sustainability

MDPI

Article

Circularity in the New Gravity—Re-Thinking Vernacular Architecture and Circularity

Marwa Dabaieh [1,*], Dalya Maguid [2] and Deena El-Mahdy [2]

1 Unit of Built Environment, Department of Urban Studies, Faculty of Culture and Society, Malmo University, 211 19 Malmö, Sweden
2 Architectural Engineering Department, Faculty of Engineering, The British University in Egypt, Al-Sherouk 11837, Egypt; dalya.maguid@gmail.com (D.M.); deenaelmahdy@gmail.com (D.E.-M.)
* Correspondence: marwa.dabaieh@mau.se

Abstract: The mounting climate change crisis and the rapid urbanization of cities have pressured many practitioners, policymakers, and even private investors to develop new policies, processes, and methods for achieving more sustainable construction methods. Buildings are considered to be among the main contributors to harmful environmental impacts, resource consumption, and waste generation. The concept of a circular economy (CE), also referred to as "circularity", has gained a great deal of popularity in recent years. CE, in the context of the building industry, is based on the concept of sustainable construction, which calls for reducing negative environmental impacts while providing a healthier indoor environment and closing material loops. Both vernacular architecture design strategies and circular economy principles share many of the same core concepts. This paper aims at investigating circular economy principles in relation to vernacular architecture principles in the built environment. The study demonstrates how circular principles can be achieved through the use of vernacular construction techniques and using local building materials. This paper will focus on Egypt as one of the oldest civilizations in the world, with a wide vernacular heritage, exploring how circularity is rooted in old vernacular settlements and how it can inspire contemporary circular practices.

Keywords: circular design; circularity; circular economy; vernacular architecture; Egypt

check for updates

Citation: Dabaieh, M.; Maguid, D.; El-Mahdy, D. Circularity in the New Gravity—Re-Thinking Vernacular Architecture and Circularity. *Sustainability* **2022**, *14*, 328. https://doi.org/10.3390/su14010328

Academic Editor: Alessia Amato

Received: 11 November 2021
Accepted: 25 December 2021
Published: 29 December 2021

1. Introduction

The growing climate change crisis and urbanization have urged more government decision-makers, urban planners, architects, and private investors to develop new policies, processes, and methods for leading more sustainable lifestyles [1]. According to the United Nations Environment Programme (UNEP) [2], cities consume 75% of the world's primary energy capacity (such as crude oil, coal, wind, natural gas, etc.), produce 60–80% of global greenhouse gas emissions, and produce 50% of the world's waste [3,4]. Buildings are considered among the main contributors to harmful environmental impacts, resource consumption, and waste generation [5]. According to UNEP [6] and the World Resarch Institute (WRI) [7], buildings account for 40% of all waste generated by volume, 40% of all material resources use by volume, and 33% of all human-induced emissions. Furthermore, the construction industry and the built environment are among the greatest contributors to natural resource depletion [3,8,9]. Thus, it is imperative for governments to start adopting more sustainable practices in the construction industry.

The concept of the circular economy (CE), also referred to as "circularity", is one of the sustainable concepts that has been gaining traction in recent years as an approach for reducing the environmental footprint of different industries, including the building sector [5,10–13]. While there is no standard definition for the CE model, it has been defined by several organizations as the opposite of the linear economy (LE) and its "make-take-waste" model [12,14]. The linear production-consumption model is concerned with producing and consuming goods made from raw materials, selling them, using them, and then disposing of them as waste [3,5]. This model, however, has become ineffective due to the increase in global populations and depleting natural resources [12]. In the building industry, CE calls for reducing the negative environmental impacts on the environment while providing a healthier indoor environment and closing material loops [15]. CE is not necessarily considered a new concept but rather one that combines several pre-existing principles for closing material loops, reducing energy and raw material waste [16,17], and prolonging the lifespan of products through maintenance and repair [18,19].

Vernacular architecture can also be linked to circular sustainable concepts. Vernacular architecture is defined as the design of buildings based on local needs, using local materials, and reflecting the local culture and traditions. In addition, they are usually built by inhabitants without any formal design training (architecture without architects) [20–22]. Vernacular buildings provide optimal solutions for local problems [22] that are in harmony with nature, in a durable, healthy, and sustainable manner [23]. Furthermore, vernacular buildings all over the world are dependent on the use of low-impact natural materials and construction techniques. Such techniques have proven to be resilient to weather conditions and fulfill the locals' needs at minimal cost and with a minimal impact on the environment [24–26]. Thus, the importance of local architecture is quite evident, along with the need to return to many of the simple, sustainable solutions that have been devised in the past [22].

2. Literature Review

2.1. The Circular Economy in the Built Environment

CE in the built environment has gained academic, governmental, and organizational recognition over the past few years [3]. The EU has developed a series of actions and legislative proposals for future reuse and recycling targets for construction and demolition waste [27,28]. Shifting to CE provides several opportunities for reducing primary material usage and carbon footprints [29], and can positively impact economic, environmental, and social sustainability [30]. Circular economy concepts can be integrated in the scale of buildings, products, and components, in two main aspects: circular material usage, and circular design [12]. The use of circular materials is concerned with the selection of materials that are renewable (biological cycles), or that are reusable after first use (technical cycles), while the circular design is defined as the design of products and components that can be easily disassembled at the end of their use, facilitating their reuse in other projects [12]. Furthermore, circular building design (CBD) is concerned with buildings that are designed, planned, constructed, operated, and maintained with CE principles in mind [31]. To be able to shift toward CBD, CE principles need to be applied to the different life cycle stages of the building, managing the building and its component parts from cradle to cradle [30]. This also entails ensuring that all materials used in the building can be recycled or composted at the end of its lifecycle [32].

Previous studies have approached CE in the built environment from different points of view. A few examples of recent studies on this topic are outlined in this section. Akhimien et al. [30], for instance, provided a review for circular economy interventions in buildings under seven main circular economy principles or strategies and highlighted the possible gaps in research on this topic. Similarly, Cimen [33] and Eberhardt et al. [5] presented a review of the literature on the circular economy in the construction and built environment sector, highlighting key findings and gaps in the reviewed studies. Munaro et al. [3] provided a state-of-the-art review on CE research and focused on analyzing what has already been done in terms of circular practices in the construction value chain. The study also proposed a theoretical framework to be used as a starting point by designers, researchers, and stakeholders for introducing circular practices in the built environment [3], while Amory [12] developed a framework (guidance tool) for the design of circular buildings, based on the "circular design" and "circular material usage" strategies. Furthermore, Cambier et al. [34] presented an overview of the available design tools related to circular design that can be implemented at different stages of the design process. Eberhardt et al. [35] conducted life cycle assessment models that compared linear and circular building components, suggesting the potential benefits of the re-use and recycling of building components in the circular approach. Huuhka and Vestergaard [36] presented a comparison between building conservation and CE concepts, addressing the relationships among them, their commonalities, and their differences. However, there was a gap in studies that linked the CE with vernacular architecture.

Moreover, despite the efforts being made, the wide-scale adoption and implementation of CE in building design and construction strategies still lack a common direction, often implemented through small-scale and fragmented approaches [3,5,33]. Buildings are complex and dynamic, involving many different systems and components, each with its own life cycle, functions, and characteristics. The environmental performance of buildings depends on several different attributes, such as building design, materials choice, operation, and maintenance [5,37]. The literature also indicates that CE initiatives are directed toward different focus areas and use different tools [38]. Thus, it is argued that these fragmented initiatives prevent the universal adoption of CE in the building industry [33,35]. Studies indicate that there is also a lack of knowledge on the definition of CE, its fundamental principles, and its implementation in an innovative manner in the building sector's business model [27,36], while Kirchherr and Van Santen [39] indicate that most CE studies focus on developed countries, making many of the CE studies irrelevant to construction in less-developed countries. This is due to differences in policy environments, access to funding, and infrastructure [39]. Cambier et al. [34] have also asserted the need for more practical examples, such as case studies and best practices for circular buildings. All of this indicates the importance of providing more studies that investigate CE in the building sector. In addition, it highlights the need for more studies on best practice in developing countries [39].

2.2. Circular Design Principles

Various CE design principles were highlighted in the literature in different classifications. These principles include adaptive design and reuse, design for disassembly (DFD), and design for repair and manufacturing [17,40–42]. Adams et al. [27] classified the CE principles regarding: designing for disassembly, flexibility and the reuse of secondary materials, the reuse of components, and the use of secondary materials in the construction value chain [5]. Likewise, Akhimien et al. [30] concluded that there were seven main circular economy principles in buildings: design for disassembly, design for recycling, building materiality, building construction, building operations, building optimization, and the building's end-of-life. Akhimien et al. [30] also highlighted that most studies were focused on two main aspects: the recycling of waste components and end-of-life. Buildings that can be disassembled are more adaptable, according to CE principles, since their parts can be reused, renewed, optimized, or exchanged for others while maintaining their value. Lastly, UNEP [43] classified CE according to four main principles. These are: (1) reduce by design, (2) refuse, reduce and re-use, (3) repair, refurbish and remanufacture, and (4) repurpose and recycle. From these classifications, four main principles were summed up to be adopted throughout this study. The concluded principles combine most of the principles discussed in the different sources reviewed and are rooted in vernacular architecture principles. These are (1) reduce by design, (2). refuse, reduce, and re-use, (3) repair, refurbish, and remanufacture and (4) repurpose and recycle. Table 1 summarizes the various classifications mentioned and highlights the circular design principles that are adopted in this study.

Table 1. A summary of the circular design principle classifications in the investigated literature.

Circular Design Principles' Classification			Sources
A	1. Adaptive design and reuse 2. Design for disassembly	3. Design for repair and manufacturing	[17,40–42]
B	1. Design for disassembly 2. Flexibility and the re-use of secondary materials	3. Reuse of components 4. Use of secondary materials in the construction value chain	[27]
C	1. Design for disassembly 2. Design for recycling 3. Building materiality 4. Building construction	5. Building operations 6. Building optimization 7. Building end of life	[30]
D	1. Reduce by design 2. Refuse, reduce, and re-use	3. Repair, refurbish, and remanufacture 4. Repurpose and recycle	[43]
	1. Reduce by design 2. Refuse, reduce, and re-use	3. Repair, refurbish, and remanufacture 4. Repurpose and recycle	**The Concluded Design Principles**

2.3. Vernacular Architecture and the Circular Economy

It has been noted that vernacular architecture shares many of the core concepts of sustainable buildings. Vernacular architecture is concerned with climate-responsive buildings that are made from local materials and technology and reflect the local customs and lifestyle of a community [44]. Using vernacular concepts can create environmentally conscious designs that respond to climatic conditions, usually using passive and low-energy strategies for human comfort [44]. Vernacular buildings correspond to local materials and the economical use of building resources [44]. Many studies highlight the importance of learning from vernacular buildings for designing contemporary sustainable buildings and of returning to local approaches that are most suitable for their local environments [44–46]. Furthermore, vernacular solutions are usually low-cost since they adhere to their local contexts. This is particularly important for developing countries, such as Egypt.

Research into vernacular architecture design concepts reveals that they coincide with many CE concepts. According to several studies [47–50], there is still a need for more research that addresses the use of vernacular knowledge in contemporary architectural examples. Although CE has been linked to sustainable concepts in the past, a gap was noted, however, in studies that linked CE to vernacular architecture. In Egypt, sustainable and circular design solutions are fundamental for addressing climate change. Egypt has multiple examples of vernacular and neo-vernacular buildings, thus providing many opportunities to learn from their techniques. Several studies have also highlighted the value of learning from vernacular buildings in Egypt. For example, a study by Ahmed [51] investigated three vernacular buildings constructed by Bedouin residents in Siwa Oasis, highlighting best practices and appropriate systems that were implemented for climate-responsive low-carbon buildings. The study also highlighted the lessons learned from environmentally friendly approaches in terms of building with local materials, passive cooling techniques, natural daylighting, and the best use of available natural resources [51]. Dabaieh [49] investigated energy-efficient and low passive strategies in a contemporary vernacular building in Saint Catherine, Sinai, Egypt, highlighting how vernacular design concepts were integrated when designing modern contemporary buildings. Fouad and Mostafa [52] discussed the potential benefits of adapting aspects of vernacular architecture for a more sustainable quality of life in arid regions in Egypt. Fernandes et al. [53] investigated strategies used in Mediterranean vernacular architecture by analyzing cases from southern Portugal and Northern Egypt, identifying key vernacular climatic strategies that can be used for improving contemporary buildings' energy performance. However, more studies are still needed that explore how learning from vernacular concepts can be useful in the future adoption of CE in contemporary buildings.

3. Methodology

This study uses an investigative and exploratory methodological approach. A literature review initially supported the identification of gaps in research that explore the link between concepts and examples of circular economy and circularity within vernacular architecture. After these gaps were identified, two cases were examined using an exploratory approach. The first case is a vernacular settlement that shows examples of circular design and construction techniques, while the second case represents a contemporary settlement that aims to revive vernacular architecture with respect to context. Four main circular design principles were elected as indicators of circularity from the literature review and were used in the case study analysis. The principles are: (1) reduce by design, (2) refuse, reduce, and reuse, (3) repair, refurbish and remanufacture, (4) repurpose and recycle. The principles were summed up from the reviewed classifications to include many of the key circular principles indicated in the investigated literature. In addition, these principles also share many of the ideas that were found to be rooted in vernacular architecture concepts. Two of the principles were merged together in our investigation as they resemble the principle of the 5 Rs, which are: refuse, reduce, reuse, repurpose, and then recycle. The methodological steps followed in this study are shown in Figure 1.

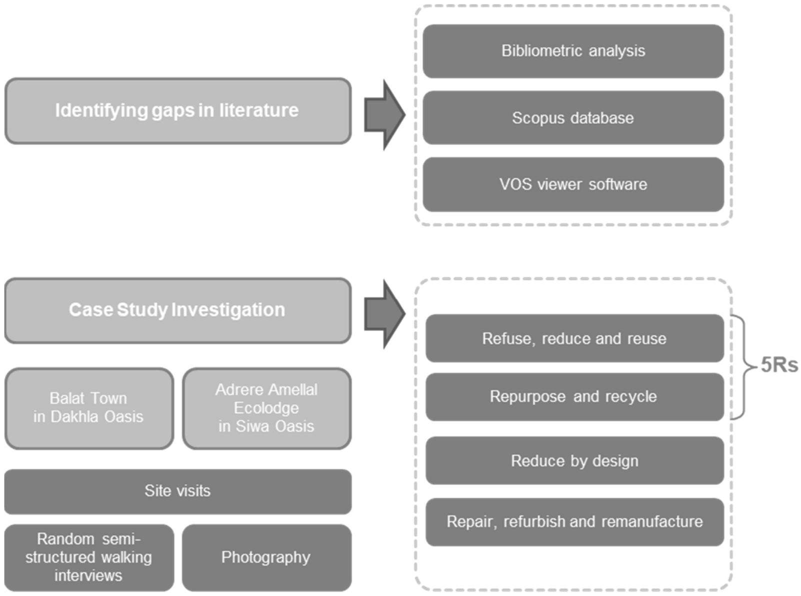

Figure 1. The methodological approach and steps followed in this study.

3.1. Identifying Gaps in the Literature Connecting the Circular Economy with Vernacular Architecture

To identify gaps in the literature that make the connection between the circular economy and vernacular architecture, this research used bibliometric analysis, searching Scopus database results from the last 10 years. To illustrate the bibliometric analysis, VOSviewer software was employed to depict the most used keywords within the field of the circular economy in relation to architecture, as shown in Figure 2. The first keywords used were "circular economy" and "vernacular architecture". There were only two publications that have a close connection to the circular economy. Both publications were based more on "shape grammar" and product design than on architecture. Shape grammar is considered a generative and algorithmic language and design tool that was established by George Stiny and James Gips in 1971 [54]. Yet, when replacing the search phrase "vernacular architecture" with "architecture" and "built environment", more links and publications appeared, with 141 for "architecture" and 200 for "built environment". Most of the papers related to architecture and the built environment mentioned topics related to sustainability, waste management, building materials, life-cycle assessment, economics, and ecology. These results concretely demonstrate the gap in research that links the circular economy and vernacular architecture, compared to research focused on circularity and architecture in general.

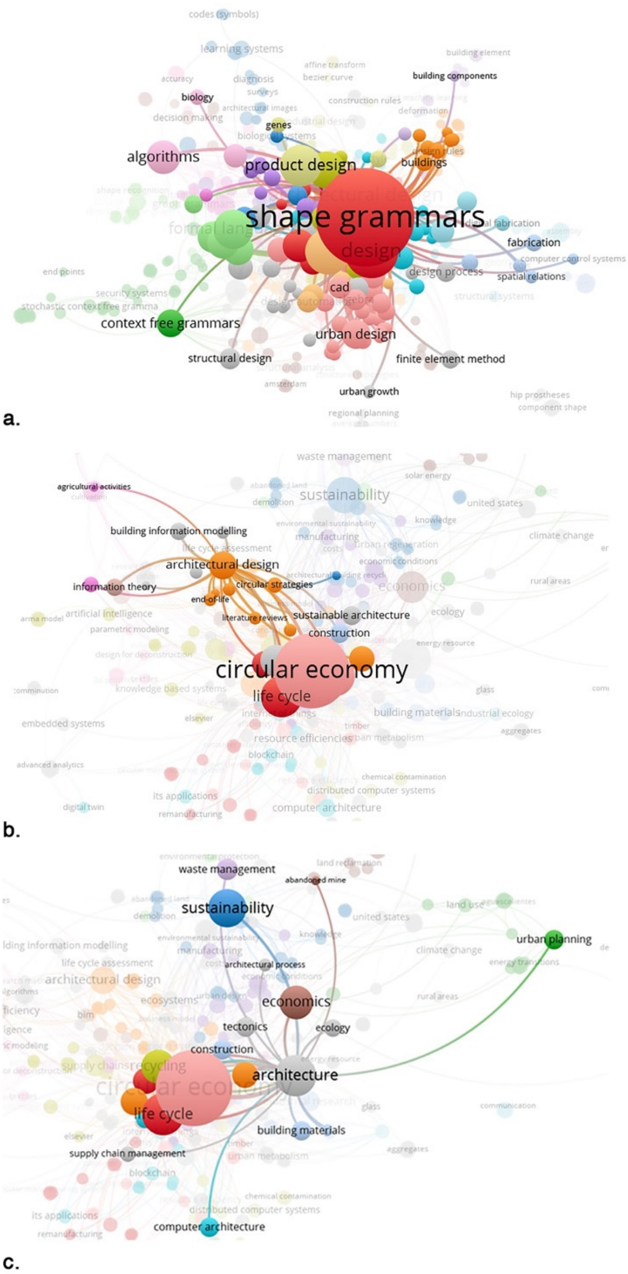

Figure 2. The gap between research on the circular economy and vernacular architecture is shown in (**a**), while (**b**) and (**c**) show the connection between research on the circular economy and the built environment/architecture.

3.2. Case Study Investigation

The two case studies chosen are located in the Western Desert of Egypt. The traditional vernacular case study that was selected is in Balat Town in Dakhla Oasis, whereas the contemporary case study is Adrere Amellall Ecolodge in Siwa Oasis. Following suggestions from [55–57] to select a single case study location to maximize what can be learned in terms of comparability in the period of time available for the study, field trips to the Western Desert were conducted in 2016 and 2017 to visit the two case-study sites. Several tools were used during these visits, including field notes, field observations, random semi-structured walking interviews with 20 locals, structured interviews with two architects, and photography. After a year of site visits, the data was analyzed using circular economy approaches from the literature review to assess the vernacular architecture.

3.3. Case Study Description

The town of Balat, built at the eastern entrance of the Dakhla Oasis, is situated at the junction of two old caravan routes in the Western Desert of Egypt [58]. Records refer to Balat as early as the 14th century [59]. Ancient Balat was a significant kingdom in the oasis [60] and was considered the chief town and headquarters for the governor of the oasis in Egypt at the end of the Old Empire (2350-2150 BCE) [61]. The main economic activity in Balat was and still is farming. They have a self-sufficient system for growing their local crops, given their remote location. Balat residents rely on underground fossil water for irrigation and drinking, as there is no water supply or drainage infrastructure. Furthermore, dry toilets are used, where organic wastes are composted to be used as soil fertilizers or as bio-fuel dunk cakes. This is one example of “closing the loop”. Inhabitants have long adapted their dwellings to the tough, hot dry desert climate. Balat’s inhabitants are accustomed to using passive techniques, especially for cooling. This is evident in the use of air shafts, shading, cross-ventilation, and high-thermal-mass building envelopes. In addition, the construction solutions adopted, using locally available materials, decrease the processing and transportation costs of building materials. Thus, the building outcomes are less energy-demanding and more environmentally friendly than many modern solutions. The main construction materials in Balat are clay, palm reeds, and acacia wood, as shown in Figure 3. Bearing-wall construction using sun-dried adobe mud bricks is the typical building technique. Such applications in building design and construction are based on cumulative previous experiences and tacit knowledge through trial and error.

Figure 3. The usage of adobe clay bricks, together with reeds and acacia wood, in construction at Balat Town in Dakhla Oasis.

Adrere Amellal Ecolodge was built in 2000 and is located in Siwa Oasis. It faces the salty lakes prevalent in the Western Desert and is surrounded by the white mountains of Siwa. The Oasis offers materials such as limestone, palm and olive trees, salt rocks, and clay that are unique compared to the typical materials available in the surrounding environment [62]. One of the most significant resources in the Oasis is the salt extracted from the salt lakes and the therapeutic mud, which is considered a unique geological phenomenon of the area [63]. The lodge includes residential units, a restaurant, and a healing center, which are all built from local salt “kershif” and clay for bearing-wall building, as shown in Figure 4. In addition, there is a water spring, as well as an organic farm that produces crops for self-sufficient farming. Adrere Amellal applies circular thinking and self-sufficiency, inspired by traditional and vernacular thinking. For example, the ecolodge depends on growing and cultivating its own crops, and the use of locally sourced natural materials in building construction and for furniture pieces. The eco-lodge has a local waste management station for treating wastewater and garbage, as well as an organic waste composting station, as shown in Figure 5. The architectural design of the building includes many passive strategies, like solar orientation, high thermal mass through the thickness of the wall, shading, passive cooling, and cross-ventilation.

Figure 4. The usage of kershif, and palms plastered with salty mud, at Adrere Amellal Ecolodge in Siwa Oasis.

Figure 5. Self-sufficient farming and the water spring in Adrere Amellal Ecolodge.

4. Results

4.1. Refuse, Reduce, Reuse, Repurpose and Recycle

From the field observations and investigations using the UNED circular economy's four principles, the researchers noticed that indigenous vernacular communities tend to apply the "5 R" principles, firstly, "refuse and reduce", using materials from outside their local context. They have learned from experience that importing non-local materials causes more problems than benefits in the long term. If non-local materials are necessary, they are reduced to a minimum and only brought in for essential needs. After the "end of life" stage of vernacular buildings, the building's materials can be easily recycled again. For example, mud bricks can be easily reused and molded again into new, fresh mud bricks. Wood used in the construction of roofs, if in good condition, can be repurposed again for roofing or can be reused for doors, windows, stairs, farming tools, or other homemade furniture, or upcycled for other functions. As a last option, if the wood is not of good enough quality for any other use, it can be used as charcoal for heating or cooking. Furthermore, it is possible to allow wood to rot/biodegrade if it has no further functionality. Similarly, mud bricks can also be broken down as clay in the soil. One outcome from the interviews with the locals, from a user-to-user perspective, is that in both the Balat and Adrere Amellal case studies, reused palm reeds were employed in construction. They were particularly useful in constructing the ceiling and roof, as well as being integrated into the design of other products. With almost no extra cost, the use of palm reeds is highly recommended due to their compressive strength and good resistance to the harsh desert climate.

4.2. Reduce by Design

Vernacular settlements were constructed in a minimalistic way. Indigenous vernacular communities are used to the principle that "forms follow resources". Taking Balat as an example, the main architectural design solutions are based on the concept of reducing the quantity of raw natural materials used in construction to the greatest extent possible. Reducing the quantity of materials used in construction and reducing the quantity of waste materials was a conscious decision. Vernacular dwellers are aware of how precious raw materials are, and they know from their accumulated experience how they can most effectively and efficiently use raw materials. Almost no waste is produced during construction, and any leftovers are used for other functions. From interviews with locals in Balat, an example of this can be seen in the way the components of palm trees are used in vernacular construction. The palm wood trunks, for instance, are used as the main beams in the roof construction. Furthermore, palm reeds are used as secondary beams by bundling them together as mats and then placing them over the main wood trunk (wood logs). Lastly, the leaflets around the palm reeds, when taken away, are used in furniture manufacturing or in weaving different sorts of household utilities, like food baskets and even bags. The palm fibers, located around the tree trunk, are also taken away and used for weaving baskets.

Adrere Amellal Ecolodge implemented construction methods reflecting the local vernacular architecture of the region, where the emphasis was on materials that are available in the desert. This helps avoid using harmful materials that pollute the environment or that consume more energy, either through construction machinery, transportation, or kiln-firing. From the interview with the two principal architects who designed Adrere Amellal, they mentioned that the design morphology of Adrere Amellal Ecolodge is based on thick kershif (a biodegradable combination of salt-rock and mud mixed together) walls that can vary between 40 and 80 cm and act as a thermal insulator. Kershif was selected in the early stages of the design for both the construction of the building and for built-in furniture design. Raw salt, extracted from the salt lakes in Siwa Oasis, as well as palm reeds from the site, were also used to construct the built-in furniture. Salt and palm reeds cost close to nothing to use and helped reduce the embodied carbon in both the construction process and in lifetime energy usage. Using both kershif and salt that were extracted from the same site allow reducing the transportation of the materials to the site. It was also observed that kershif can be easily disassembled as blocks, to be used again in construction or decomposed in the soil.

4.3. Repair, Refurbish and Remanufacture

Vernacular buildings in Egypt, especially those constructed from earthen materials, need regular maintenance and repair throughout their lifetime. From our interviews and field observations, we found that the locals use seasonal celebrations as opportunities to perform quarterly, annual, or sometimes bi-annual maintenance. Families festively gather to help each other conduct maintenance on the interior or the exterior of buildings. These activities keep their buildings fresh and reduce the possibility of any damage or deterioration due to harsh desert weather conditions. Regular repair and maintenance help increase the lifespan of buildings and reduce the need to replace parts. When needed, major repairs, such as the replacement of a structural element, patching walls or roofs, or the replacement of doors and windows, can also be conducted outside of celebration periods. Heavy rains can cause earthen building deterioration, thus requiring regular maintenance.

From the interview responses that were received, one interviewee mentioned that in the high rainy seasons in winter, rain and evaporation cause damage to some buildings, which then require maintenance. For instance, in Adrere Amellal, the crystallization that occurs in salt particles due to humidity in the summer can lead to the evaporation of some salt particles, while during winter, the rain can cause cracks and damage to the building. Accordingly, depending on the state of damage, annual repairs and renovation work are required to restore the building to its original state. In this case, two treatments are performed, either filling the cracks with a new mixture of kershif and plastering it with clay, or in the case of the total destruction of a wall, an entire wall can be replaced with a new one.

5. Discussion

From this explorative study, we can deduce that circularity in design should look at the building as a kit instead of looking at the building as a traditional structure. Design and building should be considered from the lens of disassembly, easy maintenance, and being easy to upcycle or reuse. Architects should design buildings to be easily taken apart so their materials can be reused in another building. Increasing not only a building's life span but the life span of its materials is another essential part of circular thinking and the circular economy. This might sound a bit challenging, but designers have to not only get used to working with smaller palettes of reusable materials but also design building components for disassembly as well as assembly. Yet design for disassembly, or, as some call it, "Design for Deconstruction" (DfD), offers other concerns that need to be considered. For instance, the circular design process itself requires new skills; it needs more flexibility in drawings and designs and more flexibility in terms of deadlines for assembly and disassembly.

Design for disassembly or for re-building was the primary method of conceptualizing vernacular architecture in Egypt. Designs differ from one building type to another and depend on the availability and use of construction materials. Earth, reeds, straw, wood, woven textiles, and jute are raw building materials that are easy to disassemble as small components and re-assemble again. As shown earlier in this paper, the focus is on earthen construction, mainly in the form of sun-dried mud blocks and mud-brick (Adobe) construction. Bricks are modular units that are easy to cast and assemble and easy to disassemble for rebuilding. The only design drawback of mud bricks is the time it takes to disassemble them for re-use. The use of mud bricks in construction can be labor-intensive and time-consuming in terms of casting and drying. However, nowadays, there are several methods for mechanical casting using hydraulic machines, which is a fossil-free process. Nevertheless, they are not as fragile as fired bricks, which can later be broken up easily during disassembly. Additionally, if any damage happens to sun-dried adobe bricks, they can be easily repaired using mud paste or clay mortar.

Both case studies in this paper were rich in showing the different usage of the local materials in many ways, whether in construction or in products. In addition, using adobe and kershif as traditional building techniques through time opens new doors for integrating many advanced techniques in construction, from 3D printing or robotics to traditional techniques, to enable faster building. For reducing the maintenance of adobe and kershif buildings, new additives can be integrated into the mixture that will prevent or reduce structure cracks and shrinkage with time, like adding lime and natural fibers.

Some circular materials also rooted in vernacular architecture are bio-based materials. Very soon, natural substances, such as weeds, algae, bacteria, enzymes, and even proteins, will be used to grow materials that will replace today's plastics and other industrial building and construction materials. The main goal of the development of these nature-based materials is to avoid the production of toxic waste during materials manufacturing processes and during their reuse and disposal. Ideally, these biomaterials can have positive impacts once they are no longer used in construction. For example, at the end of their lifespan, they could be used as animal feed or compost. It is worth mentioning that bio-fabrication is the future for circular design and soon, a supply chain will be integrated into the materials for building construction. Figure 6 illustrates a linear way of thinking, using industrial materials, and a circular way of thinking, using natural and renewable materials.

Still, there are challenges facing circular design and construction. Firstly, even if buildings are designed and constructed with circularity in mind, we cannot always build everything from new. Transforming existing old buildings through rehabilitation or adaptive reuse must be the number-one alternative, and rehabilitation can be performed with circular design concepts. One other challenge, depending on the size of the building, is that the process of assessment for reclaiming old materials can be time-consuming. It can also be hard to identify every single building component and decide which materials are reclaimable or not, especially when the issues of toxicity and the carbon footprint have to be considered. This chain of decision-making can hinder material reuse. Another challenge is the lack of standardization, in terms of how different architecture firms and contractors assess and reclaim materials for reuse. Labor cost is another issue, as experienced workers can be expensive and could be considered an economic burden on the project during the assembly and disassembly process. Quantifying designs for reconstruction or deconstruction can still be very undefined since there are not many well-recognized conventional methods. Moreover, there is a need for professionals who are able to judge which parts of a building can be reused as reclaimed materials. At this point in the process, circularity needs a strong desire and a will for change, necessitating dedicated and enthusiastic actors in the building sector to step in.

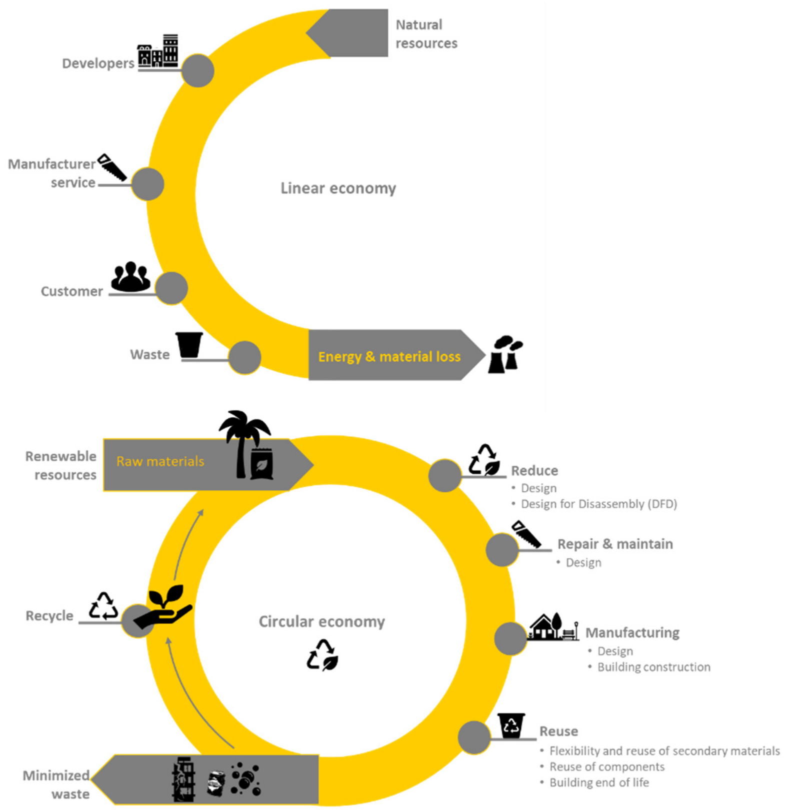

Figure 6. Comparison between a circular and linear economy in design and construction. The graphic summarizes the differences in thinking and the impact on the environment.

6. Conclusions

This study discussed four main circular building design concepts in vernacular architecture. Two cases in Egypt were chosen for this study's investigation: a traditional vernacular settlement and a contemporary project that was inspired by vernacular CE principles. Points of analysis for the two cases stemmed from key CE approaches that were found to be common to both circular design and vernacular design.

The focus was on four concepts: reduce by design; refuse, reduce and reuse; repair, refurbish and remanufacture; and repurpose and recycle. Based on the exploration of these concepts, this paper posits that the negative environmental impacts of buildings and the overuse of natural resources can be considerably reduced by drawing inspiration from vernacular architecture. However, most contemporary buildings are still not designed according to the principles of circular design, or even close to the concept of circularity. Available literature focuses primarily on topics such as life cycle assessment for building materials or the efficiency of innovative materials with low impact and potential for recyclability. A research gap remains on the hands-on design process of circular design and circular buildings and how architects can integrate circular economy concepts in their designs.

We hope this paper has shown how CE principles are rooted in vernacular heritage and can still be applicable in contemporary practice. We focused only on four principles but there are many others that can still be a good source of inspiration. We were limited in making the comparative work between a contemporary case study and a traditional case study. This research is part of ongoing work on investigating more hands-on circularity strategies in vernacular architecture. Although case studies from Egypt were displayed in this investigation, the study findings can surely be applied to other climatic zones and geographical locations. The methodological approach is holistic and will be applicable in different contexts.

Author Contributions: Conceptualization, M.D., D.M. and D.E.-M.; methodology, M.D.; software, D.E.-M.; validation, M.D., D.M. and D.E.-M.; formal analysis, M.D., D.M. and D.E.-M.; investigation, M.D., D.M. and D.E.-M.; resources, D.M.; data curation, M.D., D.M. and D.E.-M.; writing—original draft preparation, M.D., D.M. and D.E.-M.; writing—review and editing, M.D., D.M. and D.E.-M. visualization, D.E.-M.; supervision, M.D.; project administration, M.D.; funding acquisition, M.D. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Not applicable.

Acknowledgments: We thank all the interviewees for their time and contribution to this study.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Ibáñez, C.S. Circular design in everyday urbanism: Towards regenerative and restorative dynamic spaces in cities. *Vis. Sustain.* **2019**, *11*, 9–16.
2. United Nations Environment Programme (UNEP). *The Emissions Gap Report 2016*; United Nations Environment Programme (UNEP): Nairobi, Kenya, 2016. Available online: https://www.unep.org/resources/emissions-gap-report-2016 (accessed on 20 June 2021).
3. Munaro, M.R.; Tavares, S.F.; Bragança, L. Towards circular and more sustainable buildings: A systematic literature review on the circular economy in the built environment. *J. Clean. Prod.* **2020**, *260*, 121134. [CrossRef]
4. Ellen MacArthur Foundation (EMF). Growth within: A Circular Economy Vision for a Competitive Europe. *Ellen MacArthur Found.* **2015**, *100*, 81–92. Available online: www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf (accessed on 21 June 2021).
5. Eberhardt, L.C.M.; Birkved, M.; Birgisdottir, H. Building design and construction strategies for a circular economy. *Arch. Eng. Des. Manag.* **2020**, 1–21. [CrossRef]
6. United Nations Environment Programme (UNEP). *Sustainable, Resource Efficient Cities–Making It Happen*; UNEP: Paris, France, 2012. Available online: https://sustainabledevelopment.un.org/content/documents/1124SustainableResourceEfficientCities.pdf (accessed on 21 June 2021).
7. World Resources Institute (WRI). Accelerating Building Efficiency: Eight Actions for Urban Leaders. 2016. Available online: https://www.wri.org/publication/accelerating-building-efficiency-actions-city-leaders (accessed on 21 June 2021).
8. Leising, E.; Quist, J.; Bocken, N. Circular Economy in the building sector: Three cases and a collaboration tool. *J. Clean. Prod.* **2018**, *176*, 976–989. [CrossRef]
9. Zimmann, R.; O'Brien, H.; Hargrave, J.; Morrell, M. *The Circular Economy in the Built Environment*; ARUP: London, UK, 2016.
10. Ellen MacArthur Foundation (EMF). Cities in the Circular Economy. 2017. Available online: https://www.ellenmacarthurfoundation.org/assets/downloads/publications/Cities-in-the-CE_An-Initial-Exploration.pdf (accessed on 20 June 2021).
11. Liu, Y.; Bai, Y. An exploration of firms' awareness and behavior of developing circular economy: An empirical research in China. *Resour. Conserv. Recycl.* **2014**, *87*, 145–152. [CrossRef]
12. Amory, J. *A Guidance Tool for Circular Building Design*; Delft University of Technology, Architecture and the Built Environment: Delft, The Netherlands, 2019.
13. Przepiórkowska, S. The Circular Economy approach in architecture—A study of 5 bottom-up cases. *Builder* **2020**, *279*, 33–39. [CrossRef]
14. Saidani, M.; Yannou, B.; Leroy, Y.; Cluzel, F. How to Assess Product Performance in the Circular Economy? Proposed Requirements for the Design of a Circularity Measurement Framework. *Recycling* **2017**, *2*, 6. [CrossRef]
15. Díaz-López, C.; Carpio, M.; Martín-Morales, M.; Zamorano, M. Defining strategies to adopt Level(s) for bringing buildings into the circular economy. A case study of Spain. *J. Clean. Prod.* **2020**, *287*, 125048. [CrossRef]
16. Homrich, A.S.; Galvão, G.; Abadia, L.G.; Carvalho, M.M. The circular economy umbrella: Trends and gaps on integrating pathways. *J. Clean. Prod.* **2018**, *175*, 525–543. [CrossRef]

17. Dokter, G. *Circular Design in Practice- towards a Co-Created Circular Economy through Design*; Chalmers University of Technology, Department of Architecture and Civil Engineering: Gothenburg, Sweden, 2021.
18. Kirchherr, J.; Piscicelli, L. Towards an education for the circular economy (ECE): Five teaching principles and a case study. *Resour. Conserv. Recycl.* **2019**, *150*, 104406. [CrossRef]
19. Van Buren, N.; Demmers, M.; Van Der Heijden, R.; Witlox, F. Towards a Circular Economy: The Role of Dutch Logistics Industries and Governments. *Sustainability* **2016**, *8*, 647. [CrossRef]
20. Oliver, P. (Ed.) *Encyclopedia of Vernacular Architecture of the World*; Cambridge University Press: Cambridge, UK, 1997.
21. Dabaieh, M. *More than Vernacular: Vernacular Architecture between Past Tradition and Future Vision*; Media-Tryck Lund University: Lund, Sweden, 2016.
22. Sala, M.; Trombadore, A.; Fantacci, L. Chapter 12: The Intangible Resources of Vernacular Architecture for the Development of a Green and Circular Economy. In *Sustainable Vernacular Architecture-How the Past Can Enrich the Future*; Sayigh, A., Ed.; Springer: Berlin/Heidelberg, Germany, 2019; pp. 229–256.
23. Simoes, R.N.; Cabral, I.; Barros, F.C.; Carlos, G.; Correia, M.; Marques, B.; Guedes, M.C. Chapter 4: Vernacular Architecture in Portugal: Regional Variations. In *Sustainable Vernacular Architecture-How the Past Can Enrich the Future*; Sayigh, A., Ed.; Springer: Berlin/Heidelberg, Germany, 2019; pp. 55–91.
24. Turan, M. *Vernacular Architecture: Paradigms of Environmental Response (Ethnoscapes)*; Aldershot: Avebury, UK, 1990.
25. Dabaieh, M. *A Future for the Past of Desert Vernacular Architecture: Testing a Novel Conservation Model and Applied Methodology in the Town of Balat in Egypt*; Lund University: Lund, Sweden, 2011. Available online: https://lucris.lub.lu.se/ws/files/5906883/2224661.pdf (accessed on 10 October 2021).
26. Dabaieh, M. Dare to Build: Designing with earth, reeds and straw for contemporary sustainable welfare architecture. In Proceedings of the ICOMOS-CIAV&ISCEAH 2019 Joint Annual Meeting & International Conference on Vernacular & Earthen Architecture towards Local Development, Pingyao, China, 5–7 September 2019; pp. 241–247.
27. Adams, K.T.; Osmani, M.; Thorpe, T.; Thornback, J. Circular economy in construction: Current awareness, challenges, and enablers. *Proc. Inst. Civ. Eng.-Waste Resour. Manag.* **2017**, *170*, 15–24. [CrossRef]
28. European Commission (EC). Circular Economy Implementation of the Circular Economy Action Plan. 2019. Available online: https://ec.europa.eu/environment/circular-economy/ (accessed on 20 June 2021).
29. Ellen MacArthur Foundation (EMF). Towards the Circular Economy-Opportunities for the Consumer Goods Sector (Vol. 2). 2013. Available online: https://eco.nomia.pt/contents/documentacao/tce-report-2013.pdf (accessed on 10 October 2021).
30. Akhimien, N.G.; Latif, E.; Hou, S.S. Application of circular economy principles in buildings: A systematic review. *J. Build. Eng.* **2020**, *38*, 102041. [CrossRef]
31. Pomponi, F.; Moncaster, A. Circular economy for the built environment: A research framework. *J. Clean. Prod.* **2017**, *143*, 710–718. [CrossRef]
32. Kopnina, H. Circular economy and Cradle to Cradle in educational practice. *J. Integr. Environ. Sci.* **2018**, *15*, 119–134. [CrossRef]
33. Çimen, O. Construction and built environment in circular economy: A comprehensive literature review. *J. Clean. Prod.* **2021**, *305*, 127180. [CrossRef]
34. Cambier, C.; Galle, W.; De Temmerman, N. Research and Development Directions for Design Support Tools for Circular Building. *Buildings* **2020**, *10*, 142. [CrossRef]
35. Eberhardt, L.C.M.; Birgisdóttir, H.; Birkved, M. Life cycle assessment of a Danish office building designed for disassembly. *Build. Res. Inf.* **2018**, *47*, 666–680. [CrossRef]
36. Huuhka, S.; Vestergaard, I. Building conservation and the circular economy: A theoretical consideration. *J. Cult. Herit. Manag. Sustain. Dev.* **2020**, *10*, 29–40. Available online: https://www.emerald.com/insight/content/doi/10.1108/JCHMSD-06-2019-0081/full/pdf?title=building-conservation-and-the-circular-economy-a-theoretical-consideration (accessed on 10 October 2021). [CrossRef]
37. Maslesa, E.; Jensen, P.A.; Birkved, M. Indicators for quantifying environmental building performance: A systematic literature review. *J. Build. Eng.* **2018**, *19*, 552–560. [CrossRef]
38. Ellen MacArthur Foundation (EMF). Potential for Denmark as a Circular Economy a Case Study from: Delivering the Circular Economy–a Toolkit for Policy Makers. 2014. Available online: http://mst.dk/media/151170/15-11-25-cirkulaer-oekonomi.pd (accessed on 10 October 2021).
39. Kirchherr, J.; Van Santen, R. Research on the circular economy: A critique of the field. *Resour. Conserv. Recycl.* **2019**, *150*, 104480. [CrossRef]
40. Benachio, G.L.F.; Freitas, M.D.C.D.; Tavares, S.F. Circular economy in the construction industry: A systematic literature review. *J. Clean. Prod.* **2020**, *260*, 121046. [CrossRef]
41. Hopkinson, P.; De Angelis, R.; Zils, M. Systemic building blocks for creating and capturing value from circular economy. *Resour. Conserv. Recycl.* **2019**, *155*, 104672. [CrossRef]
42. Minunno, R.; O'Grady, T.; Morrison, G.M.; Gruner, R.L. Exploring environmental benefits of reuse and recycle practices: A circular economy case study of a modular building. *Resour. Conserv. Recycl.* **2020**, *160*, 104855. [CrossRef]
43. United Nations Environmental Programme (UNEP). Understanding Circularity. 2021. Available online: https://buildingcircularity.org (accessed on 20 June 2021).
44. Wahid, A. Adaptive vernacular options for sustainable architecture. *J. Int. Soc. Study Vernac. Settl.* **2012**, *2*, 74–87.

45. Naciri, N. Sustainable Features of the Vernacular Architecture. 2007. Available online: http://www.solaripedia.com/files/488.pdf (accessed on 20 June 2021).
46. Sundarraja, M.; Radhakrishnan, S.; Priya, R. Understanding Vernacular Architecture as a tool for Sustainability. In Proceedings of the 10th National Conference on Technological Trends, Trivandrum, India, 6–7 November 2009.
47. Vellinga, M.; Asquith, L. *Vernacular Architecture in the Twenty-First Century: Theory, Education and Practice*; Taylor & Francis: New York, NY, USA, 2006.
48. Rashid, M.; Ara, D. Modernity in tradition: Reflections on building design and technology in the Asian vernacular. *Front. Arch. Res.* **2015**, *4*, 46–55. [CrossRef]
49. Dabaieh, M. Energy efficient design strategies for contemporary vernacular buildings in Egypt. In *Vernacular Heritage and Earthen Architecture: Contributions for Sustainable Development*; Correia, C., Rocha, Eds.; Taylor & Francis Group: London, UK, 2013; pp. 599–604.
50. Dabaieh, M. Earth vernacular architecture in the Western Desert of Egypt. In *Vernadoc RWW 2002*; Markku, M., Ed.; International VERNADOC Network; 2013; pp. 24–30.
51. Ahmed, R. Lessons learnt from the vernacular architecture of bedouins in Siwa Oasis, Egypt. In Proceedings of the 31st International Symposium on Automation and Robotics in Construction and Mining (ISARC 2014), Sydney, Australia, 9–11 July 2014; pp. 910–917. [CrossRef]
52. Fouad, W.; Moustafa, O. Vernacular architecture approach to achieve sustainability in informal settlements. In *World Sustainable Buildings SB14*; Green Building Council España: Madrid, Spain, 2014; pp. 200–207.
53. Fernandes, J.; Dabaieh, M.; Mateus, R.; Bragança, L. The influence of the Mediterranean climate on vernacular architecture: A comparative analysis between the vernacular responsive architecture of Southern Portugal and North of Egypt. In *World Sustainable Buildings SB14*; Barcelona, Spain, 2014; pp. 264–270.
54. Tepavcevic, B.; Stojaković, V. Shape grammar in contemporary architectural theory and design. *Archit. Civ. Eng.* **2017**, *10*, 169–178. [CrossRef]
55. Yin, R.K. *Case Study Research: Design and Methods*, 4th ed.; SAGE: London, UK, 2009.
56. Stake, R.E. *The Art of Case Study Research*; Sage: Thousand Oaks, CA, USA, 1995.
57. Feagin, J.R.; Orum, A.M.; Sjoberg, G. (Eds.) *A Case for the Case Study*; University of North Carolina Press: Chapel Hill, NC, USA, 1991.
58. Bard, K.A.; Shubert, S.B. (Eds.) *Encyclopedia of the Archaeology of Ancient Egypt*; Routledge: New York, NY, USA, 1999.
59. Maqrīzī, A. *Mawaiz wa Al-'I'tibar bi Dhikr Al-Khitat wa Al-'Athar*; National Archives of Egypt: Bulaq, Egypt, 1895; Volume 1.
60. Pantalacci, L. *Epistolary Documentation of the Governor's Palace in Balat-'Ayn Asil. Bulletin of the French Oriental Institute of Eastern Archeology*; BIFAO-98; The French Institute for Oriental Archology: Cairo, Egypt, 2013; pp. 303–315.
61. Krieger, P.P. *The Archives of the Temple Funeral of Neferirkare-Kakai (BdE 65/1-2)*; Institut Francais D'archeologie Orientale du Caire: Cairo, Egypt, 1976.
62. Abdelsalam, T. A vision for future: Analysis of the prominent synthesis of culture and sustainability in Hassan Fathy architecture. *Int. J. Contemp. Archit.* **2014**, *1*, 7–16.
63. Sallam, E.S.; El-Aal, A.K.A.; Fedorov, Y.A.; Bobrysheva, O.R.; Ruban, D.A. Geological heritage as a new kind of natural resource in the Siwa Oasis, Egypt: The first assessment, comparison to the Russian South, and sustainable development issues. *J. Afr. Earth Sci.* **2018**, *144*, 151–160. [CrossRef]