Pathways toward Sustainable Architecture: Green Architecture and Circular Built Environment

Y Aliamin
An independent researcher, Jakarta, Indonesia
Email: yensen.aliamin@yahoo.com

Abstract. This paper examines the extent to which green architecture (GA) and circular built environment (CBE) methodologies and practices contribute to and operationalize sustainable architecture within the context of the UN Sustainable Development Goals. Drawing from mainly recent literature on various approaches, interpretations and definitions of GA and CBE, this article identifies key themes, sub-themes and aspects and their respective relationships to the social, environmental and economic dimensions of sustainability. Impressions of GA and CBE on a triangular “canvas” of sustainability provide a visualization of not only similarities and differences between the two pathways, but also gaps toward sustainability. Finally, the findings suggest that a more integrated, balanced approach is necessary to accelerate the greening of architecture in a quest for sustainable livelihood, fairness, and viability, for all.

1. Introduction
Today, forty (40) is a common number that illustrates the enormity of influence that man-made structures (buildings, houses, roads and other infrastructure) — the so-called the built-environment sector — has on a global scale. The built environment contributes closed to 40% of the world’s GDP, consumes approximately 40% of global materials, accounts for almost 40% of final energy use, emits nearly 40% of energy and process-related CO2 emission, and generates up to 40% of urban solid waste in the form of construction and demolition (C&D) waste [1–4]. Based on trends prior to the COVID-19 pandemic, it is projected that, from 2020 until 2050, CO2 emissions from construction as a proportion of total new building emissions will be about 50% [3], and 1 billion houses (75% residential) will built by 2025 [5]. Equally alarming is the fact that much of today’s construction depends heavily on extraction of exhaustible resources (virgin materials), thereby putting even more pressure on already strained supply and on other social and environmental concerns. Demand for materials in general is expected to double by 2050 from the 2017 level of 92 billion tons [2]. For example, to fulfill the requirement for concrete and other applications, almost four tons of natural sands per person per year need to be extracted from riverbeds and coastal areas, while around 16% of annual global production of single use plastics of 400 million tons is used for built environment [1]. Yet global waste recycling is low 8.6% [2], and so is asset utilization, as 49% of UK homes are ‘under-occupied’ [5] while around 40-60% of office space is unutilized even during working hours [3]. In short, the building industry has been a rapidly growing, tremendously resource-hungry and energy-intensive sector with many excesses and potential negative impacts on the people and the planet.
But it has not always been the case. For millennia, humans have constructed and lived in houses and structures using traditional or “ancient” technologies and processes with minimum, if any, adverse effect on other humans or on the environment. Living quarters were designed and built (and still are in some parts of the world) in conformance within the context of topography, local climate, culture, lifestyle, and the availability of resources in the vicinity. Such an approach to building – the vernacular tradition – “establishes a harmonious relationship between climate, architecture and people” [6]. So “connected” are humans and the environment in the traditional architecture that construction and living mean little impact to the environment and require no or minimal artificial energy generation [7,8]. It took a great civilization milestone, the Industrial Revolution, to shift architecture away from the tradition. Rapid technological advances and ever-increasing productivity unleashed by the Revolution led to unprecedented economic and population growth across the globe in the following two centuries. The ensuing large-scale industrialization, urbanization, and more recently globalization and consumerism, welcome as a progress or even as necessities on one hand, create undesirable social and ecological externalities on the other. Massive conversion of land, along with unbounded extraction of natural resources, and unrestrained consumption of fossil fuel, which initially raised the question of “limits to growth” in early 1970s, continued their damaging trajectories in the following decades and eventually by 2010s, surpassed four of the “planetary boundaries”, including two “core boundaries” of climate change and of biosphere integrity, as well as land-system change and altered biogeochemical cycles. [9,10]. Environment and energy crises are ‘interlocked’ and transcending political boundaries. All nations, according to the Brundtland Report, face ‘life-threatening’ challenges caused by desertification, deforestation, pollution, ocean acidification, toxic chemicals and waste and ‘the unintended changes in the atmosphere, in soils, in waters, among plants and animals, and in the relationships among all of these’ [11]. Societal distress caused by increased prevalence and acceleration of ecological crisis and disasters ushered in conservationist and environmentalist movements starting in the late 19th century [12]. Yet, despite a number of science-based, highly influential reports and appeals to address these concerns since the early 1970s, not until the second decade of the 21st century that the world finally committed to the United Nations’ 17 Sustainable Development Goals (SDGs) and to the well below 2°C global temperature increase target of the Paris Agreement [13,14].

Eco-conscious architects and home-builders have long been at the forefront of tackling environmental challenges by developing more sustainable approaches to living. While traditional methodologies helped fuel the movements especially in their early phases, over time, various paradigms influenced by different disciplines spring up, evolve and continue to gain traction until today. In architectural context, there are two broad paths toward a third, much broader concept of sustainable architecture, which balances environmental, social, and economic considerations: green architecture (GA) path and a more recent circular built environment (CBE) path. Although the two paths attempt to reach the same broad objectives, in their present constructs, there are similarities and differences. This paper, therefore, aims to explore a framework that illustrates how the two broad paths toward sustainable architecture contribute to, and operationalize the internationally-ratified SDGs. In other words, it is an exploration of how GA and CBE fit within the broader sustainability principles as formally defined by the SDGs.

2. Scope and Methodology

This research addresses “what is” rather than “what ought to be” of paradigms, approaches, methods, and tools relevant to GA and CBE at meso (buildings and houses) and micro (materials) levels. Furthermore, the study of architecture’s contribution toward the SDGs in this article is limited to the design, construction, and generic in-use phases. For example, it only considers generic uses (e.g. how energy is consumed) of the built environment rather than distinguishes its use purpose (i.e. residential, commercial, or social). Additionally, the question of how each approach impacts sustainability is reviewed through the lens of clients/users, architects/designers, and contractors/labor, rather than that of the government and other stakeholders. While architecture in its broadest sense has links to all of the 17 SDGs, this study only considers some of the most relevant Goals informed by literature on the
subject. In the course of this research, it is noticed that many of initiatives or “Aspects” in GA and CBE often contribute to a multiple SDGs at the same time, either as intended purposes or as auxiliary consequences. In line with the spirit of this study, the author does not assign any weight to distinguish such, often nuanced, intention, effect or importance. A tri-axes mapping tool corresponding to the trinity of sustainability will be used in this study. Aggregation of the 17 Goals into the three dimensions (Dimension) is inspired by the Stockholm Resilience Initiative’s (SRI) framework [9], but reinterpreted here to suit architectural context of this study. Finally, thematic aggregation and the subsequent assignment of elements within each theme (Theme) to a particular domain – GA, CBE, or overlap of GA and CBE (denoted by G∩C) – though influenced by extant literature on the subjects, are essentially determined by the author’s impressions, due to lack of a universally-accepted approach of classification.

3. Sustainability & Architecture

In an architectural context, sustainability is general term that carries “more than 100” [7] and even as many as 300 definitions [15]. The term “sustainability” suggests a broad set of aspirations that encapsulates certain essence of, and sometimes used interchangeably with, the concepts of “ecological or environmental design”, “green architecture”, “sustainable building” and other similar terminologies [8,12]. Hannula argues that in developed countries, sustainability is conventionally associated with environmental matters, while in developing countries, economic matters [16]. Since there are 600 methods to assess in architectural sustainability [7], perhaps another way of defining sustainability in architectural context is by its opposite: sustainable architecture is thinking, processes and methodologies that does not employ “conventional approaches” in planning, design, construction, and operation of built environment that disregard the broader economic, societal and ecological aspects. Humanity has made countless attempts and progress toward sustainability, long before the WCED in its iconic “Our Common Future” report calls for ‘future development paths [emphasis added] that are sustainable’ [11].

As noted earlier, generally speaking, attempts and progress toward sustainable architecture seems to follow two broad paths: the “green” path and the circular economy path. The former path comprises of many schools of thoughts and certification schemes that adopt elements that are continually evolving, with some traditions dating back to at least late 19th century. On the other hand, circularity in architectural context is a relatively recent paradigm toward sustainability [17]. There are distinctions and overlaps between the two broad trails, and even among different schools and schemes within the same path. However, given their similar mission, it is not inconceivable that a future convergent of concepts is not only possible but also arguably necessary.

Climate-adaptive, or bio-climatic design principles tend to be a core of the GA path since its conception. Among the school of thoughts within the GA path is Frank Lloyd Wright’s “organic architecture” that espouses symbiotic ‘interactions between built, natural, and human’ through, among others, nature-inspired design, natural lighting and natural airflows [18]. Another influential school is the Passive House that employs locally-driven techniques in a quest to be energy-efficient, comfortable and affordable buildings [19]. Though Passive structures have proven to be effective in reducing energy consumption, i.e. resulting in up to 90% and 75% less energy for heating and cooling compared with respectively, ‘typical building stock and average new builds – regardless of the regional climate’ [20], buildings constructed according to Passive House standards ‘still only constitute a minority’ [21].

The second broad path toward sustainable architecture can trace its beginnings in the circular economy domain, which started to take shape in the 1970’s and 1980’s when Walter Stahel – an architect by training – along with colleagues engaged in economic studies and discourses on “loop economy”, “product-life factor”, and “cradle back to cradle” concepts in efforts to create jobs, achieve competitiveness, save resources and prevent waste [22]. The fundamental purpose of circular economy is to achieve economic growth with much less resource requirements, or in other words, ‘resource use is decoupled from economic growth’ [1], and hence the significance of materials as the starting point in the circularity school. According to Ellen MacArthur Foundation, ‘integrating circular economy principles into all the phases of a building’s cycle can work to meet urban needs for built space, while staying within planetary boundaries’ [5].
4. The Sustainable Development Goals

According to the Brundtland Report, people is of the primary interest [11] and it is people who have ‘the ability to make development sustainable to ensure that it meets the needs of the present without compromising the ability of future generations to meet their own needs’ [11]. To that end, humanity must address ‘broad areas of concerns’ of ‘environment, economics, social’ [11], that are ‘integrated and indivisible and balance’ [13]. The three broad areas are often referred to as the ‘triple bottom line’ or the equivalent 3P (‘people, planet and profits’) of sustainability [23]. The triple bottom line concept is a widely used concept by the academics. For an example, applying the triple bottom line concept to urban living, Tanguay et al suggest that the overlaps of the dimensions could provide further guidance for sustainability: to be ‘equitable’ (socio-economic), to be ‘livable’ (social-environmental), and to be ‘viable’ (or development that is in line with ‘the supportive capacity of the ecosystems’) [24]. In a study on application of the trinity concept at corporate levels, von Hauff and Kleine develop the integrative sustainability triangle (IST) as a ‘systematization method’ to develop sustainability strategy [25].

The year 2015 gave sustainability movement a tremendous boost after the United Nations General Assembly passed Resolution A/70/L.1 on the 2030 Agenda that defines and articulates the 17 SDGs including 169 targets, which are structured around ‘People, Planet, Prosperity, Peace, Partnership’ themes [13]. Later in the same year, the Paris Agreement that addresses global risks and impacts from climate change by limiting temperature increase to well below 2°C above pre-industrial levels, was also ratified [14]. Subsequent to ratification of the two global initiatives, in a seminal work on sustainability through the lens of social-ecological resilience, the SRI proposes a framework that not only classifies the SDGs into three dimensions of sustainability, but also establishes causal relationships among the dimensions. In essence, they argue that wellbeing of the biosphere (related to SDGs 6, 13, 14, 15) is a prerequisite for social justice (SDGs 1, 2, 3, 4, 5, 7, 11, 16,), which in turn is a precondition for economic development (SDG 8, 9, 10, 12). In the framework, SDG 17 (partnership to attain the goals) is regarded as an integral to but not classified under any of the three dimensions [26]. The logic behind classification of the SDGs within the SRC framework is adapted for this study with some modifications as the author of this paper believes that recategorization of two SDGs is warranted in the context of architecture. Specifically, the framework of this study classifies SDG 7 (‘Affordable and Clean Energy’ as a component of the environment as opposed to that of the society. Furthermore, SDG 17 (“Partnerships for the Goals” is treated as part of economic dimension. Figure 2 shows how the SDGs are categorized along the three dimensions in this study.

![Figure 1. Sustainability Triangle](image1)

![Figure 2. The SDGs and the Triple Bottom Line](image2)
The link between architecture and the SDGs is proposed by several organizations and studies. From climate change perspectives, as noted earlier, the building and construction sector has been a major contributor of CO2 and hence lies a great opportunity. According to the International Energy Agency, emission reductions from buildings can contribute to the total reductions required to align with its Sustainable Development Scenario designed to achieve the outcomes of the SDGs 3, 7 and 13, in addition to contributing to SDG 12 through decarbonization of buildings [4]. A joint publication asserts that architecture ‘interacts with every’ SDGs and while sustainability in its broadest sense remains ‘aspirational’, architectural solutions have been making real contributions for better communities and quality of life [27]. Select “generic”, GA and CE/CBE contributions to SDGs (the last two will be discussed later) are highlighted in Table 1, constructed based on available research on the topic and author’s analysis.

### Table 1. Select Contributions of Architecture to the SDGs

| SDG | Dimension, Goal, [Relevant Target] | Examples of Contributions |
|-----|-----------------------------------|--------------------------|
| **SOCIAL** | | |
| 03 | Ensure healthy lives and promote well-being for all at all ages. [Targets 3.9, 3.d] | Contamination control measures. Avoidance of hazardous substances. Reduction of air, water, and soil pollution. Reduction of health risks. Design for improved health and well-being. |
| 04 | Ensure inclusive and equitable quality education and promote lifelong learning opportunities for all. [Target 4.7] | Educate and be educated on sustainable knowledge, practices and skills. |
| 11 | Make cities and human settlements inclusive, safe, resilient and sustainable. [Targets 11.1, 11.3, 11.4, 11.5, 11.6, 11.7, 11.a, 11.b] | Disaster-resilient building. Inclusive settlement and access to green spaces. Respect and safeguard cultural and natural heritage. Emission and pollution control. Waste management. Humane and sustainable design. Use of local materials. Resource efficiency. |
| 16 | Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels. [Targets 16.2, 16.7, 16.10] | Ethical sourcing. Participatory decision-making. Access to information and knowledge. |
| **ENVIRONMENTAL** | | |
| 06 | Ensure availability and sustainable management of water and sanitation for all. [Targets 6.3, 6.4, 6.6, 6.a] | Land and groundwater contamination control. Hazardous substances dumping avoidance. Wastewater treatment. Consumption efficiency. Responsible freshwater withdrawals. Protection of water sources. Water harvesting. |
| 07 | Ensure access to affordable, reliable, sustainable and modern energy for all. [Targets 7.2, 7.3, 7.a] | Use of renewable energy. Energy consumption efficiency. Clean energy technologies. |
| 13 | Take urgent action to combat climate change and its impacts. [Targets 13.1, 13.3] | CO₂ reduction measures. Focus on embodied energy. Use of regenerative materials. Renovation and retrofitting. Climate-adaptive design. Resilience toward climate change. Awareness-building. |
| 15 | Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss. [Targets 15.1, 15.2, 15.3, 15.4, 15.5, 15.6, 15.7, 15.e] | Conservation and restoration of ecosystems. Prevention of environmental degradation. Protection of biodiversity. Responsible sourcing (e.g. avoiding use of products unsustainably produced or from endangered species). |
| **ECONOMIC** | | |
| 08 | Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all. [Targets 8.2, 8.3, 8.4, 8.5] | Use of local labor and resources. Innovation for job creation and business opportunities. Support for informal sector. Decent pay and equal opportunity. |
| 09 | Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation. [Targets 9.4, 9.9] | Innovative design, tools, processes and solutions. Support for domestic technology and development. |
| 12 | Ensure sustainable consumption and production patterns. [Targets 12.1, 12.2, 12.4, 12.5, 12.7, 12.8, 12.a] | Do more and better with less resources. Reducing use of non-regenerative resources. Attention to life cycle of assets. Waste management and utilization. Pollution control in all forms. Promotion of human health and well-being. Responsible sourcing. |
| 17 | Strengthen the means of implementation and revitalize the global partnership for sustainable development. [Targets 17.7, 17.16, 17.17] | Collaboration involving planners, architects, clients as well as public, civil, and private institutions. Sharing and promotion of technologies and expertise. |

---

1 References: [1,7,27,28] and author’s analysis.
5. Green Architecture

The oil crisis of the 1970s spurred the need for better energy economics and more sustainable practices and later gave birth to the contemporary green building movement [29]. Even until today, green architecture is to a large extent directed by energy and the broader ecological concerns, with little attention paid to social and economic considerations [7,12]. For an example, green building standards have primarily been environmental sustainability-focused in the last decade [7]. As another example, the UNECE focuses primarily on energy efficiency aspects of green homes (an environmental concern), with references economic impacts and social effects [30]. Similar to “sustainability” term, “green architecture” can be defined in as many ways as there are agencies, certification bodies, academics, and practitioners. In short, there is no universally-accepted definition of green architecture both as a concept or as a set of practices [24]. However, literature reviews on green architecture reveal that there are identifiable common themes across diverse definitions. Below are some definitions of green architecture according to academics, building councils and accreditation bodies.

First, from academic’s point of view. Attmann, for instance, considers green architecture as a combination of ‘environmental, social, political, and technological’ values with a mission ‘to reduce the negative environmental impact of buildings by increasing efficiency and moderation in the utilization of building materials, energy, and development space’. A green building should embrace the values to some degrees in order to be concurrently “sustainable,” “ecological” and “performative”. Taxonomy of green architecture proposed by Attmann includes attention to “elements (technology and materials),” “resources,” and “environmental”. [8]. In spite of their form diversity, eco-homes share a conventional notion of ‘minimizing environmental impact’. Designing and constructing eco-homes requires a number of considerations, including context (e.g. local climate, material availability, and skill sets), impact (e.g. environmental footprint, energy and water use), and practices (technology, reliance on natural materials) [32]. More recently, Pearlmutter et al consider “greenness” in the built environment in terms of ‘nature-based solutions’ that comprise of green building ‘materials, systems and sites’ [33].

Secondly, agencies that advocate green architecture also propose their own definition of green architecture. According to the US Environmental Protection Agency, ‘green building is the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building’s life-cycle from siting to design, construction, operation, maintenance, renovation and deconstruction’, in an effort to reduce the overall impact of the built environment on human health and the environment. Key aspects of green buildings include efficiency (energy, water, and other resources), health of the inhabitants, responsible use of materials (reusables, recyclables, made from renewable resources), reduction of waste and pollution [34]. Another definition of green building is offered by World Green Building Council, which defines it as ‘a building that, in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts, on our climate and natural environment’. Some of key features include efficiency (energy, water, and other resources), renewable energy source, materials choice (non-toxic, ethical, sustainable, measures to reduce pollution and negative impact on the environment (waste, reuse, recycle), quality of life of the occupants (indoor and in general) [35].

Lastly, institutions that issue green building standards and accreditation schemes (e.g. “green building rating systems”, “sustainable building assessment methods”) also offer their own versions of greenness in building. Increasing acceptance and adoption of green assessment tools and standards [32] suggest the importance of such institutions in defining sustainability in architecture [7]. However, as suggested earlier, definitions and criteria for green building vary from one institution to another. A comparative study of five rating councils from five different countries confirms a variety of themes and importance (or weightage) attached to each theme [36]. The same study found that “Energy Efficiency”, “Water Efficiency” and “Indoor Environment Quality” are common features across all green building certification systems, followed by “Site Planning & Management” and “Materials & Resources” (each considered by 80% of the councils), while only 60% of the councils take “Environmental Protection” and “Innovation” themes into consideration [36].
Despite pluralistic definitions of GA, there are identifiable common themes which will be highlighted later. Furthermore, it has been suggested that GA contributes to the SDGs 3, 7, 8, 9, 11, 12, 13, 15, and 17 [37], even though Goubran and Cucuzzella (2019) find no established ‘framework for understanding and approaching sustainability’ in the context of the SDGs [7].

6. Circular Economy
The building and construction sector ‘needs to dramatically change the way it works’ in view of ‘continuing population growth, urbanization, climate change and resource scarcity’ [1]. The current generations ‘borrow environmental capital from future generations with no intention or prospect of repaying’ by pulling raw materials from forests, soils, seas, and waterways [11] and pouring them especially into cities, where 55% of today’s population lives [38].

‘The pathway to a low-carbon future is circular’ [2]. CE is ‘at the core of sustainability’, and it does so by attempting to reduce resource consumption rate for a given economic development rate, or in other words, ‘resource use is decoupled from economic growth’ [1]. Materials, in turn, are one of the cores of CE, covering dual minimization objectives with regards to extraction of especially non-regenerative resources and loss of value in the form of waste, as well as two maximization goals of existing stock utilization and cycling for reusability [2]. To that end, engagement of multiple stakeholders and creation of new business models are integral to realizing circular economy’s potential benefits [39].

Despite its increasing prominence, circular economy ‘remains eclectic and lacks a scientifically endorsed definition’ [21]. There is ‘no agreed and simple definition of circular economy’ [39]; a 2017 research identifies 114 definitions of CE [40]. The European Parliament, for an example, defines CE as ‘a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible’ [41]. Another defines CE as an effort to replace the linear ‘take-make-dispose’ model that assumes limitless resource usage, by ‘designing out waste and pollution, keeping products and materials in use, and regenerating natural systems’ [3]. In a joint publication by Ellen MacArthur Foundation, McKinsey & Co., and SUN, circular economy is defined as ‘an economy that provides multiple value-creation mechanisms which are decoupled from the consumption of finite resources’, underpinned by the three principles of ‘preserving and enhancing natural capital… optimizing resource yields… and fostering system effectiveness by revealing and designing out negative externalities’. The same joint publication also introduces the ReSOLVE framework to operationalize CE. Briefly, the framework espouses shifts toward renewable energy and materials (Regenerate), increased utilization through sharing (Share), optimization of performance and efficiency (Optimize), reuse and recycling of materials (Loop), digitization (Virtualize), and adoption of new products and services that are more circular-friendly (Exchange). [21].

The relationship between circular economy and the triple bottom line of sustainability is explored by Geissdoerfer et al, who conclude that the circular economy ‘is a condition for sustainability’ [15]. They also found that circular economy is often associated with management of resources, waste and emission that mostly highlights the economic benefits, ‘simplifies the environmental impacts’, and offers scant references to social implications (frequently alluding only to creation of jobs and presenting some vague connections to well-being), which fall short of balanced integration approach of the triple bottom line. In addition, compared to those on sustainability, discussions on circular economy tend to disregard ‘long-term viability’, and while sustainability approaches suggest behavioral change through engagement and education, circular economy approaches seem to propose economic motivations (e.g. incentives). However, in contrast to imprecise and broad concepts of sustainability, the more narrowly framed concepts of circular economy offer ‘clearer directions’ for implementation [15,40]. Put it differently, a study by Kanters found that architects see the connection between sustainability and circular economy concepts in terms of the former providing directions to “do less bad” while the latter specifying how to “do good” [42]. In one study, CE practices are found to have the strongest relationships with targets of SDGs 6, 7, 8, 12 and 15. Overall, direct contributions of CE are identified
in 21 of the SDG targets while indirect contributions in 28 targets. They conclude that CE practices can operationalize specific SDG targets. [39].

7. Circular Built Environment

According to the 2020 Circularity Gap Report, the built environment has a major role in the amount of materials consumed globally (more than 50%), while the circularity in the sector remains low. In their joint publication entitled “Scaling the Circular Built Environment”, World Business Council for Sustainable Development and Circle Economy believe that closing the gap in the built environment requires implementation of circular principles in maintaining existing buildings as well as in designing new constructions, and an accelerated transition to CE is needed [1]. However, as a relatively new concept within the built environment, CE has not been implemented as successfully as in many other sectors, due to among others lack of both a common definition and practical knowledge [43].

Circular built environment is firmly grounded on the circular economy principles that place emphasis on ‘industrial symbiosis, renewable materials, shared economy… proximity economics, reuse, recycling and upcycling, urban mining, detoxification of material cycles and sustainable consumption and production [1]. The intent of achieving ‘circular buildings’ is to comprehensively reduce life cycle impacts, and at the same time provide healthy and comfortable spaces for urban dwellers [33]. At meso level, circular principles can be integrated into all phases of a building’s cycle: planning, designing, making, accessing, and operating and maintaining. Among the opportunities include local circularity, flexible design, collaboration, material selection, strategic sourcing, efficient construction techniques, treatment of buildings as temporary storage, space-sharing, flexible and alternative use, new business models, use of technology, and refurbishment for better efficiency [5]. Taking a commercial building as an illustration, Arup identifies CE opportunities in the ecosystem (collaboration of stakeholders), design, sourcing, construction, operation, renewal, reassembly, and repurpose [44].

One way to implement circular principles in the built environment is to think about buildings as layers. Proposed in the 1970s and continually developed in the 1990s and 2010s, the model offers opportunities to increase the lifespan of buildings by focusing on, for instance, replacement, repair, removal, remanufacturing, and recycling of one layer without affecting other layers. Seven layers of a building are identified: Site (infinite lifespan), Structure (30-300 years), Skin (20-35), Services (15-30), Space Plan (10-30), Stuff (5-20), and finally, Social (i.e. occupants’ behavior while living in the buildings, which lasts for as long as the building is in use) [1,3,44].

CE100 network through its Co.Project Initiative demonstrates how to use the ReSOLVE framework (discussed earlier) in the architectural context. Concisely, the ‘Regenerate’ actions in the built environment revolve around use of renewable energy and production systems. The ‘Share’ initiatives involve maximization of product utilization through among others co-housing and shared facilities. ‘Optimize[d]’ systems performance can include pre-fab methods and various energy, water, and material efficiency measures. The ‘Loop’ entails extension of product life via durability, maintenance, systematic end-of-life management for recycling, and modularity design. ‘Virtualiz[ing]’ of products and processes such as tele-working and automation. Finally, the ‘Exchange’ involves adoption of better-performing materials, technologies, products and services. [45]

A number of themes in circular building sector are identified in Kanters’ (2020) study. Among those is what the author calls ‘circular materiality’, which includes considerations of choice of materials, use of new as well as recycled materials, a set of toolkits (e.g. total carbon footprint calculation, Life Cycle Assessment analysis, design for de-/reconstruction, material passports). Some of barriers and drivers include the need to flexibility in building regulation, access to recycled materials supply, which is lagging the demand, and dependence on an ecosystem to support circular economy in built environment. Other categories are ‘the new role of the architect’ (as an innovator, material expert, link to other actors), ‘building as a piggy bank’ and a compilation of circularity interpretations by survey respondents [42].

To date, most of research on CBE is on ‘the definition of circularity, life cycle analysis (LCA) and technical inventions for recycling’, while not much focus is on differences in terms of building design
processes between CBE and conventional approaches. [42]. Pearlmutter et al note that holistic approach to circularity is still lacking in existing building certification systems [33].

The circular built environment contributes in several ways in achieving the SDGs 3, 6, 7, 8, 9, 11, 12, and 13 [1]. In a separate publication, CBE is believed to contribute to stronger communities (closely associated with SDG 11), reduction of air pollution (SDGs 3, 13), lowered unemployment (SDG 8), increased asset utilization (SDG 12), and reduction in energy consumption (SDG 13), among others [5].

8. Findings and Discussion

Four Themes emerge from the literature reviews: Efficiency, Material, Health, and Enabler. Efficiency is an objective associated with energy and water use. Preferences, viewpoints and decisions with respect to materials make up the second Theme. Third is the consideration for wellbeing of the occupants. A number of important aspects toward sustainable architecture is grouped under the fourth Theme. Within each Theme is one or more Sub-theme(s), and within a Sub-theme are a number of Aspects. For example, Energy Consumption Sub-theme comprises of three Aspects, namely Bio-climate design, Renewable energy and Energy-saving features. In total, there are 10 Sub-themes and 28 Aspects.

8.1. Efficiency

Across the board, efficiency is a major consideration toward sustainability. Energy and water consumption are two objects of efficiency initiatives.

8.1.1. Energy Consumption (A.1).

- Bio-climatic design (A.1.a). Climate-responsive design approaches and techniques specific to the local context and dynamics such as microclimate (temperature, humidity, rainfall levels), latitude, orientation, and surrounding ecology, are adopted in order to eliminate or reduce energy consumption for artificial air-conditioning (reduce urban heat island effect, retain heat), lighting and other purposes.
- Renewable energy (A.1.b). Provision of onsite energy through renewable sources and storage systems (e.g. photovoltaic and wind generators).
- Energy-saving features (A.1.c). Conservation of energy through more energy-efficient appliances and devices (air-conditioning systems, lighting, smart systems) and greening of site (plants, vegetation) to provide shade for less energy consumption.

8.1.2. Water Consumption (A.2).

- Water-saving fixtures (A.2.a). Conservation of water through efficient use (water-saving devices such as low-flow faucets, showerheads).
- Water from and for nature (A.2.b). Conservation of water through rainwater harvesting, recycled grey water for non-potable purposes and preservation of the aquifers through infiltration techniques (gravel, permeable pavement, native landscaping).

8.2. Material

Material is one of the key themes identified, and material decisions seems to be driven among others by the total energy consumed and the associated GHG emissions in the extraction, production, and transportation processes, or the embodied energy of the material. Use of natural materials sourced locally are often preferred due to their low-embodied energy. In the same spirit, attention is given to recycled materials and durable, long lifespan components (especially if they are non-natural and energy-intensive) with low maintenance. Furthermore, potential of harm caused by toxic ingredients either to the environment or human health is another important consideration.
8.2.1. Characteristics (B.1).
- Regenerative material (B.1.a). Prioritization of natural, regenerative and biodegradable materials (e.g. wood, bamboo, straw bale, lake reed) and those that can easily and safely break down (e.g. earth- and stone-based, bioplastics).
- Virgin materials (B.1.b). Minimization of production inputs especially made of virgin, non-renewable materials.
- Unsafe materials (B.1.c). Avoidance of materials containing harmful and toxic ingredients (volatile organic compounds, asbestos, leaded paints).
- Durability (B.1.d). Materials engineered for maximum durability and adaptability to allow for optimum recovery and future reuse. In cases where use of biodegradable materials, which tend to have relatively short life, is either not possible or undesirable, use of durable and reusable materials could be as equally sustainable.

8.2.2. Source (B.2).
- Locality (B.2.a). Preference for locally available materials for economic (less transport costs) and social reasons such as supporting local employment, building the capacity of community. The “Lo-Fab” (Locally Fabricated) movement perhaps takes it furthest by designing and building structures onsite, using only local technology, labor, and materials [36].
- Embodied energy (B.2.b). Decision to use materials depends in part on calculation of the total embodied energy footprint accumulated in extraction, manufacturing and transportation processes.
- Ethical sourcing (B.2.c). Preference or requirements for materials that are ethically, fairly, and sustainably sourced.

8.2.3. Waste (B.3).
- Waste as an output (B.3.a). Minimization or ideally prevention of waste and its safe disposal.
- Waste as a key resource (B.3.b). Use of available recycled or reclaimed materials. A vast amount of different materials from industrial waste, household waste and construction waste can be reused in building. Emphasis on circularity in material use.

8.2.4. Utilization (B.4)
- Starting small (B.4.a). The practice of designing structures that are “just big enough” to satisfy current and foreseeable future needs has been practiced for generations. For economic or more altruistic reasons (reduce environmental footprint, responsible consumption), such a practice has started to gain popular acceptance through for instance small homes movement and modular architecture [14].
- Productivity of available space (B.4.b). Increased space efficiency through intensification and sharing of use, as well as embedded flexibility for alternative use.
- Lifetime extension (B.4.c). The decision to prolong the service life of existing structures is a way toward sustainability. Maintenance, repair, upgrade and environmental retrofitting instead of demolition are usually more economical, requiring less resource, enhancing energy efficiency as well as improving health due to better indoor environment.
- Buildings as material banks (B.4.d). Buildings and their contents are considered as stock that needs to be optimally used, hence the effort to limit hibernating assets (temporarily not in use) and the treatment of assets in use as temporary storage of materials for future use after the buildings' end-of-life.
8.3. Health

Concern for a healthy living is crucial for sustainability. Though the surrounding also influences wellbeing, it is the indoor environment is the focus to avoid issues such as sick building syndrome.

8.3.1. Indoor (C.1)

- **Hazards (C.1.a).** Careful design and use of materials to avoid occupants’ exposure to biological hazards (mold, spores) and harmful chemicals.
- **Harnessing nature (C.1.b).** Optimization of indoor livability through natural airflows and daylighting.

8.4. Enabler

Enablers are factors that support the achievement of more sustainable architecture, such as innovative business models, new technologies and processes.

8.4.1. Business Model (D.1)

- **Economic ecosystems (D.1.a).** Development of local economic ecosystems such as new or enhanced business models in the reuse/recycled product supply chain (waste extraction, collection, mining, reprocessing, distribution). Especially in developing countries, upstream recycling activities support the livelihood of informal, often marginal, sector.
- **Quality assurance (D.1.b).** Reusability of critical building components (e.g. steel beams, load-bearing walls) requires assurance from a reliable, independent party.

8.4.2. Technology & Innovation (D.2)

- **Archi-tech (D.2.a).** Adoption of architectural technologies to promote more sustainability, which include local wisdom, state-of-the-art eco-materials and innovative building engineering approach such as modular design.
- **Information and Communication Technology (D.2.b).** Use of digital technology to enable data storage and sharing (e.g. through online platforms, open data access) of recycled material availability for immediate use and material passports for future use.

8.4.3. Processes (D.3)

- **Construction processes (D.3.a).** Minimization of negative impacts (carbon emission, dust, toxic substance) on air, water and land, during construction.
- **Planning for resilience (D.3.b).** In an architectural context, possibility of natural disaster events cannot be overlooked. Not only can earthquakes, flood, tsunamis, landslides, and storms can cause physical damages, such occurrences also adversely impact the environment and the society, both the essence of sustainability.
- **Collaboration (D.3.c).** Designing, constructing, and consuming sustainable house or building require flexibility, know-how, and permanent lifestyle adjustments. Therefore, sustainable architecture necessitates active participation and collaboration among its main actors (e.g. architect, client, contractor).
- **End-of-life planning (D.3.d).** Deliberate planning for flexibility and management of materials after end-of-life (deconstruction, extraction, reuse, recycle, and final disposal). Such a practice is strongly associated with circular built environment (e.g. Cradle-to-cradle and Design for Deconstruction approaches).

Having identified key Themes, Sub-themes, and Aspects, the next process is to classify each Aspect, according to whether it is more associated with GA, CBE, or at the intersection (overlap) of the two domains (G\cap C). For example, Aspects under Material-Characteristics are classified differently: use of
Regenerative materials is considered a GA practice, attention to virgin materials is recognized as a CBE routine, while avoidance of Unsafe materials is regarded as an integral part of both domains (G∩C). The subsequent step is to identify the most relevant SDG(s) each Aspect contribute to. Lifetime expansion (Materials–Utilization), for instance, is believed to contribute to Society (through SDG 11), to Environment (SDG 13) and to Economy (SDG 12). It is worth-mentioning that the above processes of identification and classification (incorporated in Table 2) are guided as much by literature review as by author’s subjective opinion.

Table 2. Relationships between GA and CBE Aspects and the SDGs

| Theme and Aspect | Domain* | SDG Dimension |
|------------------|---------|---------------|
|                  |         | Society       | Environment | Economy |
| __________________|---------|---------------|
| **A** EFFICIENCY |         |               |             |         |
| A.1.a Bio-climatic design | GA | 07, 13 | | |
| A.1.b Renewables | GA | 03 | 07, 13 | |
| A.1.c Energy-saving features | GA | 07, 13 | 12 | |
| A.2.a Water-saving fixtures | GA | 06, 15 | 12 | |
| A.2.b Water from and for nature | GA | 11 | 06, 15 | 12 | |
| **B** MATERIAL |         |               |             |         |
| B.1.a Regenerative materials | CBE | 13, 15 | | |
| B.1.b Virgin materials | CBE | 13, 15 | 12 | |
| B.1.c Unsafe materials | G∩C | 03, 11 | 15 | |
| B.1.d Durability | CBE | 13 | 09, 12 | |
| B.2.a Locality | G∩C | 04, 11 | 13 | 08, 09 | |
| B.2.b Embodied energy | CBE | 13 | | |
| B.2.c Ethical sourcing | G∩C | 04, 16 | 15 | 08, 12 | |
| B.3.a Waste as an output | G∩C | 03, 11 | 06, 15 | 12 | |
| B.3.b Waste as a resource | CBE | 13, 15 | 11, 12, 17 | | |
| B.4.a Starting small | GA | 15 | 12 | | |
| B.4.b Productivity of available space | CBE | 11 | | 12 | |
| B.4.c Lifetime extension | CBE | 11 | 13 | 12 | |
| B.4.d Buildings as material banks | CBE | 12 | 13 | 09, 12 | |
| **C** HEALTH |         |               |             |         |
| C.1.a Hazards | G∩C | 03, 11 | 15 | | |
| C.1.b Harnessing nature | GA | 03 | | | |
| **D** ENABLER |         |               |             |         |
| D.1.a Economic ecosystems | CBE | 11, 16 | 08, 09, 11, 17 | | |
| D.1.b Quality assurance | CBE | | 09 | | |
| D.2.a Archi-tech | G∩C | 13 | 09, 17 | | |
| D.2.b Info & Comm. Tech. | CBE | 16 | 09, 17 | | |
| D.3.a Construction process | G∩C | 03, 11 | 06, 15 | 08, 12 | |
| D.3.b Planning for resilience | GA | 11 | 15 | | |
| D.3.c Collaboration | CBE | 04, 16 | 17 | | |
| D.3.d End-of-life planning | CBE | 11 | 13 | 12 | |

* GA = Green Architecture, CBE = Circular Built Environment, G∩C = Interaction of GA and CBE
Coordinates of \((x, y, z)\), corresponding to the three dimensions of sustainability are determined by summing the occurrences of SDGs for a given domain. SDGs belonging to the overlapping region are counted twice in both domains. The resulting \((x, y, z)\) coordinates are then plotted on a radar chart to visually show commonality and contrast between the two paths of sustainable architecture (Figure 3). Generally speaking, it offers visual impressions of GA and CBE on a broader, triangular “canvas” of sustainability. The impressions reflect contemporary understandings of GA and CBE as informed by extant research on the subjects. More specifically, the inequilateral shapes of GA and CBE triangles signify asymmetric attention to the triple dimensions of sustainability. The framework provides a visualization of academic assertions that GA focuses more on addressing environmental concerns \([7,18,19,36]\), while CBE on economic imperatives \([3,15,39]\).

Resonating opinions of some academics \([7,12]\), the shapes of GA and CBE triangles indicate less attention toward social aspects relative to the other two dimensions. Furthermore, a considerable overlapping area may be explained by an increased adoption of same concepts and processes by both domains, over time. Finally, relatively larger triangle of CBE suggests that the domain incorporates many more practices toward sustainability than GA does. It may well be the case because CBE, a relatively new paradigm \([17,43]\), has incorporated many practices that can trace their beginnings in the GA domain, whereas the reverse is usually not the case. The concepts of sustainable architecture ‘are dynamic in that they are constantly in flux and being (re)made through everyday practices’ \([32]\). As such, the contemporary, impressionistic visualizations of both paradigms’ current states are just temporary and will therefore evolve. As the two domains evolve, a convergence is not only possible, but necessary in a quest for a common sustainable future. In the meantime, however, adopting aspects from both domains will create a greater whole that is larger than the sum of its parts (Figure 4). In the ideal, not too distant future, as Robert Stern (Dean of Yale School of Architecture) puts it, “we’re not going to talk about sustainability anymore, because it’s going to be built into the core processes of architecture” \([46]\).

9. Conclusion
This article highlights the important role that GA and CBE play in pathways towards sustainability as defined by the SDGs. It can be concluded that the SDGs provides a broad framework toward sustainability, while GA offers a number of approaches to get there, and CBE further supports the effort with a set of complementary tools. Though there are considerable overlaps, GA and CBE in their contemporary forms remain quite distinct from one another. One key distinguishable characteristic of
GA is its relative focus on addressing environmental concerns compared to the other two dimensions. In contrast, CBE methodologies are predominantly economic-driven, and therefore provides an additional ‘incentive’ toward sustainability [43]. Their complementarity suggests it is not a question of choosing between the two, but rather a reason to adopt both.

It has been noted in earlier studies that, and confirmed by this study, generally speaking, the social dimension does not receive an equal attention as do the other two dimensions, in both GA and CBE [7,12,15]. Of particular concern is the general lack of community-building considerations in sustainable architecture. Hannula (2012) suggests that to be socially resilient, the community needs to be empowered by way of capacity enhancement, inclusivity (leaving no one behind), and involvement through ‘information gathering, planning, implementation, maintenance and monitoring processes related to housing’. In an effort ‘to position social sustainability alongside ecology and economy as an equally important factor in the sustainable consideration of real estate’, the Austrian Sustainable Building Council proposes three ‘focal points’ incorporating flexible design to accommodate future needs and conditions, creation of properly managed public zones, and adoption of a holistic view that embraces the wider community for synergies in for instance, energy production and shared infrastructure [47]. In practice, however, many architects have in fact translated societal aspirations of the SDGs into reality and therefore addressed architecture’s linkages to the question of livability and fairness [27,48].

Greening of architecture is a long and arduous journey. First, diffusion of awareness and concerns about sustainability issues among stakeholders is notably slow, even in a developed country such as the UK. A survey conducted in March 2020 by Department of Business, Energy and Industrial Strategy finds that 76% of respondents are either fairly or very concerned about climate change, up only by 10% in almost 8 years from a baseline of 65% recorded in June 2012 [49]. Specifically in the context of scaling up CE in building sector, studies have found that a lack of awareness among clients, designers, subcontractors, and construction and demolition waste management firms is a barrier [17]. Furthermore, ‘partial and often incorrect’ understanding of green homes by the public, policymakers and construction industries is noted by Pickerill [32]. Turning awareness and knowledge into practice is yet another challenge to face. The same UK survey mentioned earlier also found that less than half of respondents (47%) have actually done at least three daily behaviors related to mitigation of climate change [49]. Another example is from a study in China that found that a high level of awareness of, and agreement to practice green construction principles among on-site construction personnel is not necessarily a guarantee, because such practices were not implemented particularly by those working on small-scale projects [50]. There are other, equally vital dynamics to green the architecture. For one, cost differences of up to 30% are major economic disincentives to construct more sustainable buildings [42,51]. Behaviorally, well-established mindsets, risk aversion, and short-termism of the actors can be powerful barriers to change [16,42]. Moreover, fragmented and localized industry structure hampers the development of an ecosystem for matching the demand and supply of reusable materials and for other collaborative exchanges [4,42]. Likewise, progress toward more sustainable architecture can be accelerated by stronger regulatory and institutional support such as more stringent energy-related policies and building codes, fiscal (dis-)incentives and a financial system that is progressively moving away from the high-carbon economy mode [4,52]. Removal of barriers to accelerate and intensify the greening of architecture will be the key challenge going forward.

Shortcomings of this study are hereby acknowledged, which includes oversimplification, subjectivity, and arbitrary decision. To begin with, the act of reducing broadly defined SDGs into just three dimensions is a subjective exercise because the SDGs are multi-interpretive. Classification of Aspects under Themes/Sub-themes into either GA, CBE or G∩C domain; and the subsequent processes of linking with the SDGs, could only intensify the shortcomings identified above. Nevertheless, despite the limitations, the findings and framework presented in this study could potentially contribute to a heightened awareness and an enhanced understanding of the GA and CBE concepts and practices in the context of SDGs. The enormous impact of architecture on rapidly depleting resources and accelerating climate change also mean a tremendous potential to make a difference, fast, as the ‘critical window of opportunity’ lies only in the 2020s [52]. It is therefore hoped that this study stimulates an accelerated
development and mainstreaming of a more integrated, balanced approach in a quest for sustainable livelihood, fairness, and viability, for all.

References
[1] Thelen D, van Acoleyen M, Huurman W, Thomaes T, van Brunschot C, Edgerton B and Kуббинга B 2018 Scaling the Circular Built Environment: Pathways for business and government (Arcadis, WBCSD, Circle Economy)
[2] Circle Economy 2020 The Circularity Gap Report 2020 (Amsterdam: Circle Economy)
[3] Acharya D, Boyd R and Finch O 2020 From Principles to Practices: Realising the value of circular economy in real estate (Arup and Ellen MacArthur Foundation)
[4] GlobalABC, IEA and UNEP 2020 GlobalABC Roadmap for Buildings and Construction: Towards a zero-emission, efficient and resilient buildings and construction sector, (Paris: IEA)
[5] Ellen MacArthur Foundation 2019 Circular Economy in Cities: Urban Buildings System Summary
[6] Salgın B, Bayram Ö, Akgün A and Agyekum K 2017 Sustainable Features of Vernacular Architecture: Housing of Eastern Black Sea Region as a Case Study Arts 6 11
[7] Goubman S and Cucuzzella C 2019 Integrating the Sustainable Development Goals in Building Projects J. Sustain. Res 1 43
[8] Attmann O 2010 Green Architecture: Advanced Technologies and Materials (McGraw-Hill)
[9] Stockholm Resilience Centre 2015 Planetary Boundaries - an update
[10] Meadows D, Meadows D, Randers J and Behrens III W W 1972 The Limits to Growth: A Report for The Club of Rome’s Project on the Predicament of Mankind (New York: Univers Book)
[11] WCED 1987 Report of the World Commission on Environment and Development: Our Common Future
[12] Heilman V M 2016 Factors Hindering the Adoption of Sustainable Design and Construction Practices: The Case of Office Building Development in Dar es Salaam, Tanzania (Universität Stuttgart)
[13] United Nations 2015 UN Resolution A/70/L.1. Transforming Our World: The 2030 Agenda for Sustainable Development
[14] UNFCC 2015 The Paris Agreement
[15] Geissdoerfer M, Savaget P, Bocken N M P and Hultink E J 2017 The Circular Economy – A new sustainability paradigm? J. Clean. Prod. 143 757–68
[16] Hannula E-L 2012 Going green: a handbook of sustainable housing practices in developing countries (Nairobi, Kenya: UN-Habitat)
[17] Foster G 2020 Circular economy strategies for adaptive reuse of cultural heritage buildings to reduce environmental impacts Resour. Conserv. Recycl. 152 104507
[18] Graff S 2018 Organic Architecture and the Sustaining Ecosystem Frank Lloyd Wright Found.
[19] Feist W 2020 What is a Passive House? (Passive House Inst.)
[20] Tzar G and Bosenick F 2018 Active for more comfort: Passive House (Darmstadt, Germany: International Passive House Association (iPHA))
[21] Ellen MacArthur Foundation, McKinsey & Co. and SUN 2015 Growth Within: A Circular Economy Vision for A Competitive Europe
[22] Product-Life Institute 2017 Cradle to Cradle (Prod.-Life Inst.)
[23] Elkington J 2004 Enter the Triple Bottom Line The Triple Bottom Line: Does It All Add Up? ed A Henriques and J Richardson (Routledge)
[24] Tanguay G A, Rajaonson J, Lefebvre J-F and Lanoie P 2009 Measuring the Sustainability of Cities: A Survey-Based Analysis of the Use of Local Indicators SSRN Electron. J.

[25] Kleine A and von Hauff M 2009 Sustainability-Driven Implementation of Corporate Social Responsibility: Application of the Integrative Sustainability Triangle J. Bus. Ethics 85 517–33

[26] Folke C, Biggs R, Norström A V, Reyers B and Rockström J 2016 Social-ecological resilience and biosphere-based sustainability science Ecol. Soc. 21 art41

[27] Institute of Architecture and Technology (KADK), Danish Association of Architects and UIA Commission on the UN SDGs 2018 An Architecture Guide to the UN 17 Sustainable Development Goals (Copenhagen)

[28] WGBC Green Building & the SDGs World Green Build. Counc.

[29] US EPA Definition of Green Building

[30] United Nations Economic Commission for Europe 2012 Green Homes: Towards energy-efficient housing in the UNECE region (Geneva)

[31] Pickerill J 2017 Critically Interrogating Eco-homes Int. J. Urban Reg. Res. 353–65

[32] Pearnblumut D et al 2020 Enhancing the circular economy with nature-based solutions in the built urban environment: green building materials, systems and sites Blue-Green Syst. 2 46–72

[33] US EPA 2015 What is Green Building US EPA

[34] WGBC What is green building? World Green Build. Counc.

[35] Bahaudin A Y, Elias E M and Saifudin A M 2014 A Comparison of the Green Building’s Criteria ed M A Othuman Mydin and A I Che Ani E3S Web Conf. 3 01015

[36] Czerwinska D 2017 Green building: Improving the lives of billions by helping to achieve the UN Sustainable Development Goals World Green Build. Counc.

[37] UN-Habitat 2019 SDG Cities (Nairobi, Kenya: UN Human Settlement Programme)

[38] Schroeder P, Anggraeni K and Weber U 2019 The Relevance of Circular Economy Practices to the Sustainable Development Goals J. Ind. Ecol. 23 77–95

[39] Kirchherr J, Reike D and Hekkert M 2017 Conceptualizing the circular economy: An analysis of 114 definitions Resour. Conserv. Recycl. 127 221–32

[40] European Parliament 2015 Circular economy: definition, importance and benefits

[41] Kanters J 2020 Circular Building Design: An Analysis of Barriers and Drivers for a Circular Building Sector Buildings 10 16

[42] Eberhard L C M, Birgisdottir H and Birkved M 2019 Potential of Circular Economy in Sustainable Buildings IOP Conf. Ser. Mater. Sci. Eng. 471 092051

[43] Arup 2016 The Circular Economy in the Built Environment (London: Arup)

[44] Ellen MacArthur Foundation 2016 Circularity in the Built Environment: Case Studies

[45] Conniff R 2010 Coming to Ecological Terms in Architectural Design Environ. Yale Spring

[46] ÖGNI 2018 ÖGNI Position Paper - Social Sustainability (Vienna: Austrian Sustainable Building Council)

[47] Vil M 2015 Lo-Fab Movement MASS Des. Group

[48] BEIS 2020 BEIS Public Attitudes March 2020 (United Kingdom: Department for Business, Energy and Industrial Strategy)

[49] Zhou J, Tam V and Qin Y 2018 Gaps between Awareness and Activities on Green Construction in China: A Perspective of On-Site Personnel Sustainability 10 2266

[50] Elias E M and Chong K L 2015 The empirical study of green buildings (residential) implementation: Perspective of house developers Procedia Environ. Sci. 28 708–16

[51] GlobalABC, IEA and UNEP 2019 2019 global status report for buildings and construction: Towards a zero-emission, efficient and resilient buildings and construction sector