Circular Economy in the Built Environment: 
Supporting Emerging Concepts

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Abstract. This paper presents circular built environment case studies from Europe, Asia and Africa covering circular housing concepts, circular office refurbishment, circular construction and demolition waste management and circular building material production. One Planet Sustainable Buildings and Construction programme is developing a data base on pilots addressing different life cycle stages of circular buildings. Those cases can be exploited when developing sustainable solutions that meet local conditions. The intent of reporting the case studies is to support the building and construction sector to move towards a circular economy.

1. Introduction

One Planet Network of 10-year framework on sustainable consumption and production consists of six programmes that operate in buildings, procurement, tourism, lifestyles and education, consumer information and food systems in both developed and developing countries. The network has chosen circular economy as a common means to implement Sustainable Development Goal 12 (Target 12.1) to accelerate the shift towards sustainable consumption and production patterns. Circular economy refers to the potential to change our production and consumption patterns and associated business models to ensure that waste is reduced and waste itself becomes a resource such that virgin materials are no longer used.

The building sector has a huge potential to mitigate climate change and practice resource efficiency through applying circularity principles providing at the same time important economic and social benefits. Ellen MacArthur Foundation [1] has identified 115 billion euros investment opportunities in the built environment in Europe for designing and constructing buildings based on circular principles, closing the loop on building construction and demolition materials, and building circular cities. Not just creating jobs, application of circular principles supports resilience, reduces resource use and lowers overall emissions in the process while also creating new and profitable business opportunities.

By 2050, the estimate of material economics [2] for only cement, steel, aluminium and plastic used for construction in the EU would result in emissions of 230 Mt CO2 if they were made with today’s production processes. Demand-side measures could reduce this by 80 Mt CO2 per year, or 30% by simple measures of designing for longevity and disassembly, floor space sharing, reuse of existing buildings, materials efficiency, efficient construction practices, reduced waste in construction and building material reuse and recycling.

This paper presents examples of circular construction from Europe, Asia and Africa to show the value and success of circularity in the built environment already achieved worldwide. Policymakers,
investors and construction clients have control over the business models and contractual frameworks in which built environment assets are created and operated. Their actions can maximise impacts at all scales along the value chain.

The selected case studies demonstrate different approaches applying circularity in sustainable buildings that can help in reducing CO2 emissions, lowering maintenance costs, and which can be reused at the end of life without considerably reducing their value. The case study approach provides richness in the approaches taken, underlying drivers, value-add and key approaches.

2. The approach
Sustainable Buildings and Construction Programme (SBC) in the One Planet Network looks at circularity in buildings throughout their service life. Circularity aspects are relevant and should be considered in every phase during the service life, not only towards the end of life in renovation or demolition phases. It is important to take circularity as a starting point already in the manufacturing and design phases.

SBC has appointed circular built environment nodal points from its global network in Europe (Finland and the Netherlands), Asia and the Southern Pacific (India and Australia), Africa (Kenya and South Africa) and in Latin America and the Caribbean (Ecuador and Mexico). SBC experts in these countries collect local needs, analyse case studies and disseminate information about good practices in the region.

SBC has developed a simple framework and template to collect key information from case studies in a common format. The intention is to develop a database with a simple access to information about circular buildings in different parts of the world. Collected information contains a short summary with keywords, the life cycle phases that are relevant to the case study followed by a key message and an explanation what is unique in the project. The other aspects include the time of operation, stages of the building life cycle, stakeholders included, replicability and scalability of the case and main challenges encountered.

The next section presents successful case studies already undertaken that highlight different features of circular buildings. Circle House in Denmark is a scalable housing unit where 90% of the construction can be disassembled and reused without losing significant value during or end of life. It is intended to be scaled up to 60 units in varying shapes of row houses or apartment buildings in a new neighbourhood.

The first Dutch case, Alliander HQ, is an extension of an existing office building where 90% of its materials are reused or remain in the building site which became energy positive for the first time in the Netherlands. The other Dutch case in Brummen presents commissioning of a temporary town hall for 20 years. That building received the first materials passport turning it into a raw materials depot where approximately 90 per cent of the materials in the newly added space can be dismantled and reused.

3. Case studies
3.1. Europe

Circle House in Aarhus, Denmark, consists of 60 new social housing estates designed according to the principles of circular economy, which is expected to be completed in 2020. The goal is that 90% of the construction can be disassembled and reused without losing significant value during or end of life. These and other such projects demonstrate how sustainability and financial gain can go hand in hand to inspire future construction that has little impact on the environment. In addition to serving as housing, Circle House is a scalable demonstration project that can provide the building industry new knowledge about circular construction. Circle House consists of a range of building systems that can be assembled, disassembled and reassembled into other buildings while keeping their economic and aesthetic values intact [3].

The residential typologies are a mix of two- and three-storey terraced houses and five-storey tower blocks. The superstructure of three different typologies are built from the same six concrete elements, optimized for a quick construction, disassembly and reuse. In order to transform the building industry to a circular building practice the entire value chain of the industry needs to be engaged. The Circle House project involves more than 30 Danish companies across the entire industry. The Circle House project aims to develop, propagate and anchor knowledge about circular construction in the industry [3].

The increasing attention on resource consumption and the responsibility for future generations poses new demands and requirements for client consultancies and new constructions to reflect an integration of social responsibility and financial circumstances. Circle House is an example of this and provides insight into experiences in the circular housing development. The project demonstrates how sustainability and financial gain can go hand in hand to inspire future construction, so that we get build housing that reduce CO2 emissions, have lower maintenance costs, and can be recycled [4].

![Figure 2. Circle House in Denmark, ©Søren Nielsen, Vandkunst.](image)

Alliander HQ in the Netherlands could be perceived as a new build even though it is an extension of an existing building, where 92% of the materials are labelled as ‘circular’. Originally built 30 years ago to accommodate 600 people, the expansion in 2015 has allowed for a further 900 occupants. 90% of the building materials from the existing building are being reused or remain on-site. The existing buildings, which were composed of different blocks, are respected and integrated into the new design: up to 83% of the existing constructions remain. Circularity has been an integral part of the design in many ways: respecting the majority of the existing constructions, using waste wood for the facades, reusing the concrete from the parts which were demolished, reusing the steel construction for the extensions of the buildings, recycling the asphalt from the existing roofs, reusing the existing toilets and ceiling plates and converting the existing doors into new furniture, amongst other things. A “raw material passport” is made to assure the reuse of all the materials in the future. This passport document contains information on all the raw materials, which are added during the renovation, the new installations, and the existing materials which were already there. It includes information about who has handled the materials, where they were temporarily stored and ways in which they can be reused [5].

The building complex provides more energy than needed, which can be used by neighbours in the surroundings through the Smart Grid, starting a Green Alliance in the community. The design of the
building optimizes the use of energy, the design of the roof stimulates natural ventilation, and the atrium becomes a “second skin” for the closed volumes, creating a tempered ‘in-between’ climate. The use of solar panels and underground water for thermal storage makes it also CO2 neutral. The solar panels are placed in the parking area, acting also as shading and protection for the cars, giving them a double function. Since these were placed first, it was possible to achieve an energy positive building site for the first time in the Netherlands.

Brummen Town Hall is another circular Dutch example where due to concerns over frequently shifting municipality borders, the municipality commissioned a building for a service life of only 20 years. The answer to this request was a design made for disassembly and consistent use of reusable and renewable, high quality construction materials. Approximately 90 per cent of the materials in the newly added space can be dismantled and reused at the end of its service life. After this period, only the original 1890 building will remain on the site. The building also received the first materials passport in 2013 turning it into a raw materials depot in which the details of every piece are known, including their destination in a second life for some elements [6].

Rather than using cheap materials, the building minimises the use of concrete and incorporates a variety of high-quality reusable materials, which will be dismantled and returned to their manufacturers at the end of the building’s life. The systems were developed in co-operation with manufacturers to enable easy disassembly in conditions that maximize their inherent material, component and product value after the 20-year period. Involving suppliers at very early stages in the design phase resulted in a very high degree of circularity of the building. All details of the building are known and documented, including their destination in a second life. It was the first building in the world conceived as a raw materials depot and equipped with a materials passport. The project led to a completely new way of looking at buildings and the way the temporary function they offer can be facilitated through a modular and circular building. It introduced the concept of products and buildings as a materials depot. It also made the team realise that current models of linear depreciation are not in line with circular value preservation [7].

3.2. Asia

In an increasingly resource constrained world, the main challenge for India is to find a balance between its developmental goals and constraints on minimizing the environmental impacts from increasing resource use [8]. Over the last couple of decades most of the Indian cities have experienced dynamic transformation due to rapid urbanization and infrastructural growth. This has led to increased use of construction and therefore the need for material resources. While the Indian Government is formulating effective policies to encourage use of secondary resource materials, the city of Ahmedabad has demonstrated replicable and profitable examples of utilization of wastes to replace virgin resources through a practice-to-policy connect.

Ahmedabad is the capital of the state of Gujarat and the 7th largest city in India having a population of around 5.5 million. It is one of the most important industrial and economic hubs in the Western part of India. The development and maintenance of the city is controlled by the Ahmedabad Municipal Corporation (AMC) having a control over 464 km². As with other metro cities the spurt of construction activities has and is generating quite a substantial amount of construction and demolition waste (C&D) within the city boundaries. Thus it was imperative to have an effective eco-system to manage this waste.

To design and implement a well-managed waste management system, the first and foremost step was to quantify the amount of C&D waste being generated and their location. Thus AMC designed and implemented a well laid out system of mandatory use of permits for demolition and new construction. This helped in quantification of waste being produced which was estimated to be around 700 metric tonnes (MT) per day. However, the actual generation was estimated to be much higher since there was construction being carried out in fringe areas without mandatory permits. The C&D waste management in Ahmedabad was based on a Public Private Partnership between Amdavad Enviro Projects Private Ltd. (AEP) and AMC. AEP was responsible for managing and processing the waste. AMC supported by designing waste collection systems and policies. 16 designated waste dumping sites helped in
collection of the C&D waste from point sources. AEP transported the waste from the collection points to the processing facility and was paid Rs. 160/tonne (about $2.5 USD) as a tipping fee. The amount varied as per distance of collection points also. The collected waste was processed at a centralized processing facility into coarse and fine aggregates and used for producing standard building materials.

To understand the baseline of various building material product in and around Ahmedabad, finished products were tested which formed the minimum threshold criteria for developing products with C&D waste. The mix design was modified since the C&D waste aggregates had different properties compared to natural stone aggregates. The existing portfolio of standard building products of AEP, e.g. paving blocks, concrete bricks were augmented with high value concrete products through extensive lab and pilot scale research. Thus, heavy duty paving blocks (M80) for specialized use were also developed (Figures 3, 4). Products were also developed from the unusable fine aggregates. To increase the acceptability of the products, they were certified by external agencies (GRIHA: Green Rating for Integrated Habitat Assessment, India) which enabled users to earn green rating points. Apart from quality, product development also ensured that it fulfils all the criteria set forth by the Bureau of Indian Standards [9]. In addition to technical parameters the developed products were cheaper or at-par cost with existing products available in the market. This was the most non-negotiable criteria followed by the product development team since Indian markets are price sensitive especially when waste products are used to make finished goods.

Figure 3: C&D waste and processed aggregates at Amdavad Enviro Projects Pvt. Ltd. (AEP), ©Soumen Maity.

Figure 4: Processing facility and finished products, ©Soumen Maity.

Once the supply side of the value chain was ensured; demand of products was accelerated through public procurement policies. This was necessary since majority of the concrete products were procured by AMC at a city level and by various Government Departments at the State level. Various consultations and policy notes were prepared for preferential procurement of waste based products by AMC. They were verified through scientific and market based evidence and field visits. It was also worked out with AMC that circularity principles not only ensure sustainable use of waste materials but is also profitable for AMC since more expenses are being incurred by collection, management and dumping of wastes.

City level policies enacted by AMC, ensured that 75% procurement of non-structural products for public construction were compulsory from waste-based products. Additionally, a 5% procurement incentive was allowed for C&D waste based products compared to those produced from virgin raw
materials. These public policies not only ensured an accelerated uptake of C&D waste based products in public use but also created a large market in private commercial construction. The demonstrated projects by the Government formed excellent marketable examples to ensure that waste are not dumped but put into profitable use.

3.3. Africa

In Africa, Malawi is a landlocked country situated in Southern Africa surrounded by Tanzania, Mozambique and Zambia. It has a population of around 17 million growing at a rate of 2.8% per annum. As per UN reports [10], Malawi has one of the highest urbanization rates at 5.22% and is also one of the most vulnerable countries in sub-Saharan Africa from the negative effects on climate change. This is already being evident from the floods and droughts affecting the country and the loss of lives and infrastructure [11].

With the present rate of urbanization, it has been estimated that a minimum of 21,000 housing units are required over the next 10 years to meet the urban housing demand. In Malawi, the main and only affordable building material are “burnt clay bricks”. Use of alternate materials is sparse, limited to subsidized construction activities. If an average of 85,000 burnt bricks are required to construct a typical urban house usually brick-fenced, approximately 1.7 billion burnt bricks are needed each year to meet the housing demand only (demand of burnt bricks due to infrastructural needs will be additional). This estimate should be seen as conservative as the requirements of public infrastructure or rural housing are not considered.

Currently, brick production in Malawi is highly decentralized and unorganized. The entire Malawian brick industry uses open clamps for firing (Figure 5). Due to poor quality of green bricks, clamps are not stacked high enough. There is no control over the firing process in the clamps. Fuel used is only fuelwood. It is estimated that around 850,000 tonnes of fuelwood will be required each year to produce around 1.7 billion bricks if alternate technologies are not adopted. Besides fuelwood, fuel in the form of leafy biomass is also used to provide additional energy. However, the quantity and quality is not suitable to provide additional heat to uniformly fire the upper layers of the clamp. No waste materials are used in green brick making for use as body fuel.

This high rate of urbanization puts tremendous pressure on the entire building material sector. With constraints in supply of material both the quality of product (brick) and the application (house) has degraded to an alarming extent resulting in poor quality and increasing construction costs. The current state of housing has also put an immense pressure on the low cost housing sector. Most often it has reached beyond the means of common beneficiaries. Approximately 20% more bricks are required to be constructed with traditional bricks compared to regular shaped and sized improved products. The use of quality bricks and associated eco-concrete products can drastically bring down the cost of construction of housing. Thus, the two major concerns from the Malawi brick sector are increased deforestation due to use of fuelwood and poor brick quality resulting in poor construction quality.

To solve the issues of deforestation, climate change and housing quality, it was decided to demonstrate the EcoKiln technology for producing burnt clay bricks. Some of the major advantages of EcoKiln were use of coal for the burning process, modular structure with an option to expand as and when needed, round the year production, consistent and better quality and energy efficiency with very low levels of emission. An EcoKiln was established with private investment at Mthokya, Lilongwe, Malawi. Within 2 years of production, the EcoKiln has established itself to be the World’s most energy efficient and environment friendly clay brick firing technology having a Specific Energy Consumption of around 0.6MJ/kg. In Malawi the technology uses industrial wastes e.g. tobacco dust to improve
energy efficiency and reduce the consumption of external coal. Experiments have proven that any carbonaceous wastes e.g. boiler ash from sugar industries, coal waste from oil industries etc., can also be used as an internal fuel. Thus, the wastes that was previously discarded and dumped creating health hazards have now found a profitable use. The burnt clay brick wastage has been reduced from 40-50% to almost 5%. Thus, quite a large amount of raw materials are being profitably utilized. Various market assessment studies have been undertaken and have found that all the raw materials required to build, operate and maintain the technology are available in Malawi. This reduces the dependence of any import or external support and demonstrates profitable examples of circular economy in the construction sector.

This technology and the associated value chain have demonstrated that circularity is not only about profitable utilization of wastes in a large scale but a means to create sustainable green jobs round the year for both men and women. In Malawi this has helped in creating economic empowerment for women who now have become a decision maker in the family. Use of waste coal has opened up an entirely new business stream and has the possibility of arresting total deforestation.

The successful demonstration of the EcoKiln has enabled the Government of Malawi to decide on policy changes. Thus, as an incentive to entrepreneurs adopting EcoKilns, it has now been made mandatory to use non-wood fired bricks and building materials in public and donor aided construction. This will ensure a large demand of Eco Bricks thereby creating a market for EcoKilns.

4. Discussions and Conclusions

Key findings from the case studies are summarized below. The Danish Circle House is an example of a sustainable modular housing unit that can be scaled up in different architectural forms and components of which can be dismantled and re-assembled without losing their value. This offers opportunities from beyond this one case study to more modular housing opportunities, particularly in areas where materials may not be readily available. Alliander HQ shows how an extension of an office building can be undertaken using circular materials, forming a raw material passport for future reuse of all its materials. Good design supports regenerative practices. Brummen town hall presents a business model where the market delivers a temporary building removing it after 20 years. Thinking in the longer term is required, not just in current construction of operational practices.

The Ahmedabad example shows how waste-based products are profitable and their use can support the development of policies. Such business models can support a circular approach and governments can pave the way, leading by example.

In Malawi, EcoKiln has proved to be energy efficient and environment friendly way to produce burnt clay bricks using a waste by-product e.g. tobacco waste. The quality and efficiency of brick making processes has been improved; from 40-50% waste down to almost 5%. A whole industry can be supported based on this technology reducing deforestation and providing employment for both genders and the youth.

Next steps in the SBC programme are to disseminate information about good circular practices worldwide, to develop new initiatives to mainstream circularity in the built environment based on information available and to support development of policies and tools to support such policies.
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