Development of a Methodology based on Requirements Engineering for Informal Settlements upgrading in Cairo

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The phenomenon of informal settlements interests many areas of the world and is constantly expanding[1]. These areas are often distinguished by the lack of regulation, cheap construction materials and poor living conditions. Nonetheless, they are as well characterized by a strong general sense of community and a quite advanced organization that the community itself generates and adapts continuously to the current need. The A²L-Mobilius project[2] aims to improve the quality of life of informal settlements of Egypt, by integrating technology to a system that would fit the existing situation at most. In order to achieve this intent, a methodology based on Requirements Engineering has been developed, in order to be translated in a system as end-user-oriented as possible, with the final aim of being more easily accepted. Therefore, a comprehensive study of the existing situation and stakeholder expectations has been used as the starting point. Fitting requirements, the system is meant to follow, were subsequently deducted from it. The requirements were then prioritized and the most relevant translated into functions and specifications for the project A²L-Mobilius.

***Keywords**: Requirements Engineering, Decentralized Processing Units, Affordable and Adaptable Building System.*

INTRODUCTION: SYSTEM VISION

The A²L-Mobilius project's goal is to insert a pleasant living and working environment into the existing and individual living environment by an intelligent, modular building system, which is able to evolve and transform over time. In this project, a cell-like unit is developed, in which all the main technical units of a residential building are concentrated. The unit is meant therefore to work as a “nucleus” of the residential building. The space cell-like unit, called DPU (Decentralized Processing Unit), includes three main subsystems (one for energy production, one for mobility, one for Life-Work Balance: Mini-production unit or mini office for home). The DPU-nucleus with its subsystems will be integrated into a building kit, called A²BS (Affordable Adaptable Building System). The building kit will be designed so that it is compatible with the investigated site residential structures and in particular informal housing settlements. The building system will be able to grow or evolve over several generations within an existing informal settlement so that it gradually replaces the old unstructured environment by a more formal environment that provides better tools, technologies and living conditions for the residents. The building kit with the DPU nucleus are to be embedded in an existing site that currently no longer meets the needs of residents. This paper shows the methodology used to determine the functions and specifications of both the DPU and A²BS, and discusses the results achieved.

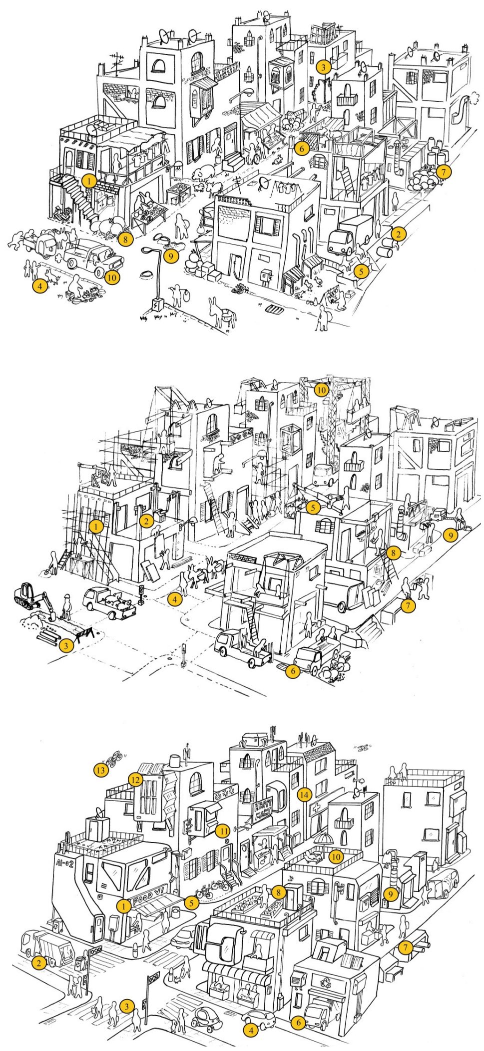

Fig. 1. Situation-as-is and situation-to-be

BACKGROUND: CURRENT SITUATION IN EGYPT

The Great Cairo Region (GCR) hosts a great informal area, that accommodates two thirds of the overall inhabitants of the region at the moment, and the phenomenon is expected to expand. Recent urban developments in Egypt in general did not consider the inhabitants' needs, and consequently did not help to improve the already critical situation. The government tried to contain the spreading of informal housing by denying the provision of basic needs to informal complexes, such as water and electricity, worsening the situation and increasing the tension with local inhabitants[1]. A solution that would address the problem to its core relies into taking into consideration the following aspects:

(1) Socio-economic issues derived from the current and expected demographic change. These issues call for a more flexible system directly involving the local inhabitants in the design process, rather than newly top-down built blocks.

(2) Increasing unemployment rate, which promotes the expansion of the informal market. If it is true that the latter provides job opportunities, its lack of regulation often translates in unsustainable working and worsening of the living condition in the settlement.

(3) Poor indoor and outdoor mobility. Similar to the job market case, the inadequacy of the public transportation system left room for the development of an informal one. Other problems concern the high traffic congestion and frequent accidents. Due to the absence of barrier-free architecture, the needs of elderly people and those with impaired mobility have been as well overlooked[1].

HYPOTHESIS: ENGINEERING INFORMAL SETTLEMENTS

Informal settlements represent one of the most spread phenomena of spontaneous architecture in the world. In order to invert the tendency of informal construction, top-down systems, even the best ones, could not stop the spreading of informal settlements, and often, brought results opposite to the ones to be achieved. This happens mainly because these systems tend to overlook the needs of the future tenants, focusing mainly on urban issues. Between the different strategies, two in particular have demonstrated flaws during the past years: urban redevelopment and legal recognition. The latter involves the amnesty of already built informal construction, usually together with a monetary exchange. However, even though this solution can control the phenomenon for a short time, it may worsen the situation, since the accepted buildings have usually several flaws, and the legality becomes dubious. Urban redevelopment consists in a firm response to informality, usually through demolition and sanctions. Novel structures are built to replace the faulty ones, with little consideration to the existing communities. As a result, this solution has proven to be, again, temporary. On the contrary, in the past a more proactive participation of the existing community to the design process ensured solutions more reliable and able to adapt to future challenges[3, 4], demonstrating how effective their feedback is in the long run. The methodology here proposed is based on requirements engineering[5], usually employed for product and software development. This field has been explored for the high weight it gives to the final customer input, and would therefore provide a more fitting result for the A²L-Mobilius project's aim. The tools retrieved from requirements engineering have been thus transferred to the construction field. Given this, the goal of this research would be to provide a flexible methodology to engineer informal settlements, using the end users' feedback as a starting point and continuous verification tool. The final aim of this method will be to achieve a holistic rational system, to be easily adjusted and mass-produced, depending on the actual environmental and societal needs.

PROPOSED METHODOLOGY

Given the importance of flexibility of the final system, the methodology has been divided into sub-steps, exploring different aspects of the project. The different steps developed will be explained in detail in the following sections.

General approach

The general structure of the project follows the broadly recognized V-Model scheme. The V-Model, initially developed for Software Engineering[6], structures project elements (which space from abstract phases to concrete operations) in an overall development method. Each element is strictly connected with the previous and the following one, thus representing either a result or a motive (or both) in the development process. The vertical axis of the V-Model represents a decomposition of the project, from modules up to the full system, whereas the horizontal axis represents time. The central part is the core of the system, representing the turning point of the development process, shifting from the planning stage to the practical one, and therefore is usually called the "prototype" stage. The two wings of the V-Model contain the project phases or activities and they are directly correlated. The right part is used for verification/validation of the left one, through continuous investigation after the concretization of the system[7]. A schematic representation of the different phases of the research project, following the V-Model, has been made for better project organization, and it is shown in Fig. 2. The system has been divided in three categories (system, sub-system and module). The activities of the left part of the V are meant as preparation for the design stage. The socio-technical analysis, the stakeholder analysis, and the requirement specification are the three main steps required in order for the design to be as accurate and tailored to final users as possible. The core part represents the design stage. The design is meant to evolve from a modular stage (units) up to the full system by integrating parts and developing a fitting overall system-architecture.

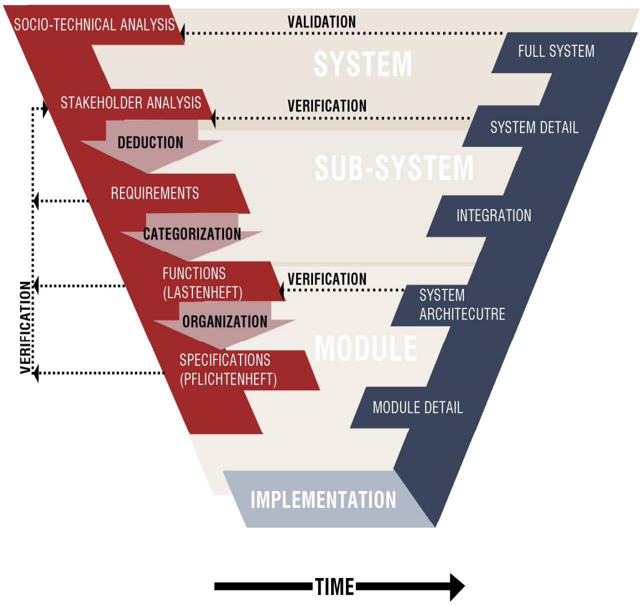

Fig. 2. V-Model of the A2L-Mobilius project

Stakeholder analysis

Following a first environmental analysis of the existing situation, a first stakeholder list has been compiled and periodically revised[8]. Subsequently, stakeholders were divided into four categories[9]: (1) Future tenants living in informal settlements, (2) Developers/contractors, who translate requirements into assets, (3) Suppliers, who provide the necessary resources to the first and second categories of stakeholders, (4) Stakeholders populating the environment (such as authorities or inhabitants of the project area). The second phase of the stakeholder analysis aimed to sort the list entries meaningfully. Therefore, firstly the role of each stakeholder in relation to the project was identified. Roles were considered either active or passive. For instance, developers will always assume an active role, whereas inhabitants of the nearby area are expected to act passively. Another important step was to give a priority index to each entry. That is, in order to identify which subjects need particular attention, and, on the other hand, who will be less affected by the project. Since a stakeholder can take position either for or against the whole project or a specific part of it, oppositions of stakeholders with high priority have to be thoughtfully considered. Given this, priority was based on a numerically countable scale, in order to have a way to compare different entries. Priority been given considering three factors: (1) how much the stakeholder may influence the project, (2) how big is the impact of the project on the stakeholder (3) how big is the interest of the stakeholder in the project, and it is a number on a scale from one to five, with five representing the highest importance. Finally, possible correlations between stakeholders were considered. The Actors Map[10] (Fig. 3) is a visual representation of the relationship between stakeholders. Each stakeholder is represented by a square, whose label refers to the identification number. Stakeholders are in relation with other stakeholders (square to square), groups (square to ellipse) or main categories (square to circle). Key stakeholders, derived from the prioritization phase, are highlighted in red. Generally, the dimension of the "icon" representing each stakeholder changes basing on their priority (spacing from the biggest, representing priority 5, to the smallest, priority 1). The category that has most influence on the others is the "Environment", and therefore it has been placed in the middle of the map, having power both on tenants (in means of social obligations) and on developers, contractors and suppliers (by regulating their activities).

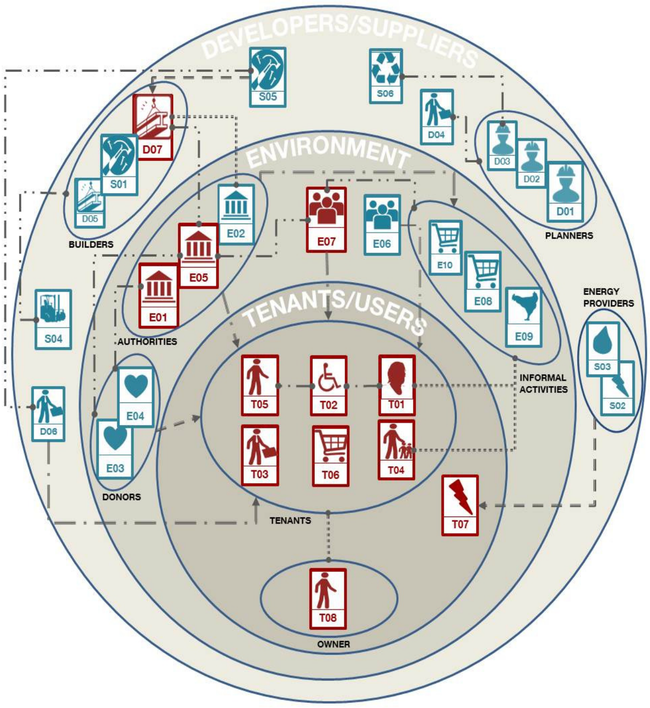

Fig. 3. Actors Map

Requirements analysis and prioritization

Each project use case is an amount of functionality needed by the product to give the correct response to the stakeholders' needs. The essence of the system is the underlying reason for having the product or accomplishing the project[5]. As the understanding of the essence of the project evolves and matures, the chosen stakeholders work alongside of the analysts and determine the requirements that will fit the project context. Once this stage is complete, the findings will be used to determine detailed functions and to draft the final design.

Functional requirements

Functional Requirements specify what the product must do and describe what the project has to do to support stakeholders' wishes. They are usually quantifiable and aim to a specific goal, which can be a particular behaviour or an output of the system. The domain of functional requirements is the scope of the work, the project area or domain under study. Therefore, four main categories were established, following the scope of the project:

(1) *Energy*: is aimed at the design of the Energy DPU-subsystem. Concerns requirements related to water, electricity, gas consumption, provision, collection, storage; power generation; pollution of air, water and environment; eventuality of roof gardening or vertical farming.

(2) *Mobility*: is oriented at the design of the Mobility DPU-subsystem. It has subcategories in internal and external mobility. It spaces from enhancement of the senior mobility and elimination of barrier, to street maintenance and road safety.

(3) *Life-work patterns*: is aimed at the Working DPU-subsystem. It concerns overall working and commuting issues.

(4) *Construction*: is oriented at the development of the A²BS. Its goal is the solution of the main construction issues from different points of view, such as sustainability, efficiency, safety, re-configurability, rationality. Comprehends as well the requirements related to the increase of the "formality level" of construction.

Non-functional requirements

Non Functional Requirements express the quality of the project and therefore are not always countable or easy to assess. They put constraints on functional requirements and help to concretely define and tailor them to the end-user need. NFR could be derived from the following aspects:

(1) *Look and feel requirements*: concern the intended final appearance. For instance, the structural element of the proposed system can be summarized as wooden frame, light steel frame, precast concrete frame or volumetric modular systems. The design needs to be durable, flexible, adaptable and affordable. The appearance of the design should not over-impact the surrounding buildings. The proposed building should respect the existing architectural characteristics of the local design.

(2) *Usability and humanity requirements*: what the product has to be if it was to be successfully used by its intended audience. This has to be identified through detailed design stage and by conducting use case scenario on the chosen stakeholders.

(3) *Performance requirements*: involve how fast, big, accurate, safe, reliable, robust, scalable, and long lasting the product should be and what capacity the product should have. For example, to install a decentralized power generation system, the design team has to take into consideration the connection of the joints of the system with the existing structure, the cost of running of such a system, and if it would be easy to train local technicians to maintain or repair it.

(4) *Operational and environmental requirements*: deal with the product intended operating environment. Thus it is important to assure that the local environment does neither negatively affect nor negatively be affected by the project, both interiorly and exteriorly.

(5) *Maintainability and support requirements*: how changeable the product must be and what kind of support is needed. This aspect needs to be considered during the design stage. There are various design method can be utilised to solve the issue, such as platform design strategy and open building design strategy[11].

(6) *Security requirements*: assure the security, confidentiality, and integrity of the product[5]. They are usually the most controversial. For instance, it could be advantageous to install CCTV cameras and other type of surveillance technology to increase the security level of the area. However, it is not always possible, since the system cannot breach of personal privacy of the residents.

(7) *Cultural requirements*: represent the human and sociological factors of the people that will finally use the product. The product should integrate as much as possible in the existing settlements, in order to be easily accepted by their inhabitants.

(8) *Legal requirements*: concern the conformance to laws and standards. A crucial point of the project is to formalise (or at least, increase the level of formalisation of) the informal settlement construction. Therefore, the project should be conformed to the Egyptian building code.

Prioritization of requirements

There are many different ways to prioritize functional requirements. Ebert[8], for instance, proposes to evaluate requirements depending on two main factors: effort and risk (regarding the development of the function). Therefore, higher priority is given to features whose development does not involve too much money or effort, and whose failure risk is consequently very low. Another famous example is the Value-Cost prioritization[12]. This method in particular has been used throughout the project with the aim of selecting the most important features to embed in both the DPU and A²BS in the later stage. The method is based on the "Analytic Hierarchy Process"

(AHP)[13]. AHP involves the building of two comparison matrices, one concerning the cost and the other the value of singular requirements. Subsequently, the eigenvalues of each matrix are computed and printed in a graph. The numbers derived, in a percent form, represent the weight of each requirement on the overall cost and value of the project. The result is a Cost-Value diagram, which renders the priority of each requirement. As mentioned, higher priority is given to requirements characterized by low-cost and high-value (Fig. 4).

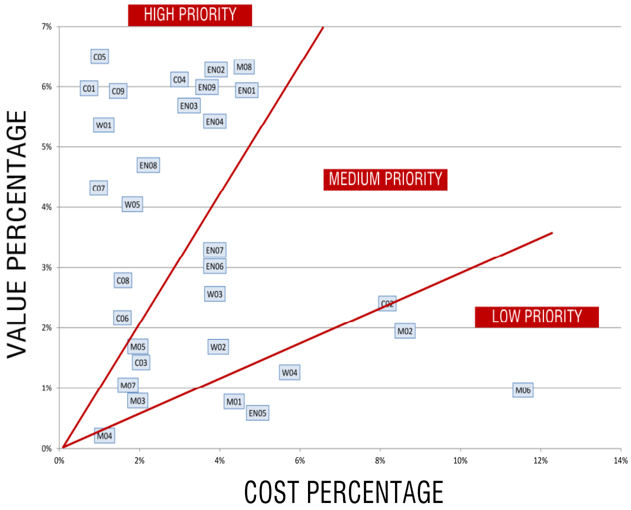

Fig. 4. Cost-Value diagram

Extrapolation of functions and specifications

After prioritizing requirements, the next step consisted in extrapolating one or more functions from each of those with the highest priority and discarding the others. In order to have a more reliable result, three variants of the environment were studied and simulated. Using the same method as above, three different requirement outcomes were given. Requirements with high value in all three scenarios were translated into *core functions*. Given that the final system is intended to be modular, core functions are considered as fixed modules to be embedded in the basic structure of the DPU. All the other requirements not discarded (i.e. relevant in at least one of the variants) have been on the contrary considered as modules to be eventually added to the core structure at need, but not essential. Basing on the requirement type, they are divided into (1) *external functions*, (2) *partially external functions*, (3) *combinable functions* and (4) *services*. The core of each subsystem has to be intended as part of the DPU nucleus. Therefore, eternal and partially external are intended respectively as part of the building and part both of the building and the nucleus. After defining functions, specifications schemes were developed. Technologies suitable for specific functions were listed with the identification letter "T" and added to each scheme. The following sections explore the outcome for each DPU-subsystem in detail.

Energy DPU-subsystem

The Energy DPU-subsystem should provide a reliable system that would respond to the needs of the community related to collection, provision, wise use and eventual production of different kind of primary resources such as electricity, gas and water. Therefore, functions have been sub-divided into five categories: (1) water, (2) recycle, (3) energy, (4) power generation, (5) pollution. Water storage, energy storage and recycling have the highest priority and were therefore treated as core elements. Other features with high priority but different application, such as provision, collection and farming are intended to be part of the building itself, rather than of the DPU, and were therefore treated as modules. In particular, provision falls under the service category.

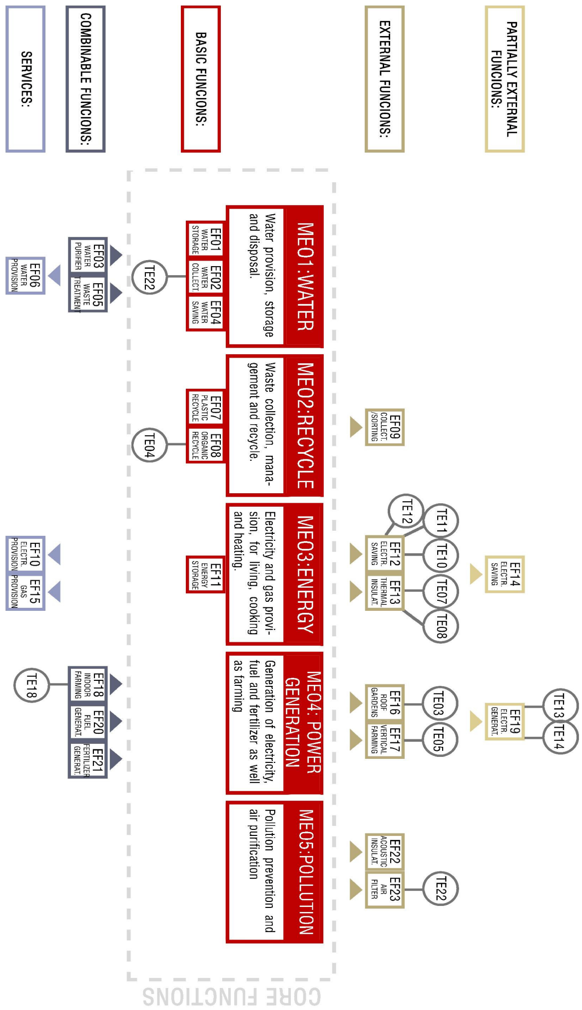

Fig. 5. Energy sub-system: specification scheme

Mobility DPU-subsystem

The mobility DPU-subsystem aims to improve the (1) external and internal mobility of the future inhabitants of the settlement. In order to have a clear system-architecture, internal mobility has been furtherly divided in (2) vertical and (3) horizontal. Moreover, this subsystem should consider as well the mobility of goods. The external category covers various features, from street security to transportation. Given this, the Mobility DPU-subsystem, unlike Energy, should not be considered as a nucleus, but rather as a sum of unit parts collaborating as a whole.

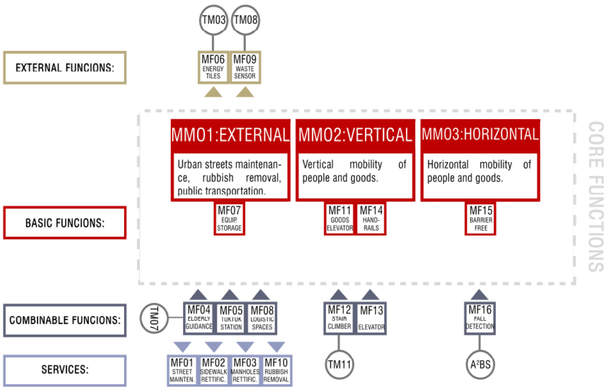

Fig. 6. Mobility sub-system: specification scheme

Home fabrication DPU-subsystem

The Home fabrication DPU-subsystem should be considered not as a singular module, but as a part of a greater interconnected system aiming to give an alternative and more sustainable work method, and therefore to provide a higher number of workplace to decrease the unemployment rate. It must assure as well a better, healthier, safer working condition. The workspaces developed are to be embedded in larger Cloud Manufacturing systems that will allow companies to utilize a highly skilled workforce (including highly experienced elderly) by teleworking, thus avoiding traffic congestions.

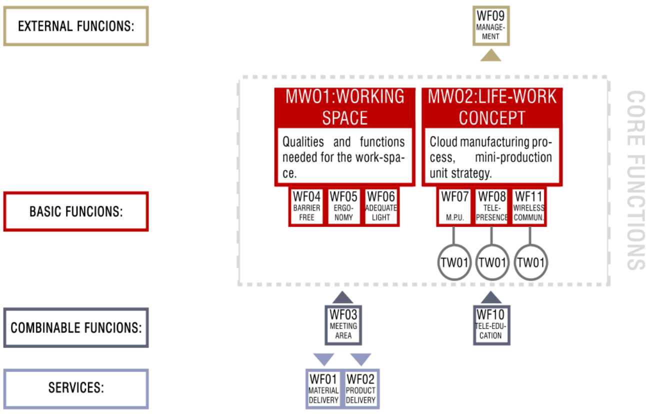

Fig. 7.Life-Work patterns sub-system: specification scheme

Conclusion and Future Work

In this paper, a methodology used to achieve a holistic system to formalize informal settlements has been developed. Since the final system's aim is to respond concretely to the existing issues both of the environment and the end users, the starting point has been set in a comprehensive environmental analysis performed by GUC, combined with a stakeholder analysis. The issues highlighted from these two sources, thoughtfully categorized and prioritized, were subsequently translated into requirements, which were then explored and sub-divided into concrete system functions. The final goal was set into create a set of three specification schemes of the three intended DPU subsystems, to be translated into a modular design system in the next phase of the project.

The system has been proven effective into the preliminary design stage, since it was able to give a rational structure to the creative process. Nevertheless, it still needs further stakeholder validation. In a future development, requirements, functions and the preliminary design will need to be verified by the end users and other parts involved, by means of questionnaires and interviews, as planned from the initial phase of the project. The feedback derived will not only prove the real effectiveness of the method, but also be a valuable base for further prioritization and research.

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