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Using the ReSOLVE framework for circularity in the building and construction industry in emerging markets

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Abstract. Circularity supports the move from linear to circular systems where more efficient, zero waste systems are created by closing material inputs and loops. The design, maintenance, manufacturing and use ensure virgin materials are no longer needed for day to day living. For the built environment sector, building materials and its use underpins the trajectory of circularity in the sector. Improved building materials, increased standardization and appropriate storage and transportation may reduce waste. Increased adaptability and multi-use spaces in buildings support multiple occupants and end users. This paper focuses on understanding the requirements to move to a circular pathway for the building and construction sector in emerging markets, using secondary literature and case studies. The ReSOLVE framework developed by Arup and Ellen MacArthur Foundation consists of Regenerate, Share, Optimize, Loop, Virtualise and Exchange to support circularity in the built environment. Not just the building materials themselves and advanced techniques of construction, but also new business models are required so that the socio-economic system may also support circularity approaches. Increased digitalisation also supports the adoption of circular opportunities. Emerging economies globally need to consider circular approaches to meet the current and future demands of climate change mitigation and adaptation.

1. Introduction

Building and construction is a key consideration in the future of our urban areas. Cities typically consume 75% of global primary energy and about 50-60% of global greenhouse gas emissions [1]. This has attendant impact on building and construction leading to consumption of a large proportion of raw materials. The sector is accountable for 50% of global steel production with over 3 billion tonnes of raw materials being used for manufacturing building industry products [2]. By 2050, unprecedented growth as a result of population pressures and urbanization will put even more pressures on natural resources. This is particularly so in the emerging markets of African, Asian and Latin American regions of the world, where by 2050, two thirds of the population are expected to live [3]. Such increases in population numbers place pressures in urbanized regions whilst also offering opportunities.

For instance, India's material consumption has increased by almost 200% between 1980 and 2010, making it the third largest consumer of materials in the world. This accounts for about 7% of global material consumption. If these trends continue, India's share of material requirements are expected to be about 15 billion tonnes by 2030 and by 25 billion tonnes by 2050 [4]. China's growth during the period 1980-1996 showed high levels of economic growth with GDP increase of 11% [5]. While energy efficiency during this period improved tremendously, it decreased from 2002 due to China's rise as the world's largest producer of steel, cement, glass and aluminum [5] (p. 1334). Future energy demand per capita in China is expected to rise as economy in China grows, as does rise in the living standards in the country. While much has been talked about in terms of reductions in energy, water and resources; when considering low carbon futures, global focus to date has largely focused on the supply side. Circularity focuses on the demand side; and on reducing the use of resources to manufacture products. Circularity therefore focuses on material efficiency; on strategies for recirculating a larger share of materials, reducing waste in production and extending the life of products.

Given the future expected use of materials in emerging markets, the aim of this study is to understand if circularity principles in the built environment may be applied in such markets to fast track to low carbon future. If so, what are some of the key considerations? The paper explores this through the use of case studies.

This paper commences with a general understanding of circularity and its impact on the built environment. This is followed by an understanding of the key characteristics of circularity in the built environment. A case study approach is used to best understand the richness of learning arising from the cases followed by analysis and discussions, and conclusions.

2. Circularity in the built environment

There are clearly some prospects for ensuring that circular principles are used in countries such as China and India to fast track to low carbon futures. Circularity and attendant frameworks are very useful in supporting novel approaches to pave the way for the future, particularly from a resource use perspective. Circular economy may be defined as a 'regenerative system in which resource input and waste, emission and energy leakage are minimized by slowing, closing and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing and recycling' [6]. The Dutch Ministry of Infrastructure and the Environment describes a circular economy 'as an economic system based on the reusability of products and product components, recycling of materials, and on conservation of natural resources while pursuing the creation of added value in every link of the system' [7] (p.4). Their focus is on ensuring no leakage or better closing of the product and material chains.

Smarter product manufacturing and use, and recycling of materials through recovery bear a higher value in a circularity strategy compared to simply using the material for incineration to generate energy. If a higher level of circularity of materials are used in a product chain, those materials remain in the chain for a longer period, hence, use of newer materials to make products are reduced or eliminated. This has a direct impact on the environment. Thus, not only from a strategic approach, but to move to increasing circularity requires innovations in core technology, innovations in product design, innovations in revenue model and social-institutional change. Potting et al [7] have identified three main transitions to a circular economy: (a) radical innovation in core technology; (b) where socio-institutional change is central and where technological innovation plays a secondary role and (c) transitions, where socio-institutional change is central and are facilitated by enabling technology.

Circular opportunities can make deep cuts to emissions from heavy industries; by as much as 296 million tonnes CO_2 emissions per year in the European Union by 2050 out of 530 million tonnes in total representing 56% of cuts resulting in some 3.6 billion tonnes per year globally [8] (p.4). Recirculation offer the best opportunities as it cuts CO_2 emissions and requires much less energy to produce materials than that produced from virgin materials. Global demand for steel, aluminium, cement and plastics is expected to increase making up two thirds of industry total emissions with the remaining third through non-material sources [8] (p.12). As noted in the introduction, countries like China and India will lead the charge for building and construction growth due to demand.

For the building sector, abatement potentials arise from floor space sharing, reduced waste in construction, reuse of buildings and building material efficiency. The abatement cost is the least profitable for floor space sharing and most for material efficiency with attendant emission savings [8] (p. 35). The next section examines the key driving principles for circularity.

3. Key principles underpinning circularity/circular economy

The history of circularity in the built environment has strong roots in industrial ecology. Industrial ecology and urban metabolism involving the study of the interdependence of human activity and economic systems on natural systems form the underpinning foundations of circularity in the built environment. While circularity refers to principles, frameworks or approaches, circular economy refers to the economic and business imperatives required to make circularity approaches a reality. This is because circularity can only work when shared models are successful.

Utilization efficiency of resources by reuse and recycling is supported so that environmental pressures are decreased. At a city, neighborhood or building scale compact, productive (including food where appropriate), efficient urban forms, that support symbiotic relationships between environmental, economic and social forms are desired. Economic activity supports better use of existing capital within the built environment. Adoption of circular resource flows assist in reducing footprints and impact on the biosphere. While a life cycle approach is useful for tracking, problems with the approach are data capture and quality of data. The data can easily be converted to carbon outputs, if desired. The next sub-section considers impacts at a building scale, which can easily be translated into larger scales as appropriate.

3.1. Key steps to achieving circularity

The key steps to transition to a circular society, according to Arup [9] are a future where the design, construction, operation, renewal and repurposing of buildings are such that:

1. *Ecosystem* remains the front and centre; where buildings are designed for whole life cycle and not just for a point in time. Life cycle thinking will ensure the construction and operation as well as the disassembly phases will maximize the principles of circularity such as using appropriate materials, use of renewal energy, adaptable designs, shared resources, lease of assets and similar circularity approaches identified in the previous section.
2. *Design* will ensure that buildings may be future-proofed, providing opportunities for adaptability and disassembly. Designs will be open source and the design community will build further from each other's work, and components will be reused and retrofitted where possible. Design is not purely aesthetic or delight, it will support comfort of space, and at the same time be energy efficient and support wellness.
3. Sourcing of *materials* adaptability and modularity. Materials are flexible, durable, and can be reused. It will contain components that will support reusability.
4. *Construction* is dominated by increased flexibility, prefabrication, digitalization and where appropriate and possible, use of 3D printing.
5. *Operatio*n is dominated by high efficiencies in energy use, water and strategies eliminating waste of materials and resources. It will be dominated by leasing arrangements in both tenancies and in servicing of equipment and maintenance.
6. *Renewal* will also be dominated by flexibility and adaptability, where designs will support reconfiguration of parts of buildings, including facades and other components of buildings. Buildings can be easily retrofitted and upgraded, eliminating the time and cost for renewal. Virgin resources are not used or are not needed to be used.
7. *Disassembly* is minimized to result in buildings that may be mobile, flexible, adaptable and resilient, expanding building life spans.
8. *Repurposing* buildings makes maximum use of components and materials ensuring that their performance and value are maintained or enhanced either in the built environment sector or other sectors.

This is encapsulated in the ReSOLVE framework, explained below.

3.2. The ReSOLVE Framework

Arup and The Ellen MacArthur Foundation [9] (p. 18-19), [10] have developed the ReSOLVE framework for the built environment to transition to a circular economy. These are: *Regenerate*, *Share*, *Optimize*, *Loop*, *Virtualize* and *Exchange*. Each element of the framework may be used across all scales of the built environment. *Regenerate* refers to regenerating and restoring natural capital, where safeguarding, restoring and increasing the resilience of ecosystem are prioritized. *Sharing* involves maximizing asset utilization, pooling the use of assets and reusing/adapting assets. Optimizing system performance, prolonging an asset's life, decreasing use of resources and implementing reverse logistics are the main aims underpinning *Optimize*. *Loop* refers to keeping products and materials in cycles, prioritizing inner loops such that remanufacturing and refurbishing products and components, and recycling of materials are prioritized. *Virtualize* involves displacing resource use with virtual use, replacing physical products and services with virtual services, replacing physical with virtual locations and delivering services remotely. This is where shared business models become particularly critical. *Exchange* is about using new business models, flexible design and use, leasing and performance-based models to ensure flexible and optimized user-focused designs. This also includes using alternative material inputs in buildings, providing service centric models, and using advanced technology where appropriate.

Thus, circularity is characterized by closed-loop approaches, resource efficiency/productivity, resource efficiency vs resource effectiveness and optimization of good/assets. Circular economy supports the building or increasing the value of asset/stock management, thereby supporting longevity and durability which in turn, requires that design for longevity and adaptability is supported, thus end of life value is retained. From an emissions perspective, reduction in demand reduces embodied resources such as energy and water, in turn reducing emissions associated with greenhouse gases and related emissions.

Ness & Xing [11] highlight that circular economy approaches are most efficient and effective in the built environment, in the construction and real estate sectors. Circularity may be achieved at city, neighborhood and building scales. At the city scale, governments need to drive policy and regulatory frameworks so that top-down approaches are able to support granular innovation at the building scale. Performance and service economy that supports utilization of products so as to enable prolonged asset life is desired. Increasing the service life of assets reduces the need to use virgin materials and therefore, resource consumption is reduced or eliminated. Pooling of materials brings about a shared society such that sharing of material banks for instance, reduces overall use of resources. Waste management may be expanded to focus on prevention or elimination of waste/maintaining the value of the waste so as to be used elsewhere such that new or virgin materials are no longer used. If building related waste were to be captured, a fairly high percentage of waste; 40% by UN estimates [12, 13] may be reabsorbed back into the system. A holistic view is therefore required where social, environmental and economic issues will need to be considered as a trifecta. There is potential for job creation in a shared economic model, thus supporting emerging economies to fast track their trajectory to low carbon futures and thus, escaping poverty and other related problems they are currently plagued with. Indicators are needed that assess against outcomes and performance rather than outputs [11] (p. 575-580).

Table 1 provides a synopsis and attendant examples of the ReSOLVE framework.

Table 1. Circularity principles using the ReSOLVE framework

Circular economy principles	Outcome/aim	Built environment policies	Examples
Regenerate	Regenerating and restoring natural capital	Policies that support TBL sustainability approaches.	Net zero strategies, closed loop systems, permaculture.
		Net zero strategies, low impact design, use of local materials, low embodied energy, water, waste and pollution.	Examples are: Off grid/autonomous/independent/no bills building
	Restoring natural	Local solutions for supporting reliable, robust and adaptable assets.	Flexible designs, sharing economy, example: Airbnb, leasing roof tops for PVs

	ecosystems and increasing resilience		
Share	Maximize asset utilization	Holistic approaches and associated policies such that spaces in the built environment, infrastructure are used more efficiently and effectively.	Spaces between buildings used for urban agriculture, shared vehicles, shared and flexible working spaces, avoiding 'dead' cities and buildings. Examples are co-housing, hot desking.
	Open source sharing of assets	Policies and programs supporting adoption of best practice, modular construction, design for disassembly, use of sustainable and circular materials.	Increase life span of existing assets, maximise use and support standardization where possible. Example: Working hubs
	Reusing assets	Policies supporting reuse of materials through resale. Integrated design and operational teams throughout the life of the asset so there is shared ownership rather than the current BAU models of design/construct/operate.	Using IT to put the demand and supply on the same platform so trade is encouraged. Support local economies and supply chains. Encourages reuse. Example: unwanted/unused furniture donated to charity.
Optimise	Optimising system performance	Maximising efficiency, eliminating waste and promoting reuse and repurposing.	Eliminating the use of primary materials in buildings. Components and materials may be reused or repurposed. Example: reusing bricks as bricks for construction.
	Prolonging asset life span	Policies and regulation that support the use of long-term durability, utilization and value of assets such that maintenance is reduced, waste is reduced or eliminated, and can be easily adapted, thus also future proofing buildings.	Support the development of mixed-use buildings, adaptable floor plates, integrated smart services, passive design, durable materials, monitoring ongoing building performance. Example: leasing of carpets in buildings.
	Decreasing resource usage	Supporting off site construction/manufacture supports reuse and repurposing while also eliminating waste. Integrated building design; where not just design, construction and operation are considered, but also specific engagement with demolition, waste management and end of life.	Supportive procurement policies. Examples: reusing excavated materials from site into the building, off-site manufacturing, using 3D printing at smaller scales to iron out construction difficulties and support realistic volume of material needed.
	Implementing reverse logistics	Policies that support the flow of materials and products through the supply chain such that remanufacturing, refurbishment, repair, reuse and recycling support maximized recovery of materials after consumption.	Long term planning and integration of operational considerations at the design and construction phase. Examples: consideration of service models such as carpets, lifts and other building products and components.
Loop	Prioritizing loops	Policies on disassembly during the design phase can provide effective second use and reuse. Remanufacturing and recycling of materials including machinery and equipment.	Modular construction approaches. Examples: use of joints that allow for easy disassembly. Joints themselves may be reused.
	Remanufacturing and refurbishing	Policies seeking to encourage reuse and repurposed materials before use of virgin materials. As a result, waste is lowered/eliminated.	Remanufacture of machinery used in demolition or specialized equipment in buildings.

	products and components		Examples: lifts and escalators can reduce greenhouse gas emissions, energy use, waste to landfill and reduction in material use compared to new products.
	Recycling materials	Policies supporting recycling and recovering materials, thus reducing or eliminating waste.	Engaging with manufacturers to support material recovery, for instance reusing rather than recycling. Example: carpets, fittings.
Virtualise	Displacing resource use with virtual use	Use of smarts where possible. The use of technology where possible (and appropriate) to facilitate real time maintenance tasks that usually require physical intervention.	Using smart technology for reducing time and energy (and attendant emissions) when there is a maintenance issue associated with a building. Onsite measurement and monitoring through the use of smart technology saves not only time but also supports targeted responses, saving money. Example: Remote Building Management Systems
	Replacing physical products and services with virtual services	Using digital technology for trouble shooting, performing upgrades and modifications to systems and components.	Use of BIM in design, construction and operation of buildings. Transparency in the use of materials (such as material banks). Example: QR codes used in materials
	Delivering services remotely	Using smarts in buildings to extend the life of assets.	Operational policies need to be considered. Example: Digital operational support such as online meetings supporting the use of flexible work places reducing travel needs and attendant impacts.
		Open design and operating standards support exchange of knowledge and information on system performance.	Sharing new knowledge and experience on open platforms supports others to improve and share this widely eliminating 'reinventing the wheel'. Example: real time monitoring information is displayed online for a type of PV system used.
Exchange	Selecting resources and technology widely	Optimised, flexible and user-focused designs to support efficiency gains and more effective use	New business models of leasing, performance-based models and flexible use of design. Example: solar panels on roof tops of buildings are leased.
	Replacing with renewable energy and material sources	Closed loop systems encouraged in buildings through the use of solar panels, use of sewerage and other waste to generate energy or other renewables such as wind.	There are many examples of low energy use buildings globally. A plethora of tools exist to support. Example: Policies for low enery use such as Passivhaus standards that support low energy use in buildings.
	Using alternative material inputs	Use of renewable materials to replace materials that are hard to reuse and recycle.	Good design and planning policies. Example: using plants in buildings to improve thermal comfort, use of building materials made from agricultural waste.
	Replacing traditional solutions with	Use of better products and services and innovative materials to replace traditional products.	Innovative thinking and planning. Example: 3D printing, LED fittings.

advanced technology		
Replacing product-centric delivery models with new service-centric ones	Focusing on performance-based contracts as a service model rather than just selling a product. Long term and life cycle thinking underpin this.	Leasing rather than owing assets where the consumer pays for the desired outcome. The service agent is responsible for maintaining the standard of performance. Example: leasing PV panels or equipment in buildings

3.3. The Seven layers (7S)
To further support building level circularity, it is important to examine the various components that make up the building. Arup [9] suggest seven layers to enable each layer to be combined, separated and removed facilitating reuse, remanufacture and recycling, thus expressing buildings as components of a system. By making each layer independent of the other but working in sync with each other supports flexibility and adaptability, without affecting the building as a whole. It supports longevity of buildings, as not all components of the building have the same shelf life. The 7S and ReSOLVE need to work together to provide best outcomes for the building.

The 7S are *System*, *Site*, *Structure*, *Skin*, *Services*, *Space* and *Stuff*. *System* includes the structures and services that facilitate the overall functioning of the building and its ecosystem including infrastructure such as road, sewerage, parks and the like. *Site* refers to the location of the building. *Structure* is the 'skeleton' of the building, including foundation. *Skin* denotes the façade and the exterior of the building similar to organisms. *Services* are composed of the mechanical systems that provide comfort for the building and ensure wellness of occupants. *Space* is the compartmentalization of the building through ceilings, walls and floors. *Stuff* includes the internal partitions, furniture, lighting and digital needs to run the space.

The next section examines selected case studies.

4. Selected case studies
As a research strategy, case studies offer insights along multiple fronts and are a very useful research strategy for exploratory stages of a project [14]. Case studies presented here have been selected based on the key learnings arising through examining these cases. Case study has been used as a method to understand the breadth and depth of issues through the application of circularity principles and in this case, the ReSOLVE framework.

Each of the case studies selected are in Europe and have been selected from Circular Economy 100 [10]. The Circular Economy 100 or CE 100 is a pre-competitive innovation programme established to enable organizations to develop new opportunities and realize their circular economy ambitions faster. It brings various stakeholders together to support, learn, build capacity, network and collaborate on circular economy.

The focus of the selected cases has been to choose a range of building types as a pilot to understand their underlying drivers, lessons learned and to determine their viability for future investigation, with the intent to ultimately support widespread use of circularity. Two refurbished office spaces: one small and one mid-size office buildings have been selected. In addition, a demonstration house, and other projects focusing on materials reuse such as a judicial facility and investigating the reuse of materials by using them as material banks were also examined.

4.1. Rehafutur Engineers House, France
This small building was initially a dwelling, converted to an office building of 400 m^2. It is located in the North of France, in a UNESCO-listed mining area. As the building was listed in a heritage area, the reuse of the building through circularity principles was critical to the project team and was a key element of the project early on. Disadvantages were some overall technical challenges as a result of the use of

different materials. Since different processes and building materials were used, reskilling and collaboration amongst all the partners was essential. The elements used from the ReSOLVE framework included *Regenerate*, *Optimize* and *Loop*. *Regenerate* included the use of eight different eco-materials made from agricultural and animal base demonstrating not only use of appropriate materials, but also ensuring good quality of the indoor environment.

Optimize includes a focus on energy efficiency in the operation phase where an expected 34KW.m^2 was the expected annual load. To support such a low load, insulation, thermal bridging and a dual flow ventilation system with heat recovery were used so that standard equipment (boiler and fuel) in an equivalent scenario is reduced/eliminated. Separation of internal and external walls, coordination of the various tradespeople and the use of interior insulation were some problems encountered. Achieving air tightness for the building was also not easy given its heritage status.

Loop considers the reuse of existing materials. In this case, marble fireplaces from the original building were reused in the refurbished building. Floor boards were reused where possible, as were the cement tiles. Rubble from the refurbishment process were reused for parking and pathways. This approach was undertaken to retain the heritage value of the components and also reuse, rather than recycle materials recovered as a result of the refurbishment process. Reuse of the debris ensured that landfill costs are also saved, but the saving in materials results in proportional higher cost of labor for the overall project. A demolition audit and plan are required during demolition to ensure material integrity and quality is retained where possible.

4.2. Liander head office, Netherlands
This is also a redevelopment, used as a head office for 1500 employees. The total area of the office is 24,000 m^2. The circularity highlights of this building are reuse of 80% of raw materials from the original structure ensuring their further reuse considering disassembly in the future, and resource efficiency in energy use and supply to the grid. Grid connected solar panels ensured energy supply back to the grid. Water captured on site was used as thermal storage. The existing complex consisting of six different construction elements were brought together in this project through the use of an atrium connecting the disparate elements visually and physically. The atrium also provides a visual connection to the natural landscape, contributing to well-being of the employees. This project uses *Regenerate* of the ReSOLVE framework.

Regeneration is evidenced by making this building energy positive through the use of onsite energy capture through photovoltaic panels and thermal storage. Some of the excess energy is exported to the grid. Energy produced may contribute to the process of constructing the building itself if used early in the process. The principles guiding the design of the space were conservation and reuse of existing materials, minimization of materials use, and careful selection of materials that may be used beyond this particular building. The roof was kept light using roller coaster engineering principles, and local materials such as using waste wood from cable rolls. This allowed the roof of the building to be lighter, thus saving on material use.

4.3. Resource efficient house, Scotland
This three-bedroom house is a modular building constructed off-site using structural insulated panels, allowing it to be light and airtight. Time and materials may be saved in off-site construction. In addition, it is easier to assemble components as they fit better (being manufactured offsite). The use of the structural insulated panels allows for thermal efficiency to be easily achieved in the operational phase of the building. End of life has been considered in the design and choice of materials. This building supports repeatability due to its off-site manufacture and scaling this, therefore, supports lower costs in the long run. This project uses *Regenerate*, *Optimize* and *Loop* of the ReSOLVE framework.

Regenerate arises from the site itself needing to be remediated. Remediating supports the use of brownfield areas of land. Although the cost was high and it took several years for the process to be completed, it provides hope for other projects to consider land remediation where appropriate. On site grey water recycling system reduces the use of water as a resource; use of photo voltaic and biomass boiler using wood pellets (renewable fuel) provide thermal space heating; all supporting regenerative frameworks.

Optimization has been achieved through the use of highly insulated wall panels even though it is manufactured from polyurethane (can be recycled). Using such a well-insulated wall construction allows the building to use less energy for heating (therefore less fuel used) and improved well-being for the occupiers due to better thermal comfort. Project managing such as project where manufacturing and installation are time sensitive needs to be factored in the process as a key learning from this project.

Loop is evidenced through reduced construction waste, using off-site construction where waste may be vastly reduced compared to in-situ construction. Since waste is on site in the factory for offsite construction, it may be readily reused on site, thus avoiding transportation costs of the waste further reducing energy. The kitchen worktops in this project were made from recycled plastic waste to reduce the use of virgin materials.

Modular construction is therefore, highly desirable as its manufacture is not weather dependent as compared to in-situ construction, providing also less wastage of materials as various components are also modular leading to no or very little waste being generated. Project management however, is very critical in modular construction to ensure that the individual components of the building, being the foundation, walls and roofs are seamlessly brought together.

4.4. Judicial Police Compound, France

This Judicial Police facility is a high-quality building designed according to high environment quality building principles to achieve high environment quality certification. To achieve this, the project was designed to be highly flexible, modular, durable and sustainable. The total gross surface area of this project was 38,182 m^2. Well managed planning and design elements were critical to ensure success of the project. Time needs to be factored into the process, to ensure commitment, ownership and buy-in for all stakeholders to be committed to the shared principles and practices of the project. Regulatory compliance and good design needed to be negotiated. For zero waste practices to work, it was essential to train contractors and tradespeople. The elements of ReSOLVE used here were *Optimize* and *Loop*.

Optimization elements were governed by low energy consumption compared to conventional buildings, use of natural ventilation in spring and summer, double flow ventilation with heat exchanger, optimization of natural light and drinking water, careful selection of materials and ongoing cleaning and maintenance practices that led to low water consumption as compared to similar projects.

Loop was demonstrated through use of materials with high recycled content, and the use of zero waste practices during construction and operation. The careful selection of materials ensured high indoor air quality to ensure no or low Volatile Organic Compounds (VOCs) and overall pollution reduction.

4.5. Buildings as material banks (BAMB), EU

This European Union (EU) funded Horizon 2020 project sought to bring various partners to create a systemic shift for creating circular solutions. The project supports transparency of material use through building material passports and thinking about reversible building designs. The project is at nearly at the end of its phase. This project uses *Loop*, *Share* and *Virtualize* of the ReSOLVE framework.

Loop is evidenced through improved deconstruction ad resource optimization at end of life. There is complete transparency in the types and placement of materials in buildings that assist in disassembly. The segregation of materials and supply chain characteristics support the reduction or elimination of resource extraction and attendant practices such as transportation and related emissions. Coupled with leasing opportunities, product and service lifespans may be increased. However, uncertainty associated with cost and values over long terms is not desirable presenting a challenge. It also requires all elements of the supply chain working collaboratively; if collaboration does not happen, the entire supply chain is affected.

Share refers to reuse of materials and products across various types of building applications and it needs greater awareness of design (including innovation) and tracking of products to support reuse. The obvious advantages are avoiding the use of virgin materials and associated emissions. Challenges to this approach are issues of transparency of materials and life cycle data.

Virtualization can be evidenced through the use of tracking mechanism for materials. This may be easily undertaken by digital processes such as Building Information Modelling (BIM). Such methods of increased digitization also support transparency, storage, access and exchange of information. A clear disadvantage of course, is setting up all the systems to support such types of digitization and populating it with reliable data. Getting all the fields of information to collect the data is a learning process, as is populating with the data to create a comprehensive database.

The next section focuses on the analysis of the case studies and discussions.

5. Analysis and discussions

Five case studies from Europe were examined to understand the underlying drivers and learning for supporting circularity approaches in buildings and construction. Table 2 provides a synopsis of the case studies. While it is not possible to generalize given the small number of studies, nevertheless, some insights may be gained.

Table 2. Case study synopsis

Case study	Elements of the ReSOLVE framework						Building stages considered				Key learning
	Regenerate	Share	Optimise	Loop	Virtualise	Exchange	Conception	Construction	Operation	Deconstruction/recycling stages	
Rehafutur Engineers House											Technical difficulties with using different materials Reskilling needed Demolition audit of original building required to ensure material reuse
Liander head office											Good design Material selection
Resource efficient house											Use of brownfields land Zero waste due to offsite construction Project management of various stages critical
Judicial police compound											Planning and design critical, as is project management Time needs to be factored to bring stakeholders on board and commit to collaboration
Buildings as material banks											Capture of materials for all fields and capture of database still in progress

It was found that of the cases selected, none of them were able to demonstrate all six elements of the ReSOLVE framework, i.e., *Regenerate*, *Share*, *Optimize*, *Loop*, *Virtualize* and *Exchange* in the one project. It was possible to achieve up to three elements in a project, but not all six elements demonstrating that a pecking order or priority of issues need to be considered with the client and stakeholders and of course, the budget to determine the best value for the client. Of all the elements from the ReSOLVE framework, four of the five projects were able to demonstrate the use of *Loop*, i.e., keeping products and materials in cycles by prioritizing inner loops such that remanufacturing, refurbishing and recycling were all prioritized. Projects were able to demonstrate the use of *Regenerate* and *Optimize* following *Loop*. As shown in Section 3, *Regenerate* refers to restoring natural capital, and *Optimze* refers to prolonging the life of the asset and decreasing use of resources. None of the projects were able to evidence *Exchange;* this is partly because exchange requires setting up disruptive business models which require a great deal of innovation. That is not to say that case studies of such innovation are not available in other projects in Europe.

Three of the five case studies considered all stages of the building life cycle; conception or design, construction, operation and deconstruction. This shows that long term planning is really critical when considering circularity. The impact of the 'seven layers' were not explicitly explained in the case studies as separate components of the building and its surrounds. However, all the case studies treated the building as a whole in sync considering the four stages of the building life cycle. Whether it was regeneration of a contaminated site, providing energy back to the grid through the façade of the building, use of modular construction, choice of materials to maximise reuse; all these decisions ensured that the building was performing as a holistic system to ensure maximising the shelf life during operation and deconstruction.

There were different underlying drivers for each of the projects. Bringing in new materials to ensure reuse presents technical challenges. Technical difficulties with using a variety of materials and lack of skills in installation of unfamiliar materials requires training. Reskilling or upskilling is required when using new materials, reusing materials and new processes are employed on the construction site. Collaboration and communication between the suppliers of materials and trades personnel is essential for smooth construction processes. If materials on site are to be reused, a demolition audit is critical; so also, innovative thinking on where materials may be reused and associated limitations understood. Materials also need retesting for different structural properties prior to reuse. Materials selection to maximise reuse and to ensure transparency requires digital solutions. Project management become critical when modular construction is used, to ensure that the various elements of the structure and skin slot seamlessly during the construction process. Good planning and engagement with all the relevant stakeholders are critical at the start of all projects.

All the projects studied considered the ecosystem, good design, sourcing/careful material selection, construction and operational processes and challenges, elements of renewal across all the layers of the building, end of life and reuse of the building. A challenge remains with future uncertainties and data capture, including transparency of data and structural performance over time. Thus, if circularity processes are to be considered in emerging markets, industry (including the private sector) and governments need to work together to develop circular economy vision and business models, collaborate with each other, demonstrate through appropriate case studies and examples that support their own climate and cultural contexts, innovate where possible and support innovation and engagement/collaboration through education and awareness.

The key message for emerging markets, therefore, are to consider holistic processes in the design and construction of buildings. Private sector may be able to take the lead, but if governments are able to back up with policies and regulations, it will enable private sector to support innovation and take the risk where established markets are yet in the making.

If buildings are to be refurbished or renovated a genuine effort needs to be made to ensure some, if not all building materials are reused. A demolition audit in such an instance is critical and education and reskilling to facilitate this is required. Likewise, if prefabrication materials are to be used project management skills become critical. Where energy efficiency and resource use are the drivers, good design, planning and careful selection of materials and renewable energy may need to be considered as priorities. In some instances, governments in emerging markets may need to take the lead to showcase examples of circularity so that the private sector will rise to the challenge.

A 'cut and paste' approach of using the same drivers in the case studies showcased in Section 4 cannot work; tailor-made solutions to fit functional requirements of the building, client needs, design to respond to the climate and availability/suitability of local materials will need to be taken into account. The elements of the ReSOLVE framework may be used to initiate discussions with the client/s and may serve to recognise key elements of circularity to be prioritised across the life cycle of the projects. Key learning will need to be documented and shared with the building and construction industry stakeholders. Underpinning all this requires education and upskilling as appropriate.

6. Conclusions

This paper set out to determine if circularity approaches may enable emerging markets to fast track to low carbon futures. A future built on circularity principles requires design, construction, operation, renewal and repurposing of buildings to consider long term scenarios. Buildings need to consider ecosystem sensitivities and regenerate energy where possible. Regeneration may be in the form of energy generation on site or a use of energy efficient designs (passive designs) and construction processes such that very little energy or no energy is used to operate buildings. Designs themselves will be flexible, adaptable and future proofed, and material selection will enable reuse and remanufacture where possible. Construction may be pre-fabricated or modular to enable speedy construction, and operations will be dominated by high efficiencies in energy and water use, and zero waste. Buildings will act as close looped holistic systems that support site, structure, skin, services space and stuff to encourage and enable renewal, repurposing and disassembly in the future.

The ReSOLVE framework enables practical decisions to be prioritized at the building level as demonstrated by the case studies. Examining five diverse case studies of buildings in Europe highlights some elements of the ReSOLVE framework where priorities will vary depending on the type of building, site conditions, climate, context, users, type of building, life span, materials available, refurbishment or new building and a range of other factors as already explained across the various phases of the building life cycle. The case studies demonstrated that good design can never be underestimated. Education is required where new materials, techniques or processes are used as all stakeholders will need to learn how to deal with the materials/processes and limitations. Careful planning and project management cannot be underestimated. Pre-fabrication and modular construction support zero waste. Operational energy may be reduced through on-site energy generation. Transparency of materials for future reuse is highly desired, but data capture from cradle to gate may be a limitation.

Such an approach requires leadership at the policy level to facilitate innovativeness where possible. It also requires building and construction industry stakeholders to also show leadership and be prepared to negotiate with each other and ensure the outcomes of the project across the various life cycles are achieved. While building industry regulations may also require to be changed, innovativeness in the industry is not tied to regulation. A vision for circularity is required, as is a genuine commitment to support this through practical actions on the ground. Some of these actions such as regeneration of energy through photovoltaic (PV) panels, building integrated photo voltaic panels (BIPV) and Net Zero Energy building (NZEB) policies have already been legislated in some countries such as China.

For the ReSOLVE framework to be used as guiding principles in emerging markets also needs consideration of scale and replication where modular approaches may be particularly relevant. Considered effort is required to plan such approaches and move from current business as usual practices to make genuine inroads to truly support low carbon futures. Emerging markets may learn from the developed world and avoid making the mistakes that the developed world has undertaken by fast tracking to low carbon futures during their high growth phase.

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