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TECHNICAL PAPER

Flooded architecture as an adaptation tool for climate change impact—a case study of possible interpretation in Egypt

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Abstract
In light of the current global environmental issues, such as floods, underground water problems, and soil salinity, there is a growing need for sustainable architectural and housing solutions that can effectively address the impact of these challenges on food and security (Nation 2002). In Egypt, frequent incidents of flooding and sinking roads and cities are observed, particularly after rainfall or in projects that involve underground water drainage (UN-Habitat 2022). This paper explores the concept of flooded architecture, which involves designing buildings and spaces that are intentionally flooded with water. Through a review of relevant literature and case studies, the paper investigates the potential benefits and drawbacks of this approach nationally inside Egypt, structure, and construction used materials, including its impact on energy efficiency, sustainability, and resilience to natural disasters. The findings suggest that flooded architecture has the potential to offer innovative solutions for a range of environmental and social challenges but also raises important questions around safety, maintenance, and cultural acceptance in Egypt.

Keywords Floods · Resilience · Floating architecture · Sustainable materials

Introduction

It is imperative to develop innovative and sustainable architectural and housing solutions that can effectively deal with the impact of floods and water infiltration. The proposal presented here aims to offer a conceptual solution for creating communities that can effectively manage water infiltration using sustainable, affordable materials, and architectural designs. By implementing such solutions, it is expected that the adverse effects of water infiltration, such as flooding and sinking, can be mitigated, thus enhancing food and security in affected areas. Flooded architecture is a concept that has been explored by architects and designers for centuries. The idea of intentionally incorporating water into buildings and public spaces has been used in different cultures around the world, from ancient civilizations in Mesopotamia and Egypt to contemporary examples in the Netherlands and Japan [1]. In many cases, flooded architecture has been used as a response to the challenges of living in areas prone to flooding, such as the need to protect buildings and infrastructure from water damage and the desire to create more livable and sustainable environments [2]. This paper provides an overview of the history of flooded architecture design, highlighting key examples and discussing their significance for contemporary discussions around environmental design and resilience.

In recent decades, the world has faced a multitude of challenges and crises including droughts, depletion of natural resources, land degradation, and rising sea levels, which have put immense pressure on urban areas. Egypt, as one of the most vulnerable countries to the impacts of climate change, is particularly at risk of the phenomenon of sea level rise which threatens the Nile Delta [3]. The unique geographic features of Egypt, including its flat delta and its diverse Red Sea and Mediterranean shorelines across different climatic zones, interact with the effects of global warming. The resulting impacts and vulnerabilities on the Egyptian landscape, particularly the shorelines, would cause severe changes on social, economic, urban, and

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environmental levels (Coastal Research Institute, the Egyptian Shore Protection Authority). This would have dangerous and destructive effects on food resources, agriculture, land use, climate conditions, and the economy. As architects, engineers, and urban planners, it is crucial to develop solutions and mitigation plans that can address these challenges and offer alternatives to forced migration. This requires a deep understanding of the complex interplay between climate change and the built environment in Egypt, as well as the ability to translate this knowledge into practical and effective interventions. By doing so, we can help to safeguard the future of Egypt's communities and ecosystems, while ensuring their resilience in the face of a changing climate.

Literature review

A. *Use of possible technologies and materials in flooded architecture related to Egyptian history*

Floods are increasingly becoming a significant challenge for many regions around the world due to climate change and its impacts. In response, flooded architecture has emerged as a promising solution to manage the effects of flooding and enhance resilience to climate change. Flooded architecture refers to the design and construction of buildings and infrastructure that can withstand or adapt to periods of flooding [4]. Flooded architecture involves several design principles that can help mitigate the impacts of flooding. For example, buildings can be designed with elevated foundations or stilts to minimize damage from floodwater. Additionally, materials that are resistant to water damage, such as concrete and steel, can be used in the construction of buildings and infrastructure. Green roofs and rain gardens can also be incorporated into building designs to absorb and retain rainwater, reducing the risk of flooding.

Moreover, flooded architecture can also incorporate sustainable and innovative technologies to enhance resilience to climate change [5]. For instance, buildings can be designed to generate their electricity using renewable energy sources such as solar and wind power, reducing reliance on fossil fuels and enhancing energy security. Smart building technologies and sensors can also be used to monitor flood levels and alert residents to potential flooding risks, allowing them to take proactive measures to protect their property. Despite its potential benefits, implementing flooded architecture faces several challenges. One of the significant challenges is the cost of implementing such designs, which may be higher than traditional construction methods. This may limit access to such designs and require financial support from the government or other sources. Additionally, the adoption of flooded architecture may face regulatory and legal challenges related to building codes and zoning regulations.

Floods in Egypt have prompted indigenous solutions among farmers, enabling them to continue living and working in their birthplaces despite the risks posed by flooding. Such solutions are aligned with their right to choose whether to leave or remain in their threatened lands. Moreover, in the past, people living in the northern delta used to construct housing units made of light wood or ashes to adapt to the flood-prone environment. Therefore, building on water is not a new or modern concept for Egyptian society. By leveraging and merging old techniques with recently available technology, it is possible to create innovative;yet, sustainable solutions can save lives and secure a sustainable future for people living in flood-prone areas. However, this may require significant investments in research and development, as well as the participation of various stakeholders to ensure the feasibility and effectiveness of such solutions.

B. *National Egyptian vision of using flooded architecture to mitigate climate change impact*

There are ongoing efforts to develop sustainable solutions for flood-prone areas in Egypt. For instance, the government of Egypt has launched several initiatives aimed at addressing the challenges posed by floods, such as the National Strategy for Water Resources Management and the National Plan for Integrated Coastal Zone Management. These initiatives aim to promote sustainable water management practices, enhance the resilience of coastal communities, and protect and preserve natural resources. In addition, there are several ongoing research projects and collaborations between academic institutions, non-governmental organizations, and the private sector aimed at developing sustainable solutions for flood-prone areas in Egypt. For instance, some researchers are exploring the potential of using natural materials, such as bamboo and straw, to construct flood-resistant housing units that are affordable and environmentally friendly.

Furthermore, several innovative projects are already being implemented in Egypt to address the challenges posed by floods. For example, in the city of Alexandria, a project was launched to construct a "sponge city" that can absorb and retain rainwater, preventing floods and replenishing groundwater resources. The project involves the construction of green roofs, porous pavements, and rain gardens that can capture and store rainwater for later use. There are plans to expand sustainable solutions to other flood-prone areas in Egypt. The government of Egypt has recognized the importance of sustainable development and has integrated it into its national policies and plans. For instance, Egypt's Vision 2030 includes a goal to promote sustainable development and enhance the resilience of communities and ecosystems to climate change and other environmental challenges.

However, several challenges need to be addressed to ensure their successful implementation. One of the primary challenges is the lack of funding and resources to implement these sustainable solutions on a large scale. Another challenge is related to the availability of skilled labor and technical expertise to implement these sustainable solutions.

Furthermore, there may be social and cultural challenges related to the adoption of these sustainable solutions. For example, people may be resistant to the idea of using natural materials or changing traditional building practices. This may require extensive community engagement and education programs to ensure that people understand the benefits of these sustainable solutions and are willing to adopt them. There may be regulatory and legal challenges related to the implementation of these sustainable solutions. For example, building codes and zoning regulations may not be designed to accommodate these new technologies and practices. This may require collaboration with government agencies and policymakers to ensure that these solutions meet all necessary regulatory requirements and are legally permissible.

Overall, while there are many challenges to the implementation of sustainable solutions for flood-prone areas in Egypt, addressing these challenges is critical to promoting sustainable development and enhancing the resilience of communities and ecosystems in the face of environmental challenges.

Methods

The methodology involved a comprehensive review of literature and case studies related to floods, resilience, floating architecture, and sustainable materials. Additionally, it incorporated an examination of international case studies, Egyptian current cases, and future vision through the analysis of published papers, UN reports, and public lectures. The methodology also included on-site investigations in various locations on the northern coast of the Nile Delta to gain insights into the current situation. The selection criteria for literature involved studying recent achievements of relevant case studies and their methods of integrating people and innovation. The application of the methodology was carried out through a project-based experience, which involved designing a reference architectural model and exploring related technologies.

C. *International techniques and national proposal*

Various architectural solutions and concepts have been examined worldwide to mitigate and adapt to water infiltration and drainage, with a focus on managing and sustaining environmental resources. These trials depend on water's existence and effects, while also reusing water as a resource rather than a threat. With the increasing possibilities of water infiltration in different sites around Egypt, it is important to learn from previous trials, especially indigenous ones, and reuse these experiences in a way that adapts to the Egyptian environment and matches new technology and threats.

A case study of library innovative design and construction techniques employed in the Queenslander Library, located in the flood-prone region of Queensland, Australia (Fig. 1). The library exemplifies a floating architecture approach that combines various strategies to mitigate the impact of floods on both existing and new buildings. Key features of the structure include block walls constructed from wood with augmented chemical treatments and mechanical techniques that enable the buildings to float with the water level. This case study highlights the successful implementation and effectiveness of these techniques in flood-prone areas.

The design of the Queenslander Library prioritized flood resilience, incorporating elements that enable the structure to withstand and adapt to changing water levels. Special attention was given to the choice of materials, construction techniques, and the integration of mechanical systems to facilitate the floating capability of the building. One of the key design elements of the Queenslander Library is the use of wooden block walls treated with advanced chemical technologies. These treatments enhance the wood's durability and resistance to water damage, enabling it to maintain its structural integrity during flood events. The wooden block walls provide buoyancy to the structure, allowing it to float as the water level rises.

To ensure the seamless floating of the Queenslander Library, mechanical techniques were employed in the building's foundation and structural elements. These techniques involve the use of boles and mechanical systems that adjust the building's position in response to changing water levels. The integration of these mechanical components enables the structure to remain stable and secure while floating.

The construction process of the Queenslander Library involved a meticulous execution of the design principles. The installation of the wooden block walls, the implementation of the chemical treatments, and the integration of mechanical systems were carefully coordinated to achieve the desired floating effect. Close collaboration between architects, engineers, and construction professionals was crucial to the successful realization of this innovative architectural solution.

The effectiveness of the floating architecture techniques employed in the Queenslander Library was evaluated through comprehensive testing and simulations. The structure demonstrated its ability to adapt to rising water levels, effectively mitigating the risk of flood-induced damage. The results of this evaluation confirm the feasibility and practicality of employing a mix of wooden block walls with enhanced chemical treatments and mechanical techniques in flood-prone regions.

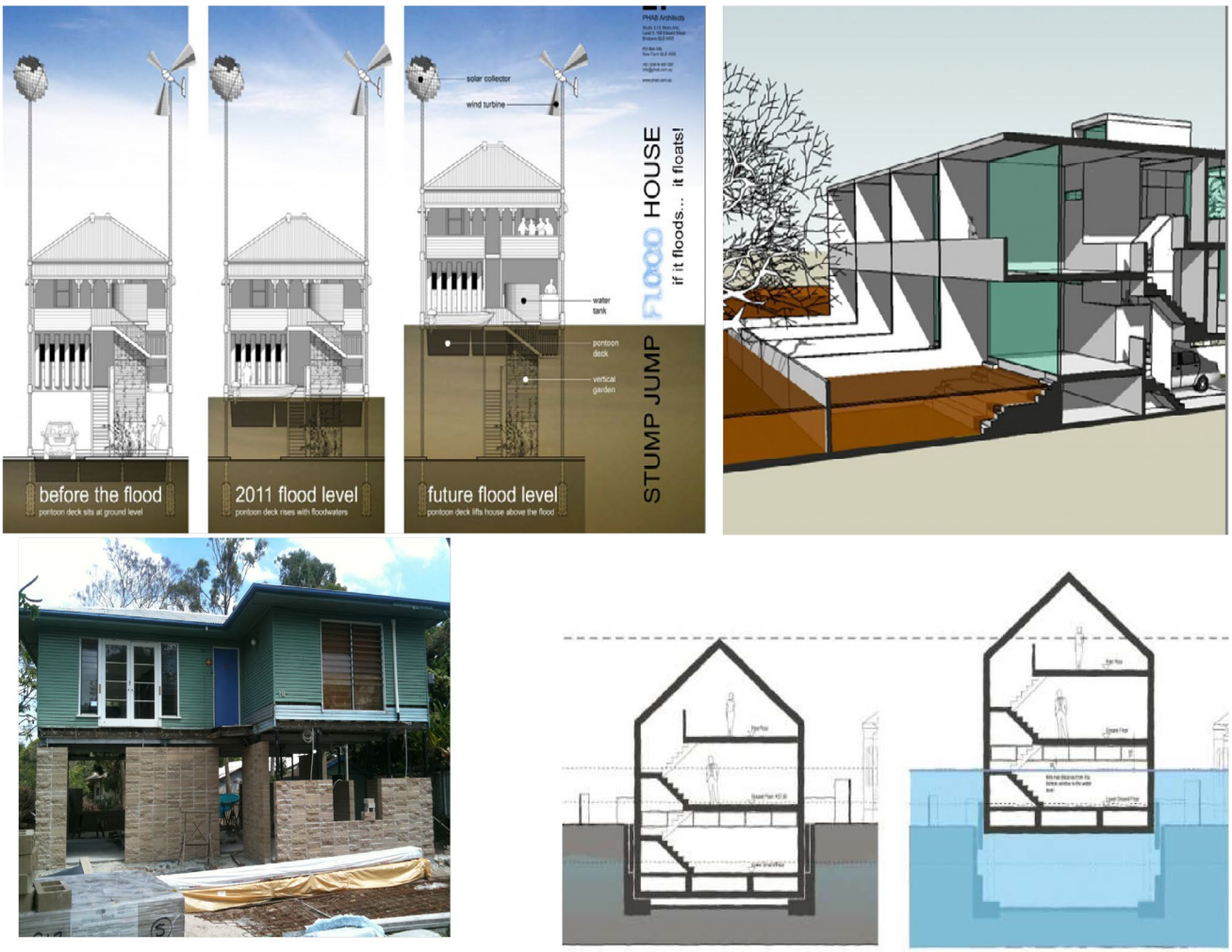

Fig. 1 Pic (1) A proposal: raising a traditional—Queenslander (State Library of Queensland, 2011)—Pic. (2) A proposal: architecture as infrastructure using water comes from different directions—Pic. (3) Harp St with single skin block wall—Pic (4) Amphibious House, BACA Architects, UK using mechanics to elevate house when water intervenes

In recent years, the global community has witnessed an increased frequency and severity of flooding events due to climate change and rising sea levels. As a result, architects and designers are exploring innovative solutions to address the challenges posed by these environmental changes. This case study examines the use of amphibious house design and integrated flood warning systems as proactive measures to mitigate the impact of flooding on residential areas.

Figure 2, labeled as "Pic 1. Amphibious House, BACA Architects, UK," showcases an exemplary design by BACA Architects in the UK. The concept of an amphibious house involves constructing a dwelling that can adapt and float on water during flood events. By incorporating buoyant foundations and flexible building materials, these structures can rise and fall with the water levels, minimizing damage and ensuring the safety of residents. The BACA Architects' design serves as a notable example of integrating amphibious architecture into real-world applications. The garden design incorporates terraces that act as an "early warning system" for flooding, we observe an innovative approach to landscape design that doubles as an early warning system. The terraces, intelligently integrated into the garden layout, serve as indicators of rising water levels. By strategically positioning these terraces at different heights, residents can visually assess the water's encroachment and take appropriate actions to safeguard their property and well-being. This design concept demonstrates the potential for merging esthetics with functionality to create resilient living spaces.

The design by Adjaye Associates for Cube Haus. Photograph: ©Adjaye Associates presents a design by Adjaye Associates that addresses the economic aspect of flood-resistant housing. By designing modular and cost-effective structures, this project aims to make flood-resistant homes more accessible and affordable to a wider population. The

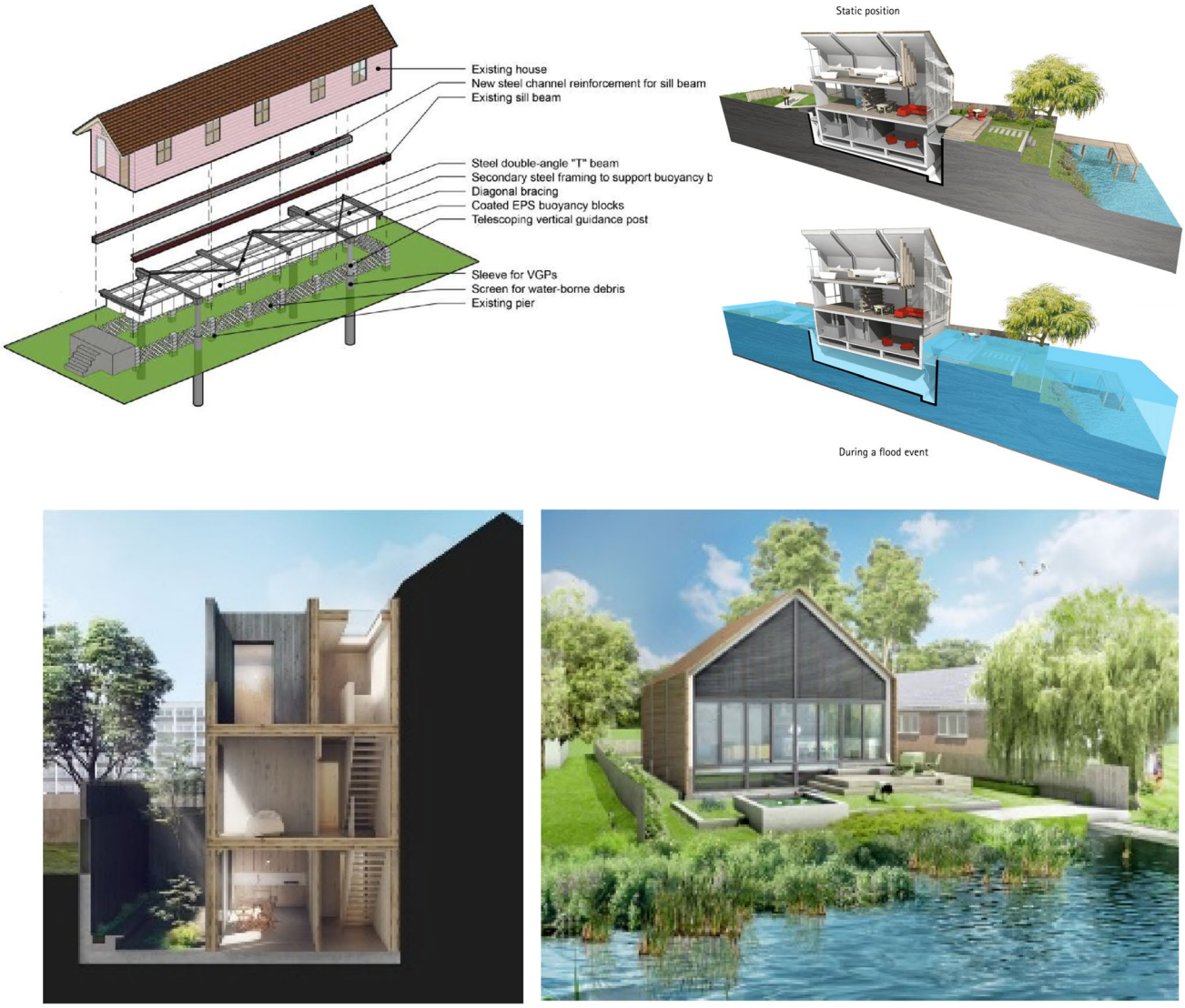

Fig. 2 Pic 1. Amphibious House, BACA Architects, UK—Pic 2. The garden design incorporates terraces that act as an "early warning system" for flooding—Pic 3. The garden design incorporates terraces that act as an "early warning system" for flooding—Pic 4. Sinking costs … a design by Adjaye Associates for Cube Haus. Photograph: ©Adjaye Associates

use of adaptable building components allows for easy assembly and disassembly, enabling residents to relocate their homes in response to flood events while minimizing financial burdens.

These case study examples highlight the importance of embracing innovative architectural approaches to tackle the challenges associated with flooding. By combining elements of adaptability, early warning systems, and cost-effective design, architects and designers can significantly improve the resilience of communities in flood-prone areas. These forward-thinking solutions provide a glimpse into the future of water-based architecture, where safety, sustainability, and livability are seamlessly integrated.

D. *The proposed proposal of the Egyptian floating building*

The proposed solution involves creating a community with flexible and changing needs, offering public alternatives and choices for how homes and workplaces should look. This solution also aligns with the national vision of expanding communities vertically rather than horizontally to preserve land, particularly agricultural land. The proposal utilizes natural or sustainable artificial materials that can be recycled within the Egyptian market to build different zones inside the proposed project. The housing or family zone is represented by the red zone in the figure, while the blue zone refers to the workshops or retail area. This proposal can be applied in areas that are affected by underground

water, such as Dar El Salam and other zones along the Ring Road. Additionally, the proposal introduces vertical gardens instead of relying solely on horizontal areas, allowing people who may lose their agricultural lands to have elevated zones with agricultural areas and space to grow their own crops.

The design of this proposal integrates different techniques to mitigate and adapt to floods and water intrusion. First, anchors in the structure (Fig. 3) to enable the building to float also the use of elevating gardens, block walls, and basement wetlands could be integrated in the same way as in previous examples. Next materials used will be discussed suggesting some local materials as structure and construction methods of the same techniques.

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E. *Used materials in structure and construction*

Urban forests are a large source of biomass worldwide. The amount of urban tree biomass removed nationally due to land clearing, tree and yard maintenance activities, and tree removals caused by natural mortality, pests, windstorms, and other disturbances is comparable to the total annual harvests from the Forests. Recently, urban tree and yard wood waste have been promoted as a potential way to create useful products (i.e., ecosystem goods), and more importantly, this wood waste can also be reused, burned for fuel, or recycled in the form of wood products. Because of the constant supply of urban forest wood waste and its proximity to bioenergy and wood products plants, further research on the use of wood biomass waste as an ecosystem service and good and the supply of wood waste as a cost-effective source of bioenergy is warranted (Fig. 5) [1].

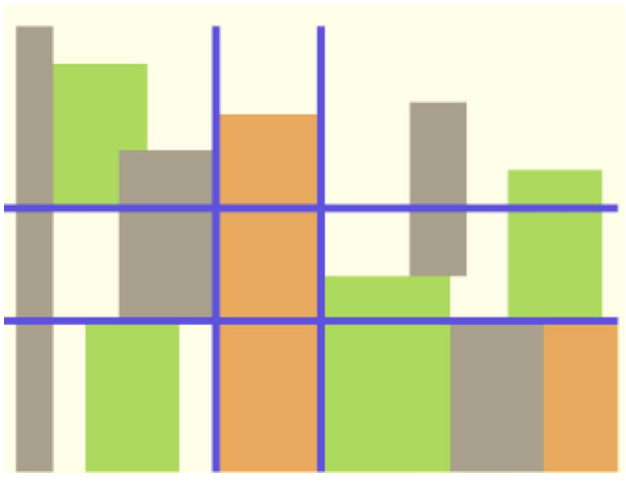

Fig. 3 The housing unit contains all the basic activities in one place: orange for possible commercial and agricultural activities as well green for productive

Producing sustainable products is one of the most popular interests worldwide nowadays. The reason for that is that it has a reduced carbon footprint. A huge amount of wood waste is produced during the processes of agriculture or the manufacture of wood in every single factory all over the world, and most commonly, these wastes are disposed of in landfills. Also, the hazardous content of biomass wood waste is plentiful in addition to the fact that its decomposition process takes significant time [6]; The other alternative is burning that biomass wood waste may be more hazardous than disposing of it in landfills because it generates huge ash and smoke that are correlated directly to the air pollution we have nowadays. While developing this research, we had the challenge in mind in order to create the most efficient product and alternative which is not energy intensive and produces a large amount of harmful atmospheric emissions (Fig. 6).

Engineered wood products (EWPs) are manufactured from wood particles and sheets bonded together by an adhesive material, such as plywood, fiberboard, particle board, or oriented strand board. The binder adhesive materials used in those boards are urea-formaldehyde (UF), melamine urea-formaldehyde, phenol-formaldehyde (PF), polyurethane (PUR), and epoxy. The disadvantages of those boards are that they require more energy for their manufacture, and the adhesives used in some products may be toxic, like urea-formaldehyde; therefore, cutting and working with some products can expose workers to toxic compounds [7].

Hybridization is one of the methods used to produce high-performance composite materials. Hybrid composite materials are manufactured by combining several types of different fibers within a common matrix. This merge of two different types of materials offers some advantages to advance the properties of plastic composites [2, 3], such as wood sawdust or chips together with plastics or other lignocellulose products derived from the fibrous parts of plants like hemp or cotton or the husks of rice grains and sunflower seeds. Bio composites are composites with natural fiber reinforcement and a polymer matrix, which may or may not be derived from biological sources. The inception of bio composites as technology goes beyond mitigating the prevalence of synthetic composites. This suite of technologies has the potential to overcome the disadvantages of synthetic composites by being eco-friendly, biodegradable, renewable, and flexible in design. All of these materials are 100% recyclable. The pressed WPC boards are formaldehyde-free. Wood-polymer composites (WPCs) have

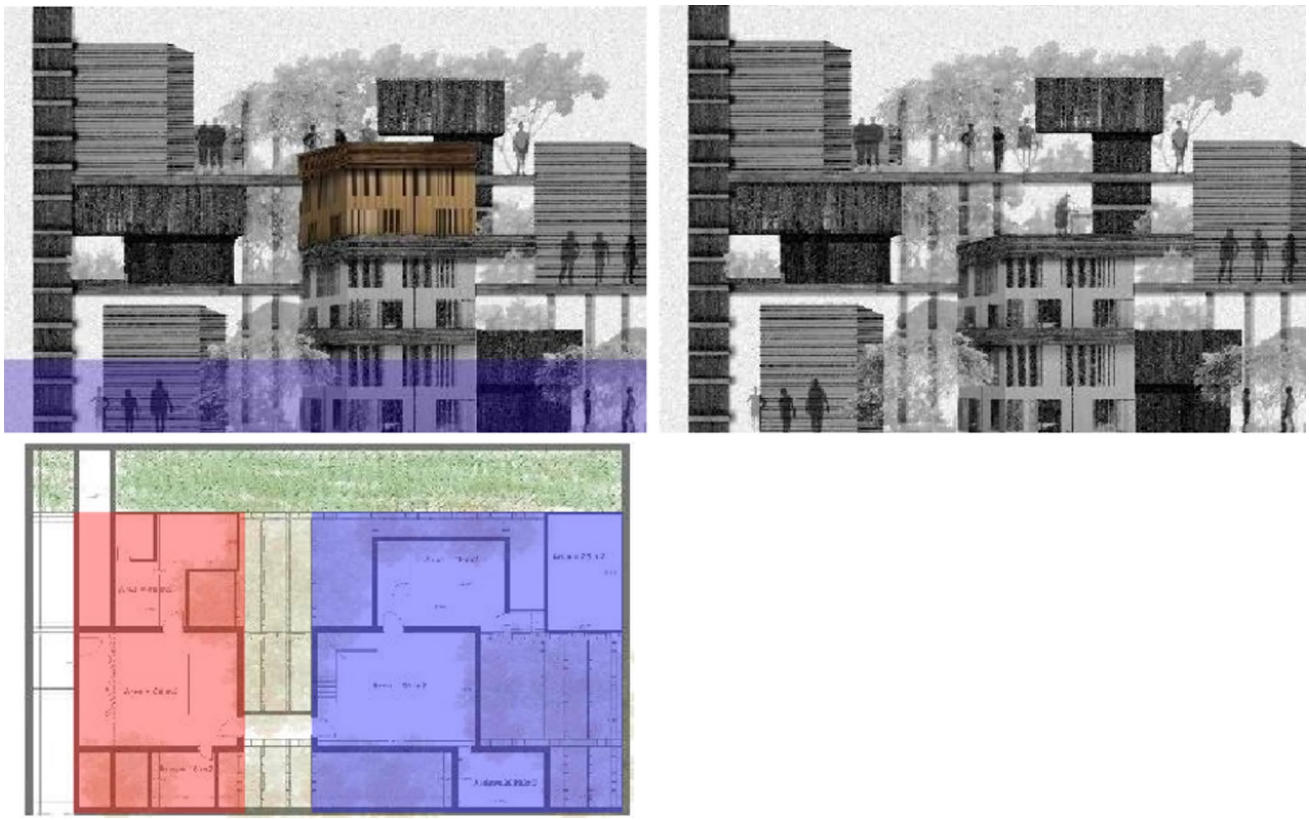

Fig. 4 Pic. (1) showing sectional of the elevated part in the time of floods—Pic. (2) A sectional view in the norm time—Pic. (3) Plan for the different zones of the unit—Pic. (4) the structured pillars to elevate the building of the time of floods. *Source* main author

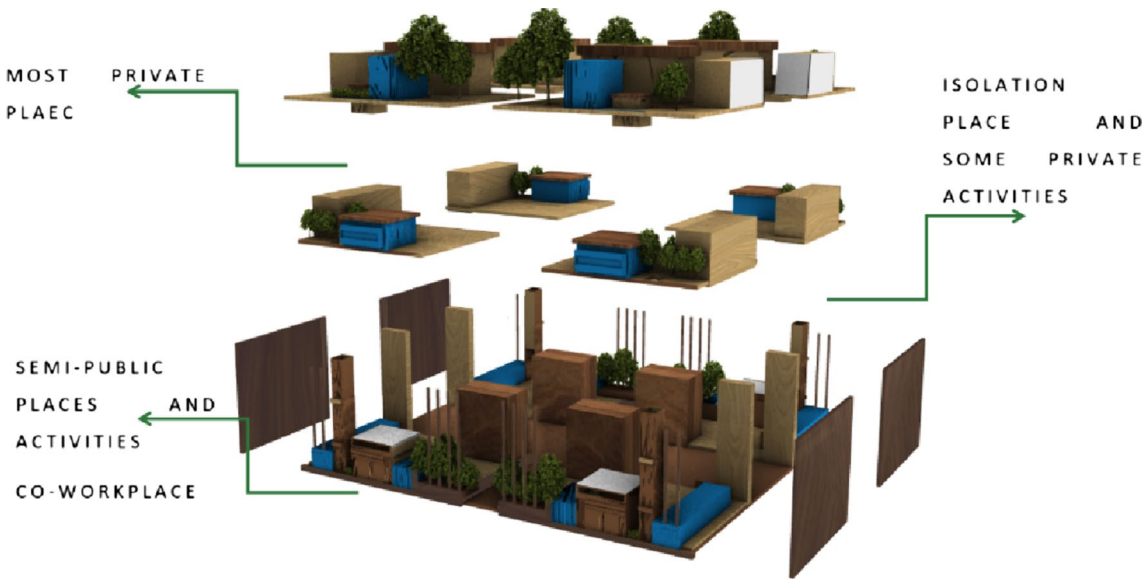

Fig. 5 Isometric sectional diagrams for main functions integrated with the main structure module. *Source* main author

many advantages, including but not limited to the fact that they do not need protectors and sealants, can be painted, have better moisture resistance compared to manufacturing pure wood products, and are more sustainable since they can be manufactured from recycled materials and machined and fixed in the same manner as wood [4].

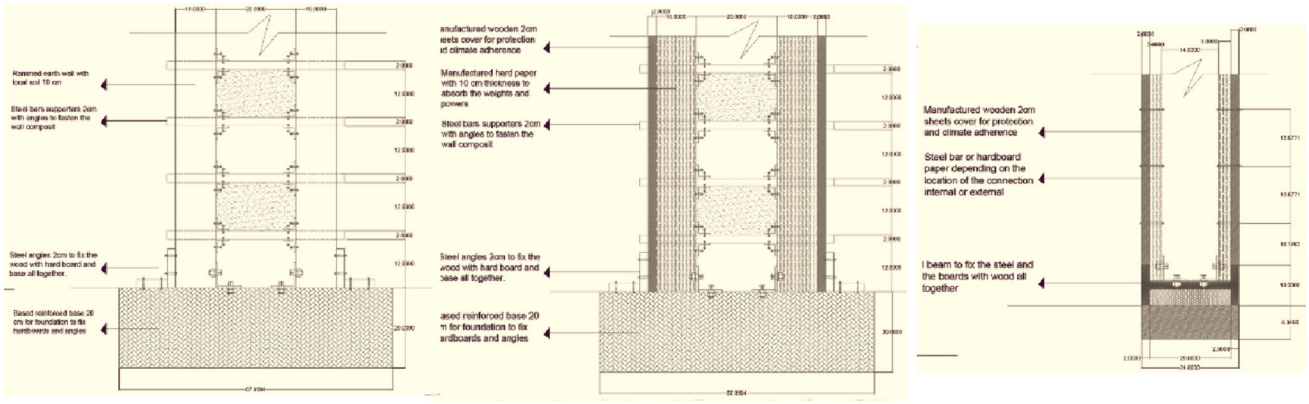

Fig. 6 Sectional details of the structure material used in different structure elements in the model. *Source* main author

Wood-plastic composites are a relatively recent group of polymeric composites studied and used by many researchers worldwide. A WPC is a blend of wood (small particles) and plastic (thermoset or thermoplastic), which gives rise to a finished product having the synergistic properties of both constituents [5]. The basic process involves compounding the polymer and the wood a little above the polymer's melting point and then molding the mixture into various desired shapes, sizes, colors, and textures. Manufacturing involves different compounding techniques, various extruders, and a range of optimum process conditions [8]. Markets nowadays are turning their interest to using plastic waste within various industries due to the huge amount of disposition, which makes up the largest portion of the global public's solid waste. The plastic waste accounts for more than 60% of the total solid waste, of which only one-fifth was recovered. The short life-cycle of plastic caused a significant increase in its consumption; hence, many countries now favor minimizing landfills, which led to the importance of recovering plastic waste instead of disposing of it [9].

The advantages of WPCs composites: the wood gives a comparable reinforcement to the composite at a lower cost when compared to synthetic fibers, and WPCs can be recycled and reused as the constituent materials can be melted and reformed [10]. The introduction of synthetic fibers in a composite is detrimental to the machine and instruments, and in addition, the synthetic fibers can cause attrition on the processing instruments [11]. The wood and polymer/plastic in WPC have a complementary relationship, alleviating the finished product's overall quality. Wood is a renewable material that mitigates the use of fossil fuels. Wood creates a stiffer product than if only polymer is used. Wood has been found to reduce fiber damage during processing, and it requires low maintenance [12]. Using differing kinds of plastics in numerous industries, such as different types of polyethene, polypropene, and PVC, because the plastic or polymer improves the compression properties and masks the hydrophilic nature of wood, making it resistant to thickness swell and rot. The plastic makes the finished WPC recyclable, safe from splintering, and low density [13, 14].

Conclusion

The escalating impact of climate change and rising sea levels in various parts of the world, including the northern coastal regions of Egypt, necessitates the development of localized tools to mitigate and adapt to these challenges. This scientific paper has proposed a solution that carefully considers national and local materials, crops, cultural influences, and vernacular building techniques. By incorporating these elements, the proposed solution aims to address the pressing need for adaptation measures in the northern coastal cities, while also aligning with a forward-looking vision.

The proposed solution emphasizes the construction of a central facility in the middle of these cities, strategically positioned to enhance the region's potential for food production while simultaneously reducing emissions associated with construction and subsequent maintenance. By harnessing the local resources and leveraging traditional building methods, the proposed solution seeks to create a sustainable and resilient framework for the affected coastal regions. The integration of national and local materials ensures a harmonious blend of the proposed solution with the region's cultural and environmental context. This approach not only enhances the socio-cultural fabric of the communities but also promotes a sense of ownership and pride among the local population.

In summary, the urgent need to adapt and mitigate the impact of climate change and sea level rise in the northern coastal cities of Egypt calls for innovative and context-specific solutions. The proposed solution presented in this scientific paper offers a holistic approach that combines the utilization of local resources, preservation of cultural heritage, and forward-thinking strategies. By embracing this vision, the northern coastal cities can aspire to a sustainable

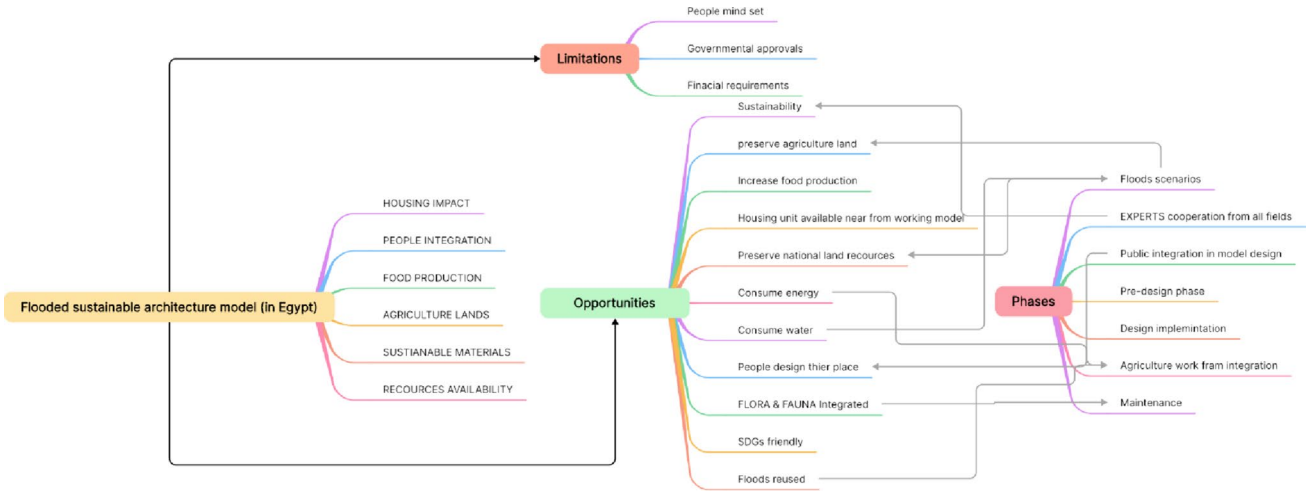

Fig. 7 Shows a mind-map of the strategic flow of the model and potential principles to consider. *Source* main author

future that safeguards their ecosystems, supports food security, and reduces carbon emission (Fig. 7).

Authors' Contributions All authors contributed to the study conception and design.

Availability of Materials The data that support the findings of this study are available on request from the corresponding author.

Declaration

Competing Interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported.

Ethical approval This article does not contain any studies with human participants or animals performed by any of the authors.

Informed consent Informed consent was obtained from all individual participants in the study.

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