspective on environmental sustainability in the construction sector. Circular construction firstly emphasises material recycling and construction-related waste reduction. Research pointed out that up to 95% of environmental impact can be avoided by reusing building materials according to reprocessing the most commonly used construction materials, such as steel, timber and concrete (Chen et al., 2021). From a macro perspective, circular construction also has the opportunity to promote the development of urban planning towards user-centred communities and nature-based directions. Marcellus Zamora et al. (2020) built up an urban circular model through open data and found that 77% of selected buildings contain reusable materials for further recycling. Some researchers have also found that integrating urban development with local natural resources is helpful to urban regeneration, such as selecting renewable resources around the city for building renovation (Sierra-Pérez et al., 2018). From an economic perspective, circular construction provides a new business model for the construction industry. As materials can be recycled, some original material suppliers can upgrade to become recycling suppliers, and the ownership of materials will also be changed, so users can choose to purchase materials or rent and share construction materials. The transfer of ownership also provides new possibilities for maintaining and reusing materials (Chen et al., 2021).

Circular construction development also relies on the development of the Building Information Modelling (BIM) and the support of the local policy. The BIM model can record detailed information on the entire lifecycle of one building, providing stakeholders with more transparent information for the assessment of circular economy in the construction process and material recycling by supervising building components, material lists, lifecycle costs, carbon emissions, etc. (Chen et al., 2021). Government support is also an essential reason for promoting circular construction. Countries have also launched policies related to construction based on their own needs for a circular economy. The EU's Circular Economy Action Plan includes the construction industry as a crucial part of its circular policy. The construction industry must improve resource efficiency, encourage material recycling and set targets such as recycling 70% of construction waste (Spani, 2020). China has included the circular economy as a supporting target in its 13th and 14th Five-Year Plans and stressed the importance of recycling construction waste (National Development and Reform Commission People's Republic of China, 2021). The UK government has introduced the Construction 2025 strategy to promote sustainable buildings and adopt circular economy principles to reduce the environmental impact of buildings (Maqbool et al., 2023).

However, the development of circular construction also faces challenges. Firstly, the selection of materials is influenced by cost, social, and environmental factors. For instance, although steel structures can be disassembled, their market share in the UK is less than 10% due to high costs and low market demand (Dams et al., 2021). Similarly, the sensitivity of timber structures to hygrothermal conditions challenges their durability (Dams et al., 2021). Regarding design concepts, integrating DfMA and DfD remains theoretical rather than practical. Effective construction waste management requires collaborative efforts to establish contracts or standards that encourage stakeholders to improve the scale and quality of recycling and reuse (Ghaffar et al., 2020). Moreover, the complexity of the construction industry and the focus on short-term profits limit collaboration among stakeholders in the supply chain, affecting the practical implementation of circular construction (Eberhardt et al., 2018).

The fundamental step in achieving circular construction is design, which involves considering materials and their end-of-life disposal during the design phase. Apart from the previously innovative concepts of DfMA and DfD, researchers also focused on selecting building materials. They have proposed that selecting timber and integrating it into the cycle of forest development is a promising direction for developing circular construction (Dams et al., 2021). Additionally, using waste glass as a substitute for cementitious materials in concrete production can reduce carbon emissions by up to 20% (Hossain et al., 2020). With the advancement of prefabricated construction, using materials that are easier to disassemble, such as wood, steel, and glass, can also increase the reuse rate of components (Dams et al., 2021). As construction technologies such as 3D printing and on-site automated construction improve, waste and carbon emissions are further reduced during building and production (Wasim et al., 2022). Furthermore, the integration of BIM and digital twin technologies has positively impacted efficiency in building construction and transportation (Loo and Wong, 2023). These studies address various stages of the lifecycle, creating conditions for the construction industry to implement a circular economy based on the 3Rs principle.

6. International Case Studies

The advantages of circular construction are demonstrated in some construction examples worldwide, as shown in the following case studies, through the applications of modular integrated construction (MiC) technologies for practical and experimental purposes:

6.1 Legacy Living Lab (L3) in Australia

L3 is a two-storey building (Figure 6) in Australia, the first modular building that can be disassembled, designed on the principles of circular economy. Figure 7 shows the eight modules of L3, with a total floor area of 251 m^2, including a conference area and café on the ground floor and an office area on the first floor. The modules have a steel structural frame with a recyclable timber envelope, connected using nuts and bolts, spacers and magnets for easy disassembly. The first life cycle of L3 started in 2019 and lasted for three years before moving to another location. A study was conducted to analyse the lifecycle of L3 and to compare its environmental impact with that of a non-disassemble design (Minunno et al., 2020). Compared to a linear design with concrete foundations and non-removable connections, the L3 has an 88% reduction in global warming potential. Also, it demonstrates advantages in terms of reduced fossil fuel use and ozone protection (Minunno et al., 2020).

Figure 6: Photo of L3, Australia

Source: https://www.fleetwood.com.au/projects/legacy-living-lab-l3/, accessed Oct 2024

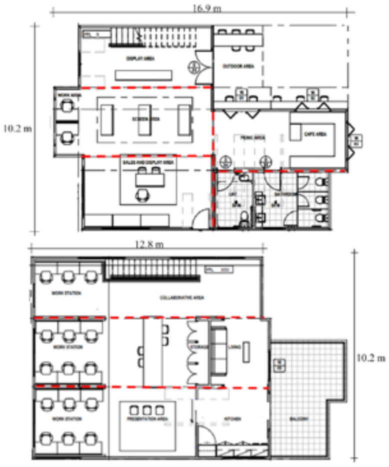

Figure 7: Plane of the 8 Modules Arrangement of L3, Australia

Source: https://www.sciencedirect.com/science/article/pii/S0921344920301750, accessed Oct 2024.

6.2 220 Terminal Avenue in Canada

220 Terminal Avenue (Figure 8) is a transitional housing for homeless people in Vancouver, Canada. The three-storey building includes 40 units. Each unit is in a 25 m^2 floor area, with a bedroom, living room, kitchenette and private bathroom (Luk et al., 2023). The construction time is around six months, which is only around 50% of the average construction time for a building of the same size in Canada, with fewer construction costs (Canada Mortgage and Housing Corporation (CMHC), 2021). Given the pressure on land prices in Vancouver, the building is on a 10-year lease, so disassembly was considered at the beginning of the design. Firstly, the foundation was deployed above ground for future reuse, a design that reduces site

excavation and fulfils the need for easy relocation (CMHC,2021). The building modules that make up the rooms can also be reassembled on the new site according to the original layout, significantly reducing waste and environmental impact (CMHC,2021). 220 Terminal Avenue, as Vancouver's first relocatable MiC, allows the authorities to understand the modular technology better to improve the quality of the building method in the future and helps to spread the knowledge of the building method to the public, allowing people to accept this type of building better (CMHC,2021).

Figure 8: Photo of 220 Terminal Avenue, Canada

Source: https://vipco.ca/news/terminal-avenue-project/, accessed Oct 2024.

6.3 Nam Cheong 220 (NC220) in Hong Kong

Nam Cheong 220 (Figure 9) is the first steel-framed social housing project in Hong Kong using MiC technology and the first to be relocated due to the expiry of the land lease (Luk et al., 2023). NC 220 is a transitional housing project with 12 MiC modules comprising 89 housing, accommodating approximately 162 residents. It took approximately one year from construction to occupancy (Luk et al., 2023). Similar to the previous two cases, the foundation of the building is an above-ground reinforced concrete raft slab on which the steel modular frame is fixed, and the modular envelope is a precast concrete slab (Luk et al., 2023). Due to a land use change, the project was relocated to Wong Yue Tan in 2023 for reassembly. Figure 10 illustrates the timeline for the relocation of the building. The relocation achieved over 95% reuse of materials, with up to 100% reuse of the modular frame and envelope (Luk et al., 2023). This was mainly due to the adoption of DfD construction ideas at the beginning of design, including detachable modular connections such as bolts. The use of BIM to simulate the maintenance during the use phase to maintain the condition of building components is also a key factor for a high reuse rate (Luk et al., 2023). BIM is also able to simulate the disassembly process of the building, providing strategies to facilitate the relocation of the building (Luk et al., 2023).

Figure 9: Photo of the NC220, Hong Kong

Source: https://www.hb.gov.hk/eng/policy/housing/policy/transitionalhousing/details_43.html, accessed Oct 2024.

Figure 10: The Relocation Timeline of NC220, Hong Kong

Source: https://www.researchgate.net/publication/380296288_Technical_Report_on_the_Deconstruction_Relocation_and_Reinstallation_of_MiC_modules_in_the_Nam_Cheong_220_Transitional_Housing_Project, accessed Oct 2024.

6.4 Finch Buildings System in Netherland

Finch Buildings is a series of building modules made of Cross-Laminated Timber (CLT) and Glue-Laminated timber (GLT) (Figure 11). The modules comply with MiC technology and can be used permanently and temporarily. Such modules comprise temporary or permanent MiC buildings of various sizes in cities including Amsterdam, Haarlem, Alkmaar and Leiden in the Netherlands. The project in Leiden is a 3-storey residential building with 38 units (Figure 12). The construction lasted only three months and saved around 568 tons of carbon emissions in the construction stages (Gerard, 2020). The carbon sequestration property of the timber used to manufacture the modules also stores about 319 kg/m^2 of CO_2 (Gerard, 2020). Due to the flexibility of modular combinations, this form of construction can be applied to residential, official, and even commercial buildings. Timber's excellent insulation reduces the heat demand, potentially saving more operational energy for this project. The project was completed in 2020, with a ten-year lease period, after which the government will select another site for permanent accommodation, and the modular construction format will provide convenience for relocation, which more than 95% of the project, including technical appliances, can be directly recycled or reused after disassembling (Izabela, 2016).

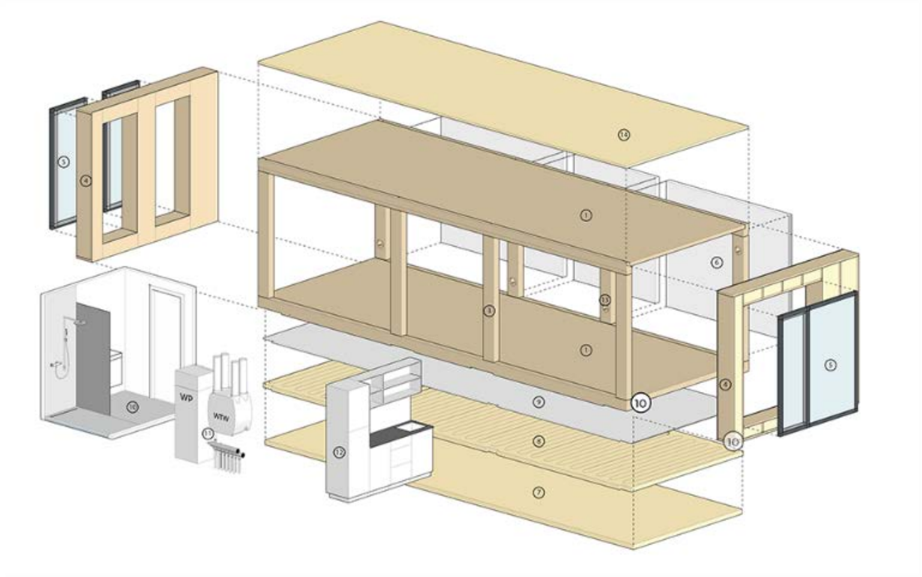

Figure 11: Module example of the Finch Buildings System

Source: https://finchbuildings.com/en/product-2/, accessed Oct 2024.

Figure 12:Photo of the Project in Leiden with the Finch Buildings System https://circulairebouweconomie.nl/wp-content/uploads/2022/01/Circular-Buildings-Strategies-and-case-studies-2021.pdf, accessed Oct 2024.

6.5 NEST research building in Swiss

The NEST research building is located on Empa's campus in Dübendorf, Switzerland (Figure 13). It is an experimental building for modular building research. The building features a central core and three open platforms designed for seamless integration of research modules. It has ten types of construction units covering different research topics. Among them, one type of residential unit, the Urban Mining and Recycling (UMAR), aims to explore how natural resources can be more sustainably used to manufacture building components. UMAR presents a core design concept that requires 100% reuse, recycling or degradation of all materials (Heisel and Rau-Oberhuber, 2020). In addition, as a temporary experimental unit, reassembly is also its design focus, so most unit components are prefabricated (Kakkos et al., 2020). The structure frame is made of wood, with plug-and-socket and screws joints for the convenience of disassembling. The rest of the construction materials mostly come from building waste that has been recycled and processed for reuse, and the technologies included here include cultivated mycelium boards, innovative recycled bricks, and repurposed insulation materials (Heisel and Rau-Oberhuber, 2020). The UMAR unit can save around 39% GWP compared to traditional concrete buildings (Kakkos et al., 2019). All building materials can be cleanly separated and sorted after demolition at the end of life, making the unit valuable for space use and material testing and storage (Heisel and Rau-Oberhuber, 2020).

Figure 13: Photo of the Nest Research Building in Empa's Campus

Source: https://parametric-architecture.com/hilo-nest-research-building-by-block-research-group-eth-zurich/, accessed Oct 2024.

Figure 14: Installation of the UMAR Unit to the Nest Research Building

Source: https://labs.aap.cornell.edu/ccl/umar-unit, accessed Oct 2024.

Resource Rows in Denmark

The Resource Rows is a circular residential project in Copenhagen, completed in 2020. It includes 29 houses and 63 apartments, covering 9,148 m² (Figure 15). This project is a typical example of material upcycling, and the brick used is the key feature representing the circular property. Those bricks are from four demolished buildings whose masonry was cut into 1x1 meter modules, avoiding the need to clean individual bricks (Langer, 2023). These brick modules were assembled onto steel or timber frames, with some embedded in a thin layer of concrete for structural support, and finally used as the prefabricated wall (Figure 16) (Langer, 2023). This innovative process allowed for large-scale reuse of brick sections. The wood used in this project is recycled from the waste during subway construction. After treatment with the Japanese Yakisugi technique, 7 tons of wood were used for the facade and flooring. Around 463 tons of waste are transferred into upcycling materials, accounting for around 10% of the total weight, which reduced around 29% CO_2 compared to the benchmark building in Denmark.

Figure 15: Photo of the Resource Rows

Source: https://www.tudelft.nl/bk/circular-design-atlas/resource-rows#&gid=1&pid=1, accessed Oct 2024.

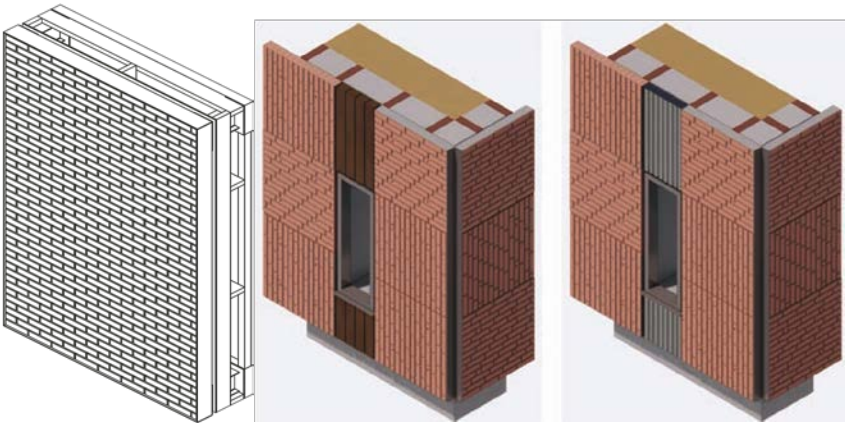

Figure 16: Assembly of the Upcycling Brick Wall in the Resource Rows Project
Source:https://www-tandfonline-com.eproxy.lib.hku.hk/doi/full/10.1080/24751448.2023.2245711, accessed Oct

2024.

7. Key Points in Circular Construction

The application of the circular economy in construction must be considered from the earliest design stages. Firstly, the design should include the concern of reuse. Considering building flexibility and adaptability in the design to allow for modification, disassembly, and reuse of components are essential factors in realising the circular economy in construction (Chen et al., 2021). For example, in the case of UMAR and the Resource Rows, removable building components are easier to reuse and have a higher recycling rate than non-disassemble components in the circular process. In addition, the selection of materials should be according to the ability to reuse, recover or recycle, and this strategy should be extended to all stages of the building life cycle. The circular trajectory design is another critical factor influencing the successful circular economy of one construction project, as other processes, such as transport and second-life treatment of materials, may offset the benefits of reusing materials or components (Ben et al., 2018). Additionally, the number of cycles of building components reuse is also an essential factor affecting the benefits of recycled buildings, and this consideration may affect the initial construction and choice of materials, structures, and facilities.

Economic efficiency is another key to realising circular building's price competition with conventional methods and materials, which remains a significant challenge, especially when processing reused materials. For instance, the brick-cutting and timber treatment methods used in the Resource Rows case are relatively advanced and complex technologies. As a result, there is no significant advantage in terms of construction costs compared to benchmark buildings. This lack of cost advantages may be one of the reasons why this type of construction is not widely adopted. Circular construction development led to an economic transformation in the building-related sectors. Since the recycling potential is different at each stage of a building's lifecycle, the specific business opportunities for stakeholders will change, and other than focusing on construction waste reduction and material reuse, attention should also be paid to the business potential related to upcycling, designing for disassembly, and the sharing economy (Chen et al., 2021). A closed-loop supply chain network can improve the efficiency of the circular flow of materials, selection of industrial facilities locations, and transportation to achieve construction circularity (Chen et al., 2021).

Digital technology applications are another factor that influences the development of circular construction. BIM is the key to establishing digital construction platforms that can link 3D information with material, building components, construction plans and recycling plans, providing clear protocols for stakeholders, which can further optimise cooperation among different sectors in the construction process (Chen et al., 2021). Additionally, the use of blockchain technology in conjunction with RFID, QR codes, and other sensors can enable the development of building material passes (BMPs) that provide decision-makers with more accurate data and information throughout the lifecycle (Chen et al., 2021).

8. Summary

This report discusses the circular economy principles within the construction industry, focusing on reducing, reusing, and recycling to extend the lifecycle of building materials. It highlights the roles of DfMA and DfD in promoting sustainable building practices, allowing for efficient construction, disassembly, and material reuse. While upcycling and downcycling are explored as methods to manage construction waste, challenges such as material selection constraints, high costs, and insufficient stakeholder collaboration hinder widespread adoption. Despite these challenges, technological advancements like prefabrication, 3D printing, digital twins and sustainable material development present promising opportunities for implementing circular construction practices to reduce emissions, minimise waste, and improve overall sustainability in urban environments. The international case studies show the successful implementation of circular construction practices with prefabrication and MiC technology. It also pointed out that the success of circular construction development depends on integrating circular design concepts, new business models, and the implementation of digital technologies.

References

Akanbi, L.A., Oyedele, L.O., Akinade, O.O., Ajayi, A.O., Davila Delgado, M., Bilal, M., Bello, S.A., 2018. Salvaging building materials in a circular economy: A BIM-based whole-life performance estimator. Resour. Conserv. Recycl. 129, 175–186. https://doi.org/10.1016/j.resconrec.2017.10.026

Ben, C., Ramon, M., Simon-Joe, P., Dimitrios, R., 2018. Circular options for building services: Case Studies; 22 Gordon Street, Arup Circular Building.

Cai, G., Waldmann, D., 2019. A material and component bank to facilitate material recycling and component reuse for a sustainable construction: concept and preliminary study. Clean Technol. Environ. Policy 21, 2015–2032. https://doi.org/10.1007/s10098-019-01758-1

Canada Mortgage and Housing Corporation (CMHC), 2021. A Temporary Building Leaves a Lasting Impression-The City of Vancouver uses available sites to build modular affordable housing.

CEDD, n.d. Handling of Public Fill. https://www.cedd.gov.hk/filemanager/eng/content_954/Info_Sheet7.pdf

Charef, R., Lu, W., Hall, D., 2022. The transition to the circular economy of the construction industry: Insights into sustainable approaches to improve the understanding. J. Clean. Prod. 364, 132421. https://doi.org/10.1016/j.jclepro.2022.132421

Chen, Q., Feng, H., Garcia De Soto, B., 2021. Key approaches to construction circularity: a systematic review of the current state and future opportunities. Presented at the 38th International Symposium on Automation and Robotics in Construction, Dubai, UAE. https://doi.org/10.22260/ISARC2021/0127

Crowther, P., 2018. Re-Valuing Construction Materials and Components Through Design for Disassembly, in: Crocker, R., Saint, C., Chen, G., Tong, Y. (Eds.), Unmaking Waste in Production and Consumption: Towards the Circular Economy. Emerald Publishing Limited, pp. 309–321. https://doi.org/10.1108/978-1-78714-619-820181024

Crowther, P., 2005. DESIGN FOR DISASSEMBLY – THEMES AND PRINCIPLES. Environ. Des. Guide 1–7.

Dams, B., Maskell, D., Shea, A., Allen, S., Driesser, M., Kretschmann, T., Walker, P., Emmitt, S., 2021. A circular construction evaluation framework to promote designing for disassembly and adaptability. J. Clean. Prod. 316, 128122. https://doi.org/10.1016/j.jclepro.2021.128122

Eberhardt, L., Birgisdottir, H., Birkved, M., 2019. Comparing life cycle assessment modelling of linear vs. circular building components. IOP Conf. Ser. Earth Environ. Sci. 225, 012039. https://doi.org/10.1088/1755-1315/225/1/012039

Eberhardt, L.C.M., Birgisdottir, H., Birkved, M., 2018. Potential of Circular Economy in Sustainable Buildings. Mater. Sci. Eng.

EU Demolition Association, 2022. Upcycling, recycling, and downcycling. Is there any problem with downcycling?

European Parliament, 2023. Circular economy: definition, importance and benefits. European Parliament.

Gerard, V., 2020. Circular buildings Strategies and case studies. Circular Construction Economy Transition Team.

Ghaffar, S.H., 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

Ghisellini, P., Ripa, M., Ulgiati, S., 2018. Exploring environmental and economic costs and benefits of a circular economy approach to the construction and demolition sector. A literature review. J. Clean. Prod. 178, 618–643. https://doi.org/10.1016/j.jclepro.2017.11.207

Heisel, F., Rau-Oberhuber, S., 2020. Calculation and evaluation of circularity indicators for the built environment using the case studies of UMAR and Madaster. J. Clean. Prod. 243, 118482. https://doi.org/10.1016/j.jclepro.2019.118482

Herczeg, G., Akkerman, R., Hauschild, M.Z., 2018. Supply chain collaboration in industrial symbiosis networks. J. Clean. Prod. 171, 1058–1067. https://doi.org/10.1016/j.jclepro.2017.10.046

Horvath, M., Trachte, S., Pardoen, T., 2021. New circular building composite material to upcycle building wastes. J. Phys. Conf. Ser. 2042, 012167. https://doi.org/10.1088/1742-6596/2042/1/012167

Hossain, Md.U., Ng, S.T., 2018. Critical consideration of buildings’ environmental impact assessment towards adoption of circular economy: An analytical review. J. Clean. Prod. 205, 763–780. https://doi.org/10.1016/j.jclepro.2018.09.120

Hossain, Md.U., Ng, S.T., Antwi-Afari, P., Amor, B., 2020. Circular economy and the construction industry: Existing trends, challenges and prospective framework for sustainable construction. Renew. Sustain. Energy Rev. 130, 109948. https://doi.org/10.1016/j.rser.2020.109948

Izabela, A., 2016. Finch Buildings crafts modular boxes as a flexible solution with durability. Frame Mag. https://frameweb.com/article/finch-buildings-crafts-modular-boxes-as-a-flexible-solution-with-durability

Kakkos, E., Heisel, F., Hebel, D.E., Hischier, R., 2020. Towards Urban Mining—Estimating the Potential Environmental Benefits by Applying an Alternative Construction Practice. A Case Study from Switzerland. Sustainability 12. https://doi.org/10.3390/su12125041

Kakkos, E., Heisel, F., Hebel, D.E., Hischier, R., 2019. Environmental assessment of the Urban Mining and Recycling (UMAR) unit by applying the LCA framework. IOP Conf. Ser. Earth Environ. Sci. 225, 012043. https://doi.org/10.1088/1755-1315/225/1/012043

Kirchherr, J., Reike, D., Hekkert, M., 2017. Conceptualizing the circular economy: An analysis of 114 definitions. Resour. Conserv. Recycl. 127, 221–232. https://doi.org/10.1016/j.resconrec.2017.09.005

Langer, C., 2023. The Resource Rows. Technol. Des. 7, 175–179. https://doi.org/10.1080/24751448.2023.2245711

Loo, B.P.Y., Wong, R.W.M., 2023. Towards a Conceptual Framework of Using Technology to Support Smart Construction: The Case of Modular Integrated Construction (MiC). Buildings 13, 372. https://doi.org/10.3390/buildings13020372

Lu, W., Tan, T., Xu, J., Wang, J., Chen, K., Gao, S., Xue, F., 2021. Design for manufacture and assembly (DfMA) in construction: the old and the new. Archit. Eng. Des. Manag. 17, 77–91. https://doi.org/10.1080/17452007.2020.1768505

Luk, C., Yang, J., Chung, K.-F., Jia, A., Shen, J., 2023. Technical Report on the Deconstruction, Relocation and Reinstallation of MiC modules in the Nam Cheong 220 Transitional Housing Project. https://doi.org/10.13140/RG.2.2.17237.64484

Manickam, P., Duraisamy, G., 2019. 3Rs and circular economy, in: Circular Economy in Textiles and Apparel. Elsevier, pp. 77–93. https://doi.org/10.1016/B978-0-08-102630-4.00004-2

Maqbool, R., Namaghi, J.R., Rashid, Y., Altuwaim, A., 2023. How modern methods of construction would support to meet the sustainable construction 2025 targets, the answer is still unclear. Ain Shams Eng. J. 14, 101943. https://doi.org/10.1016/j.asej.2022.101943

Marcellus-Zamora, K.A., Gallagher, P.M., Spatari, S., 2020. Can Public Construction and Demolition Data Describe Trends in Building Material Recycling? Observations From Philadelphia. Front. Built Environ. 6.

Minunno, R., O'Grady, T., Morrison, G.M., Gruner, R.L., 2020. Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building. Resour. Conserv. Recycl. 160, 104855. https://doi.org/10.1016/j.resconrec.2020.104855

Monsù Scolaro, A., De Medici, S., 2021. Downcycling and Upcycling in Rehabilitation and Adaptive Reuse of Pre-Existing Buildings: Re-Designing Technological Performances in an Environmental Perspective. Energies 14. https://doi.org/10.3390/en14216863

National Development and Reform Commission People's Republic of China, 2021. 14th Five-Year" Plan for the Development of a Circular Economy.

Nuñez-Cacho, P., Górecki, J., Molina-Moreno, V., Corpas-Iglesias, F.A., 2018. What gets measured, gets done: Development of a circular economy measurement scale for building industry. Sustainability 10, 2340.

Parece, S., Rato, V., Resende, R., Pinto, P., Stellacci, S., 2022. A Methodology to Qualitatively Select Upcycled Building Materials from Urban and Industrial Waste. Sustainability 14. https://doi.org/10.3390/su14063430

Roxas, C.L.C., Bautista, C.R., Dela Cruz, O.G., Dela Cruz, R.L.C., De Pedro, J.P.Q., Dungca, J.R., Lejano, B.A., Ongpeng, J.M.C., 2023. Design for Manufacturing and Assembly (DfMA) and Design for Deconstruction (DfD) in the Construction Industry: Challenges, Trends and Developments. Buildings 13, 1164. https://doi.org/10.3390/buildings13051164

Salama, W., 2017. Design of concrete buildings for disassembly: An explorative review. Int. J. Sustain. Built Environ. 6, 617–635. https://doi.org/10.1016/j.ijsbe.2017.03.005

Sierra-Pérez, J., García-Pérez, S., Blanc, S., Boschmonart-Rives, J., Gabarrell, X., 2018. The use of forest-based materials for the efficient energy of cities: Environmental and economic implications of cork as insulation material. Sustain. Cities Soc. 37, 628–636. https://doi.org/10.1016/j.scs.2017.12.008

Spani, R.C., 2020. The new circular economy action plan. FEEM Policy Brief. https://environment.ec.europa.eu/strategy/circular-economy-action-plan_en

Sturgess, D., 2012. An architecture of disassembly and cyclical material life. https://figshare.com/articles/thesis/An_Architecture_Of_Disassembly_And_Cyclical_Material_Life/14644215/1?file=28122570

Vaz-Serra, P., Wasim, M., Egglestone, S., 2021. Design for manufacture and assembly: A case study for a prefabricated bathroom wet wall panel. J. Build. Eng. 44, 102849. https://doi.org/10.1016/j.jobe.2021.102849

Wasim, M., Han, T.M., Huang, H., Madiyev, M., Ngo, T.D., 2020. An approach for sustainable, cost-effective and optimised material design for the prefabricated non-structural components of residential buildings. J. Build. Eng. 32, 101474. https://doi.org/10.1016/j.jobe.2020.101474

Wasim, M., Vaz Serra, P., Ngo, T.D., 2022. Design for manufacturing and assembly for sustainable, quick and cost-effective prefabricated construction – a review. Int. J. Constr. Manag. 22, 3014–3022. https://doi.org/10.1080/15623599.2020.1837720