The 5th International Conference on Architecture and Built Environment with AWARDs
CONFERENCE S.ARCH ARCHITECTURE AWARD 2018
CONFERENCE – THE WAY IT'S MEANT TO BE
22-24 May 2018 I Venice, Italy

AN AFFORDABLE AND ADAPTABLE BUILDING SYSTEM TO TRANSFORM INFORMAL SETTLEMENTS IN CAIRO

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Abstract

Today, approximately 70% of Greater Cairo's 20 million inhabitants are living in urban informal settlements, and the number is expected to continuously increase. These informal settlements suffer from various issues such as overpopulation, high unemployment rate, land shortage, poor living conditions, inadequate infrastructures, and environmental pressures. This paper is a scientific summary of the results from the research project A^2L-Mobilius, which is partly funded by the German Federal Ministry of Education and Research (Project: AL^2MOBILIUS; Grant Number: GERF-IB-033 Almobilius_01DH14003). The goal of this research is to explore an integrated approach to improve the living condition of local residents as well as to revitalize the local communities. By investigating the context of informal settlements in Cairo, an Affordable and Adaptable Building System (A^2BS) based on open building concepts is proposed, which can be easily prefabricated and assembled by unskilled labor. Meanwhile, Decentralized Processing Units (DPUs) tailored to the building system are introduced to enhance three main aspects of life (working, energy, and mobility). Finally, a simulation of a regenerated house based on selected case study building is presented, which integrates A^2BS and various DPUs. Additionally, an appropriate business model for the future prosperity of the local communities is discussed in the context of Decentralized Industrial Village (DIV). In conclusion, this research will be a step forward to improve the living conditions of informal settlements in Cairo and worldwide.

Keywords

Cairo, building system, informal settlements, open building, urban regeneration

1 Introduction

The process of urbanization has reached an unprecedented level. According to a recent UN study, 66% of world population will be living in urban areas by 2050 [1]. Currently most of the urban sprawl processes happen in developing world, which trigger a series of social, economic, and environmental challenges as well as opportunities. For instance, Greater Cairo Region is arguably the largest in Egypt, Africa, and the Middle East, and one of the most crowded metropolises in the world. In recent years, nearly 70% of Greater Cairo's 20 million inhabitants are living in urban informal settlements, and the number is expected to continuously increase

[2]. Due to the unorganized administration and many other reasons, these informal settlements suffer from various issues such as overpopulation, high unemployment rate, land shortage, poor living conditions, inadequate infrastructures, and environmental pressures [3]. To tackle these issues, this research presents an integrated approach to improve the living condition of local residents as well as to revitalize the local communities.

2 Methods

The methodology for the project plan is based on the V-Model diagram. The project has been divided into smaller issues that can be addressed with a design module or various modules. As shown in Figure 1, the steps of the model embody one or more work packages of the project. On the left side of the scheme, the preliminary work or project definition starts from a general perspective to details over time. On the right side, the project implementation starts from detailing the modules to reaching a general system in the later stages. As shown in the diagram, the system is set to go through several repetitive loops for optimization. Two cycles particularly concern the communication with stakeholders, of which one is to verify the premise of the project, thus the requirement analysis, and the other to verify the design. Final validation will be conducted at the end of the project, with the comparison of the final system and the revised requirement and stakeholder analysis [4].

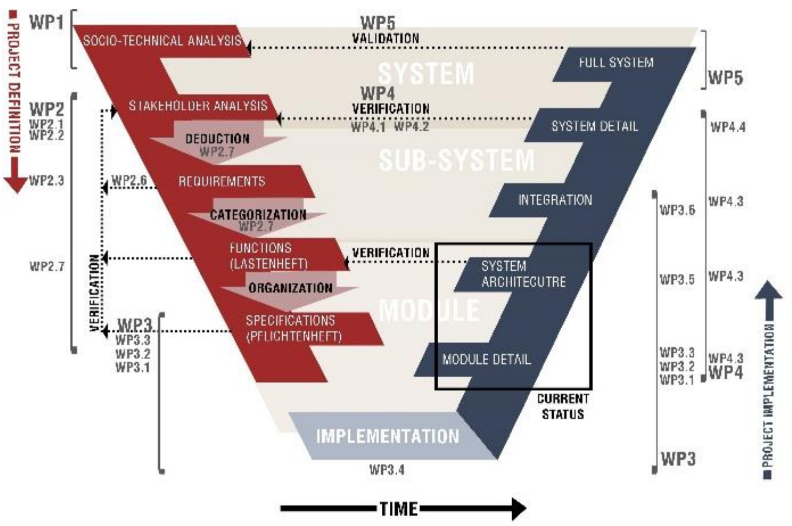


Figure 1. V-Model for the A^{2}L-Mobilius project

Collaboration with the local stakeholders is critical to the success of any projects to regenerate informal settlements. Therefore, participation and feedback from stakeholders throughout the project is an important factor to be ensured. Thus, a methodology based on Requirements Engineering (RE) has been developed and followed, in order to find the optimum solutions based on environmental requirements and stakeholders' wishes. The structure of the methodology takes repetitive optimization loops into consideration to constantly monitor and optimize the stakeholder analysis and requirements analysis throughout the project. The aim of the requirements analysis, together with a technological feasibility study, is to identify concrete functions to be interpreted into design elements, and to establish a suitable system architecture to provide a common structure for the project (see Figure 2) [5].

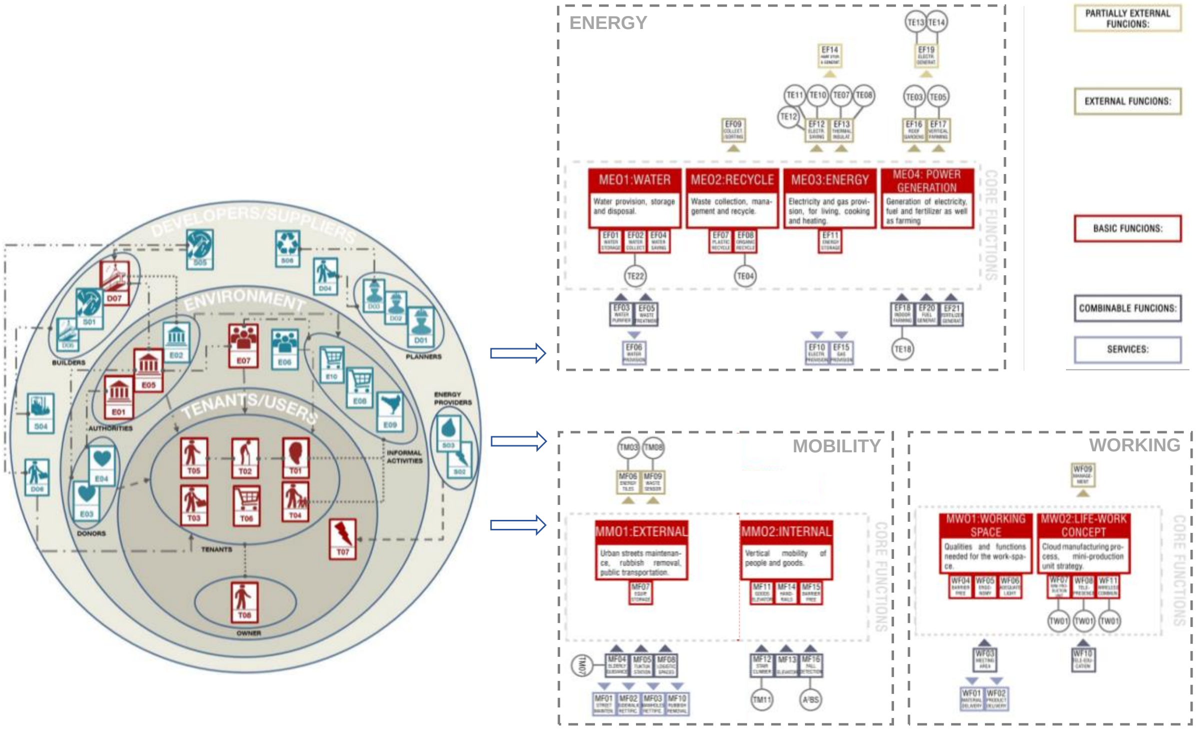


Figure 2. The results of stakeholder analysis (left) and requirements analysis (right)

3 Proposed building system

In this section, the Affordable and Adaptable Building System (A²BS) based on open building concepts is proposed, which can be easily prefabricated and assembled by unskilled workers. Meanwhile, Decentralized Processing Units (DPUs) tailored to the building system are introduced to enhance the working, energy, and mobility of people's life. Finally, a simulation of a regenerated house based on selected case study building is presented, which integrates A²BS and various DPUs. In addition, an appropriate business model for the future prosperity of the local communities is discussed in the context of Decentralized Industrial Village (DIV).

3.1 Affordable and Adaptable Building System (A²BS)

As illustrated in Figure 3, A²BS is a flexible and affordable building system composed of prefabricated elements. The system has been designed to fit the informal environment and adapt over time to the community's needs. The goal is to gradually replace the informal structures and thus "formalize" the built environment. The system is based on the principle of open building concepts, which consist of three sub-systems: the modular structural sub-system, the building envelope sub-system, and the service infill sub-system (including DPUs and services) [6]. It is highly standardized, customized, flexible, and affordable. The system is able to be implemented as various configurations and specifications to match client's requirements. More importantly, the system can be produced with basic tools both on-site and off-site which are affordable for wider groups of customers.

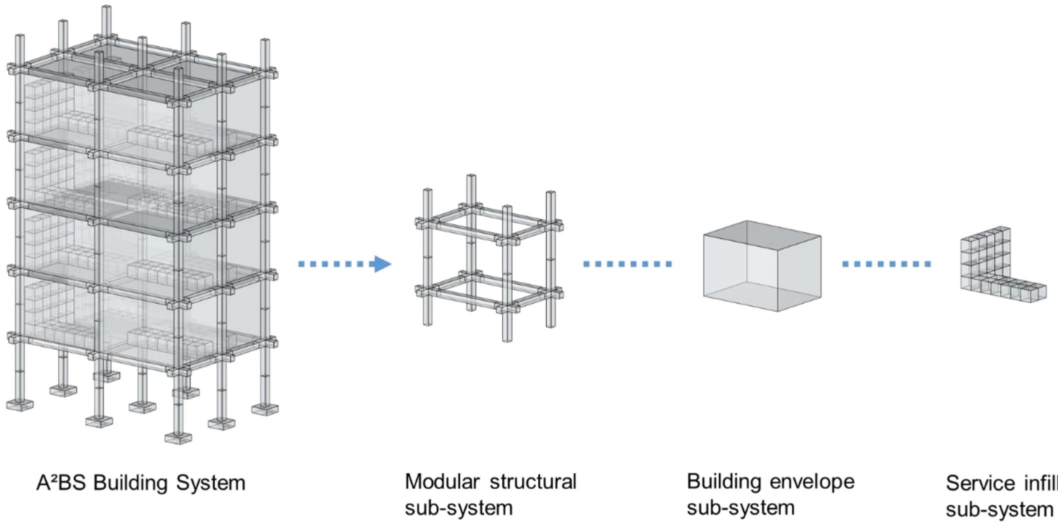


Figure 3. Schematic diagram of A²BS Building System

An easy-to-prefabricate modular concrete structural system is developed which has the ability to both vertically and horizontally extend. This proposed system can be easily made in a low-tech environment both on-site and off-site. The system consists of concrete elements and the connecting beams in between. As shown in the diagrams on the left side, there are two main dimensions for the beams: 2m and 3.5m in length, which will fit the common housing standards in Cairo (see Figure 4).

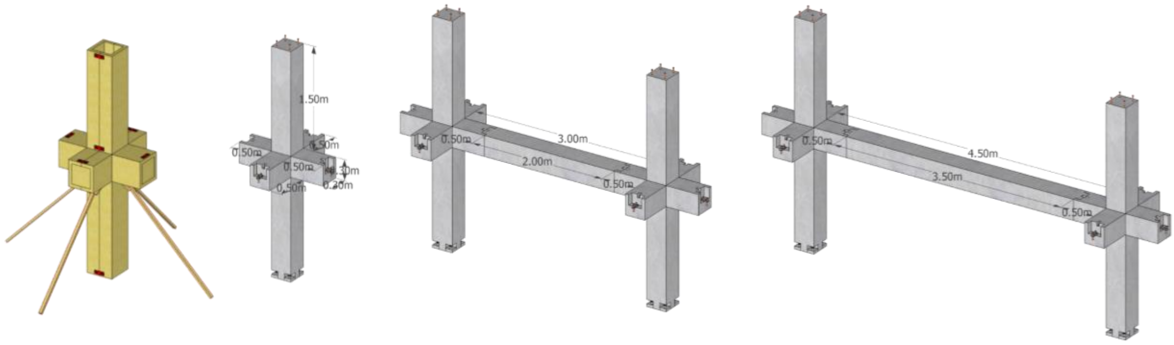
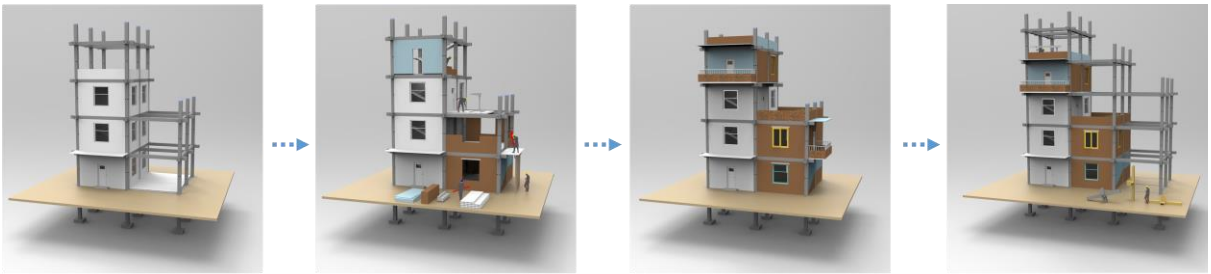


Figure 4. Modular concrete structural system

The principle of this system has indicated substantial potential to address the issues of rapid urbanization and urban poverty that the building can be erected and extended over time to ease the financial burden and to meet the needs of increasing population. Residents can choose whatever materials they have (such as bricks, aluminum panels, concrete, wood etc.) to fill up the reserved spaces. Meanwhile, the local residents are invited to participate in the building and extension process of their own dwellings, as the building system is designed in a user-friendly and low-tech manner. According to previous studies, when compared with conventional construction, the adoption of concrete prefabrication techniques could approximately save construction time by 20%, reduce construction waste by 28%, and decrease labor demand by 9.5% [7]. In the future, when further living space is demanded as the residents' financial status improves and the number of the family members increases, the structure itself can also be vertically and horizontally extended with new-built structural elements. To achieve maximum flexibility and to allow the building to evolve over time, the building system is designed in an expandable and modular manner, eventually functioning as an organism for living. Figure 5 shows an instance of a 30-year development scenario of a building based on A²BS system.



Initial housing unit with reserved structure (Phase 1: year 0-10)

1 round extension (Phase 2: year 11)

Extended housing with local material(Phase 2: year 12-29)

2 round extension (Phase 3: year 30-)

Figure 5. 30-year development scenario of A²BS Building System

3.2 Decentralized Processing Units (DPUs)

DPU represents a prefabricated, self-sustaining, interchangeable, and standardized system that integrates a series of technological equipment that is needed for a household. It allows for a step-by-step upgrade of the informal settlements. The geometries of the DPUs are tailored to the dimensions of A²BS. The DPU includes three main subsystems (subsystem for energy collection, provision, wise use, and production; subsystem for improving mobility; and subsystem for life-work balance: Mini production unit or mini home office). The DPU itself with its subsystems will be easily integrated into the modular building system (i.e. A²BS), which is fully reusable in the future. Developed based on the aforementioned requirements analysis, DPU submodules function as decentralized components that work together as a whole. Therefore, users can decide the amount and types of DPUs, keeping the system affordable.

3.3 Decentralized Industrial Village (DIV)

Decentralized Industrial Village (DIV) is a concept developed throughout the project to describe a type of village, which contains decentralized manufacturing workshops that manufacture a series of components of a product or products, as in the case of a streamline, meanwhile preserving the existing urban context and local business. One way to reduce the unemployment rate, thus revitalizing the informal settlements, is to exploit profitable business model for the local people. Meanwhile, there have been a variety of existing local businesses and craftsmanship (e.g. carpentry and rubbish recycling). In order to promote innovative business model, part of the Cairo informal settlements can be transformed into DIV for innovative product manufacturing without undermining the intactness of existing local business. There are many possibilities of innovative product manufacturing within the DIV. For example, one of the possibility is to prefabricate the aforementioned modular building components which can be utilized in the regeneration of the local community. Generally, the procedures include rebar fabrication, formwork fabrication, concrete casting, curing, storing, and transport, which can be allocated in different households nearby (see Figure 6).

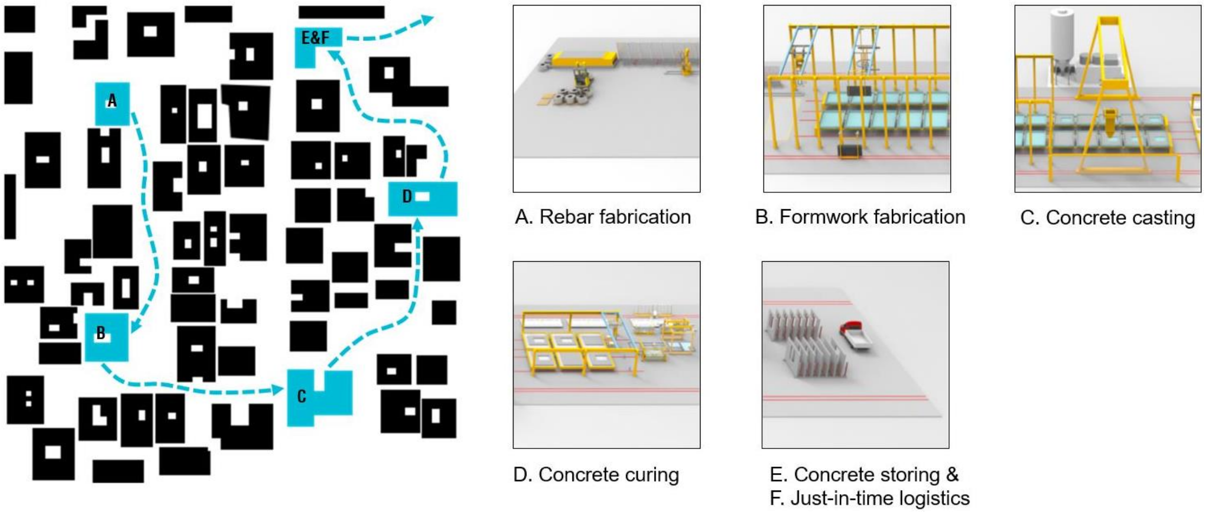


Figure 6. Exemplary business model in the Decentralized Industrial Village

4 Case study and simulation

In the Sakiat Mekki area located on the west bank of Nile River in Giza District, Cairo, a plot in Farahat Street is selected as the case study site. This informal area suffers from various issues. For instance, the street is usually overcrowded due to the limited number of roads; the building quality of the informal settlements are usually poor since most of them are undocumented constructions; the sanitation is also inadequate as garbage and puddles can be often seen on the street.

The selected building, which is owned by the tenants, is a three-story housing unit with one apartment of 45 m² on each floor. The ground floor is an active mechanical workshop. The tenant of the first floor flat is a single woman who lives alone and works at home making handicrafts. The flat on the second floor is a second home for a family of four who only stay here during summer. The flat on the third floor is unoccupied. Stairs are used as extra space for washing, cooking, and storage. These stairs have no handrails and the risers have height differences. The roof is utilized by the users as an extra gathering space. The housing unit suffers from problems such as lack of garbage cans, noise from workshops in the ground floor, lack of ventilation, no handrails in the stairs, risers of different height, sanitation issues, and space shortage. In addition, horizontal extension is not applicable in this case, since the width of the street is relatively narrow and the sidewalk is occupied by local vendors. In addition, concrete casting on site is not applicable as there is no sufficient space on streets for the casting process. Because of the unclear condition of the existing structural system, building extension on the existing structure is not applicable [8].

Therefore, in order to improve the living quality of the tenants and to tackle the above mentioned issues, an upgraded building simulation with A²BS system as well as a series functional DPUs is proposed in detail, based on the proposed building system and the analysis of the case study building (see Figure 7 and its detailed description in Table 1). The construction process would be rapid thanks to the flexible modular building system, and the relocation process during construction would be fast and easy since the single woman on the first floor is the only permanent tenant of this housing unit.

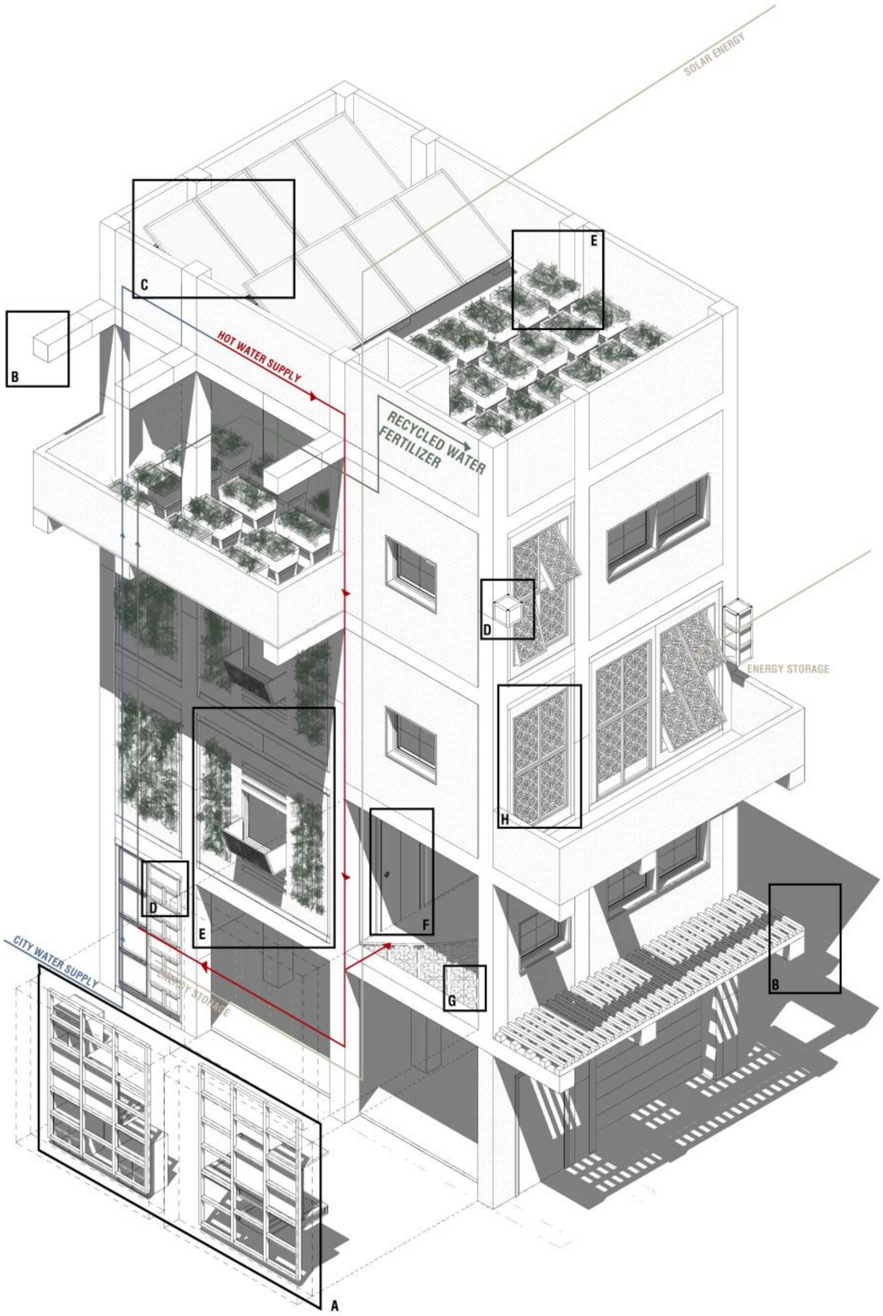


Figure 7. A simulation of regeneration based on the case study building

Table 1: Details of technologies integrated into the case study building

A. Work DPUs	The modular working station has been tailored to the case study to develop the business model [9]. The station proposed is divided into four main steps of production. The different workstations can be distributed in the settlements. They are conceived as equipped walls to save space and can be mounted directly on the A²BS system.
B. Open Building Concept	The concept of Open Building (OB), also known as Support / Infill (S/I), is now representing one of the most flexible construction principles. The building has been designed in different levels: support structures, infill system, fit-out, and appliances. These have been reinterpreted and updated to harness the benefits of state-of-the-

	art industrial production, emerging information and digital technologies, improved logistics, and changing social values and market structures.
C. PV Panels and Solar Heaters	Solar panel is a broadly known technology for collecting solar energy. Composed of small silicon cells, they convert solar energy into either electricity or heat. Nowadays at a relatively reasonable price, solar panels planned for the project are used for both purposes: some will be used to provide additional electricity that will be stored in the DPU cluster at the ground floor; some heat the water received from the city supply and warm it before it is distributed to the different apartments.
D. Modular Energy DPUs	The energy subsystem provides a reliable system that responds to the needs of the community related to collection, provision, wise use and eventual production of different kinds of primary resources such as electricity, gas, and water. The functions of the energy subsystem have been sorted into five main clusters, based on their scope: water, recycle, electricity, power generation, and ventilation. The function clusters try to address the most relevant issues related to energy consumption, collection, and saving. The DPU physical modules that accommodate the different technologies for this purpose have different shapes and dimensions. The picture above represents one of the one used, the “box” modules, which are to be installed alone or in clusters and to be attached to the A^2BS structure. The joints will make it feasible to easily install and detach the modules, making the system flexible.
E. Farming Modules	The project considers the use of aeroponics technology on the roof, which refers to a technology allowing plants grow without soil or other aggregate media. Plants are periodically irrigated with fresh air, water, and nutrients 24 hours per day [10]. Meanwhile, vertical farming is applied in the installation of green walls on building façades. Green walls are usually composed of a frame that hosts soil to grow climbing plants. There are many advantages of vertical farming, such as insulation, evaporative cooling, temperature reduction, and space saving [11].
F. Mobility DPUs	Firstly, one approach proposed for the mobility subsystem is a gradual modification of the interior in the form of Mobility DPUs, aiming to “infect” the environment and gradually upgrade it. Thus, stair and door modules have been elaborated to seamlessly integrate into the interior space. Secondly, exterior mobility is also considered. A typical instance of Egyptian small range mobility is the tuk-tuks, which are popular privately-owned vehicles that serve as public transportation. A similar concept is employed by the VOI electric motorcycle, developed by TUM Create [12]. Similar to a tuk-tuk, the vehicle can transport one passenger at a time. Moreover, it is equipped with an interchangeable capsule in the front, which hosts various pods. The functions vary from passenger transport to goods delivery. This approach would be ideal because the local streets are often overcrowded with insufficient space for mobility.
G. Modular Infill	The modular infill system is intended to be embedded as “second layer” of the building, while the modular structure as the “first layer”. It provides a framework that will accommodate different ranges of functional modules. The framework consists of the wall frame and floor module, that both are easily connected with the structure and detachable when replacement is needed. Basic electrical wiring and pipes will run through the framework, by internally adding a layer of plasterboard to provide a finished wall. The material of the wall frame can be locally sourced. The floor module is made of fire-resistant polystyrene material, enabling flexible installation of pipes and other services. The floorboards above the floor module can be easily removed, in order to gain access to the pipes and services.

H. Hybrid Mashrabiya Panel	Mashrabiya denotes a traditional architectural element especially used in Islamic culture with both aesthetic and functional purposes. Its functions include, but are not limited to controlling light and air direction, reducing temperature, and providing privacy. Size, pattern, and distance from balusters determine how extensively these functions are employed. The proposed solution has a hybrid approach of using photovoltaic with traditional Mashrabiya. The photovoltaic film is attached to the frame carved with the traditional pattern. Different technologies are considered for the film, which is required to be transparent, in order not to block the view from the window. The electricity will be stored in the DPU clusters on the ground floor, serving the whole building. The module appears to be highly efficient, according to a simulation to evaluate its feasibility in the context of informal settlements [13].

5 Conclusion and discussion

The informal settlements in Greater Cairo Region suffer from various aforementioned issues (e.g. overpopulation, high unemployment rate, land shortage, poor living conditions, inadequate infrastructures, environmental pressures, etc.). In order to tackle them, this research explores an integrated approach to improve the living condition of local residents, thus revitalizing the local communities. By investigating the status quo and urgent needs of Cairo's informal settlements with a scientific methodology, an Affordable and Adaptable Building System (A²BS) based on open building concepts is proposed, which can be easily prefabricated and assembled by unskilled workers. Meanwhile, Decentralized Processing Units (DPUs) customized to A²BS are introduced to enhance three main aspects of life (working, energy, and mobility). In addition, a simulation of regenerated case study building is presented, which integrates A²BS and various DPUs. Furthermore, a suitable business model for the local communities is discussed based on Decentralized Industrial Village (DIV) concept.

The proposed system is favorable according to the local residents and stakeholders' feedback during site visits. The proposed system can be further adjusted according to the feedback (e.g. improved dimensions of the structural system, improved load distribution on the roof, optimized layout of the Decentralized Industrial Village, etc.). Future pilot projects will be helpful to validate the feasibility and efficiency of the proposed system. More in-depth cooperation with local institutes and industry is also crucial to the successful implementation of the proposed building system in the local context. In conclusion, this research raises public awareness of the challenges and opportunities in Cairo's informal settlements, provides a valuable reference to researchers, architects and urban planners in the related fields, and takes a step forward to improve the living conditions of informal settlements in Cairo and worldwide.

Acknowledgements

This research is partly funded by the German Federal Ministry of Education and Research (Project: AL²MOBILIUS; Grant Number: GERF-IB-033 Almobilius_01DH14003). Furthermore, the authors are grateful to Mr. Maged Helal for his diligent and professional support.

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