Exploring the Feasibility of Constructing Recyclable Prefabricated Buildings to Expedite Sustainable Urbanisation in Developing Countries

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Abstract. Prefabricated buildings have been intensively studied for its multiple virtues, probably to become the main architectural form in the future. However, though prefabricated buildings have attracted enormous interest in energy-saving field for its pollution reduction action, its contribution is paltry when compared to the great amount of waste produced in construction, demolition or reconstruction stage. The idea of constructing buildings with recyclable materials may provide a new train of thought. Current application of using recyclable materials to construct prefabricated buildings is still in the exploratory stage. The corresponding researches are also rare, especially in developing countries. Literature review and qualitative methods were adopted in this study to discuss whether the idea is conducive to facilitate the implementation of sustainable urbanisation, and consider another alternative - Additive manufacturing (AM) technology. This paper is expected to contribute to the data transformation of the construction industry.

Keywords: Prefabricated Buildings, Modular Buildings, Recyclable Materials, Urbanisation, Sustainable Development

1 Introduction

Developing countries account for a large proportion at the second Belt and Road Forum [1]. These countries are still in the early stages of industrialization and urbanization, despite their abundant natural resources. They are the biggest beneficiaries of the cooperation under the Belt and Road Initiative (BRI) framework. Although urbanisation has been a driver for global economic development, it also leads to a lot of urban challenges on social and environmental issues, especially in those developing countries (icRS 2020). Thus, realizing sustainable development has become an urgent topic.

With the development of the city, the demand for building space and resource utilization is increasing, and the problem of housing shortage is becoming more and more serious. Prefabricated and modular systems have been adopted to solve these problems in construction projects for reducing the impact of construction on the environment, including natural resource loss, cost and energy consumption caused by landfills. However, at the end of the structure's life cycle, there is a lack of structure that can be disassembled and reused. In the process of construction, demolition and renovation, only 20% of the construction waste could be recycled and reused [2]. Based on the lower material recovery rate, the idea that applying recyclable materials to construct prefabricated buildings may be a feasible way to reduce the waste of materials and energy consumption.

Current researches are mature in Prefabrication Technology, while in terms of recyclable materials, it is still in the experimental stage, mainly the trials of the low-rise temporary communal facilities. Literature review and qualitative research would be conducted to explore the feasibility of constructing prefabricated buildings with recyclable materials and whether it could contribute to expedite sustainable urbanisation in developing countries. The finding is that it would be helpful to some extent, but due to the technical conditions and other factors, further researches are needed.

2 Background

2.1 Ubanization: Environmental Issues

The rapid development of urbanization has promoted China's economic trans-formation in the past 30 years, with a substantial increase in GDP, which has helped more than 500 million people out of poverty. By 2030, according to the growing trend of per capita income, China's urbanization rate is expected to reach about 70%, and about one billion people will live in cities.[3]. Economic growth and rapid urbanization have benefited China greatly in reducing poverty and improving people's living standards, but has also brought China environmental pressure. Low efficiency of land development, pollution, increasingly scarce resources and other issues have emerged. As Sri Mulyani Indrawati stated at the launching meeting, urbanization creates opportunities, but cities also account for nearly 70% of world energy consumption and 80% of global greenhouse gas emissions [3]. Thus, a more coordinated urbanization process is needed.

2.2 Solution: Sustainable Development

The concept of sustainable development was proposed as a solution to the negative impact of the urbanization process. In National New Urbanization Plan 2014-2020, measures to improve the sustainable development ability of cities have been raised, including optimizing urban industrial structure, spatial structure and management pattern, conforming to the new concept and trend of modern urban development, promoting urban green development and enhancing urban innovation ability, improving intelligent level [4]. This concept could be traced back to the book published by UN-Habitat in 2012, and earlier The State of Asian Cities 2010/11 and Training courses on Sustainable Urbanization launched by the International Urban Training Centre in 2007. The UN-Habitat note that green economy is committed to leading the economy to a higher and fairer development direction based on low-carbon and energy intensive utilization. It is considered to be a scientific and modern means to apply the principle of sustainable development to the present city, which integrates all aspects and protects the environment while promoting economic growth and employment [5].

2.3 Building: Essential Element

According to Malik, A., & Maheshwari, A. (2018), “the global construction industry is the world's largest consumer of raw materials, and constructed entities account for between 25 and 40 percent of total carbon emissions in the world”, but less than a third of construction and demolition waste is recycled or reused [6]. It proves that construction has been an essential part in the progress of sustainable urbanisation. Urbanization drives the demand of sustainable development of construction industry and transitioning. The United Nations Environment Programme estimates that improvements in the construction industry could help

countries to reduce emissions economically and effectively and achieve energy savings of more than 30% [7]. Recycling the waste materials reduces global emissions for the industry and makes its businesses more environmentally sustainable. There are also considerable commercial benefits in the use of circular economy in the construction industry.

3 Literature Review

3.1 Prefabricated Buildings

Prefabrication has environmental advantages in reducing components, reusability, adaptability and recyclability [8]. Prefabricated buildings almost eliminate the waste generated by demolition. After prefabrication, waste can be greatly reduced in plastering, wood formwork, concrete pouring, reinforcement and other on-site production activities, and the waste of plastering can be reduced by 100% [9]. The construction cycle of prefabricated building is short, and it is easy to recycle, re-purpose and reuse. By adopting certain strategies for prefabricated buildings, circular economy can be implemented in the construction industry.

Although more and more modular buildings are oriented to permanent buildings (modular structures are not intended to be relocated, just like traditional buildings), many enterprises still rely on the temporary use of modular buildings. When rapid expansion of space is required, resettable buildings are brought to the site or used as swing space to accommodate students, patients, or employees in case of renovation or emergency. When additional space is no longer needed, the modular building will be removed from the ground and reused.

Unlike traditional building strategies, these modules will not be removed and the materials will not be thrown into the local landfill after one use. Instead, used modules are updated so they can be reprocessed and used in future projects, further reducing the need for additional raw materials and energy to create new things from scratch [10].

Although modular housing has its advantages, it is difficult to resell because of its low quality. Modern modular structures are trying to change the general perception of these houses, but it may take some time for the public to see them as the same as traditional brick and concrete structures. In addition to quality concerns, other problems such as excessive energy consumption during the construction process and the high cost of special design still exist, so that modular buildings can not give full play to their original value.

3.2 Recyclable Materials

As a way to promote waste reduction or prevention, 3R rules are created: reduction, reuse and recycling [11]. The first rule of 3R is reduction, which is quite extensive. It can be understood as the reduction of materials, energy consumption and waste, especially the reduction of ecological footprint. Reduce the pollution of building materials, reduce the use of building materials, reduce the use of building materials, reduce the use of building materials. Reuse is a concept based on the multiple use of materials and does not require processing and therefore does not require energy. In architecture, reuse can change from reusing materials and construction elements to reusing structure. This process is called adaptive reuse. Finally, recycling, which requires the transformation of a material before it can be reused. This means that manufacturing or manual processes that require energy are necessary

to enable materials to take on new forms and uses. Recycling is a substitute for waste materials that do not meet the reuse conditions. Compared with the use of traditional materials, recycling is usually cost-effective.

The ideal recyclable materials should be reused, i.e., without energy consumption, among which the recycled plastic, glass, timber, recycled steel, mycelium, ashcrete, repurposed tile and aluminum have been adopted in real case.

3.3 The Combination——Recyclable Prefabricated Building

The sustainability characteristics of advanced off-site construction solutions have been well documented, greatly reducing waste and improving thermal efficiency and life cycle cost-effectiveness. Whereas recycled and renovated modular buildings take sustainable construction to a whole new level.

Case Study - the NEST "Urban Mining & Recycling" unit

In Switzerland, a residential module built entirely of reusable, recyclable and compostable materials, a modular research and innovation building operated by EMPA and EAWAG in Dubendorf.

The growing scarcity of resources and the resulting desire to move away from today's one-off thinking means that the construction sector must give more consideration to the multiple uses and recyclability of materials, as well as other construction methods. The latest nest unit called "urban mining and recycling" implements these ideas; the result is a residential module whose structure and materials can be completely reused, reused, recycled or composted, and then decomposed.

"The materials we use will not just be used and processed; instead, they will be extracted from the loop and returned to it," Dirk E. Heber explained the concept [12]. As a result, a variety of continuously processed components are used in the "urban mining and recycling" unit; the various materials can be separated, classified and returned to their respective material cycles without any residue. In addition, the unit also used a new type of heat insulation board made of mushroom mycelium, innovative recycled stone, recycled insulation materials and rented carpets.

Besides Switzerland, U.K., U.S., Indonesia and even rural Chinese village has established some modular buildings utilizing local unique recyclable materials [12].

4 Limitations and Further Studies

4.1 Limitations

Cost Prefabricated integrated building needs an integrated manufacturing base with modern chemical plant. The construction of the base has a huge one-time investment, which raises the threshold for enterprises to enter and brings greater investment risk. Although the application of prefabricated buildings and recyclable materials can bring economic benefits, it also requires a large amount of R & D and design costs.

Strength The integrity and stiffness of prefabricated buildings are weak, so the seismic impact capacity of prefabricated buildings is also poor. In addition, the strength, durability and accessibility of the prefabricated buildings and recyclable materials are remain to further study.

Restrictions There are some restrictions on the height and the number of floors of prefabricated buildings. The cases mentioned above are all low rise prefabricated buildings, instead of high-rise example. There is also a lack of skilled workers, so the after-sales and maintenance will be relatively troublesome.

4.2 Further Studies

In addition to the analysis weight, recovery, cost, durability, renewability, greenhouse gas emissions, energy consumption and other material characteristics, economic benefits and environmental impact, digital planning and management may become the next evolution. Wang et al. [13] present the potential viable alternative for modular buildings, the Additive manufacturing (AM) technology (also known as 3D-printing). The AM technology could counter the deficiency of prefabricated buildings in terms of cost, size, quality, safety, and environment. The whole process of AM technology is controlled by computers, thus could prevent fragile structures and structure risks, extend the life of the architectures. Moreover, it could avoid high costs for long-distance transportation, reduced carbon footprint and environmental impact, which simplifies the process of recycling, and allow more freedom in design. Whether it could make the construction industry keep pace with the times requires more feasibility studies.

5 Conclusion

Employing recyclable materials in the construction of prefabrication buildings does improve the original cons of prefabrication buildings, the life cycle, availability and reusability of materials, and avoid demolition, thus reducing the emission of construction waste and carbon dioxide, which benefits the acceleration of the sustainable urbanisation. Nevertheless, new issues are also emerging. For instance, the durability, strength, accessibility and specific characteristics remain further research and attempt.

An interesting concept “build for unbuild” is noted during the progress of literature review. Dirk E. Hebel [14] explains that “The materials that we utilize will not just be used and then disposed of; instead they will be extracted from their cycle and later returned to it”. That should be the goal when construction to reach the sustainable development, producing the minimum waste and minimal impact on the environment.

Despite prefabricated buildings are widely used and praised, the Additive manufacturing (AM) technology could be the new trend to replace prefabrication. It may even be more energy-efficient and cost-effective than the combination of recycled materials and prefabricated buildings. Technological progress and further research on MA technology are also required. Developing countries should seize the opportunity of BRI cooperation to complete the digital transformation and upgrading of the construction industry to realize sustainable urbanization.

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