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PARAMETRIC ELEMENTS TO MODULAR SOCIAL HOUSING

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INTRODUCTION

The United Nations expects an exponential growth in Sub-Saharan African region due its fast economic development, mainly provided by natural resources¹. However this growth is associated to the deterioration of urban environment and precarious living conditions for the poorer due an ineffective response to population housing demand. The urban growth and the development of the main urban centres is leading to its densification i.e. internal migrations from the rural areas to urban centres where there is an economic cycle able to provide employment. These rural populations, mainly coming from the poorest countryside areas, had occupied cities outskirts, giving rise to slums deprived of infrastructures and social facilities as well as precarious housing. According to John Beardsley “Slums are now the dominant form of urban land use in much of the developing world”², meeting the UN-HABITAT recent data that reports about 863 million people living in slums in 2012³. John Turner pointed out an important factor related to slums formation: “The urban poor have to solve a complex equation as they try to optimize housing cost, tenure security, quality of shelter, journey to work, and near job (...) is even more important than a roof. For others, free or nearly free land is worth epic commutes from edge to the centre. And for everyone the worst situation is a bad, expensive location without municipal services or security of tenure.”⁴.

This situation is particularly severe in Sub-Saharan African Region where about 62% of the population lived in slums in 2012⁵. Low quality of life and precarious living conditions show, however, two contexts: urban areas are characterized by its massive densification and consequent overcrowding housing for which there is no effective and fast solution by far; rural areas show a context marked by remoteness mostly related to lack of basic infrastructure and mobility. The lack of a development strategy for these lasts is leading to its isolation, desertification and consequent population migration to urban centres, becoming a closed-loop⁶. As a consequence, in both geographical contexts, these populations are socially excluded from remaining society; worsen their social and economic conditions and establishing an obstacle for development.

In this context, governments and public entities are trying to implement urgent solutions for low-income population (re) housing. However, these models are facing difficulties in terms of social, economic and environmental aspects. In first place, the applied solutions are showing social inadequacy to household dimension and dynamic as well as to its lifestyle and source of income, regarding economic aspects (Teige, 2002). According to Werna, in developing countries, housing is simultaneously a shelter and a basis for income generation⁷, which requires a new approach to the dichotomy between housing and informal employment and economy. In second place, the lack of an integrated methodology and criteria for material selection and consequent building process is leading

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to severe consequences in terms of economic and environmental features: housing affordability becomes compromised due the construction processes and adopted materials, mainly imported, which results in transportation and specialized labor costs; the inadequacy to territorial characteristics results in thermal inefficiency, which is related not only to occupant's thermal comfort but also with energy consumption of heating, cooling, ventilation and natural light (Whitehead and Scanlon 2007). The mentioned problematic is aggravated by insufficient funding associated to a weak industrial sector and mobility network, and unskilled labor.

Modular solutions, related to prefabrication, show a potential and opportunity to address this problem. Economically, prefabricated solutions become viable and thus affordable by low-income populations i.e. its production is cheaper, showing a cost reduction of 30% comparing to common solutions ⁸. Standard elements also turn the construction easy to assembly within an assisted self-construction process. For manufacturer, prefabrication shows advantages, namely in terms of waste reduction and energy consumption. According to Stallen et al. the application of prefabricated elements results in 52% less wasting material and a reduction of 50% of water and energy consumption ⁹ due the rationalization process in terms of costs and resources. These characteristics directly revert to environmental implications related to management resources, energy and water.

Taking advantage of self-construction potential of slums residents, which in some countries is already institutionalized ¹⁰, there is an opportunity to complement prefabricated solutions with local materials in order to accommodate economic premises (reduced transportation costs; improvement of national/local economic cycle; increase population skills and capacities in order to get a formal job) but also environmental concerns due less energy consumption during the whole construction process. The adoption of local materials has also an important social component i.e. its application facilitates its acceptance by the population by an architectural image that they are familiar with; instead of just provide an impersonal housing solution (Jiboye 2011).

Modular housing also allows the implementation of an incremental process for (re) housing through expansion and retraction models enable to suit occupants' needs. In developing countries, the population cannot afford housing adequate to their needs, namely to their immediate financial capacity, ending up living in informal settlements where they have the possibility to transform the domestic space. ¹¹. However, an incremental process allows the acquisition of a housing core, with all the minimum standard conditions, able to be expanded according to household financial capacity ¹².

Thus, there is an opportunity to consider a faster and less costly process for social housing solutions based on a parametric approach that integrates social, economic and environmental premises for a modular solution i.e. a solution able to lead to environmental improvement, fair resource management and also to a better quality of life.

METHODOLOGY

The present research refers to the development of a parametric framework for modular social housing that considers a set of interrelated parameters associated to housing and construction schemes identified in four countries: Angola, Cape Verde, Mozambique and Guinea-Bissau.

Thus these parameters will result into an optimal modular solution that is adaptable to different socioeconomic, cultural and environmental context as an integrated solution.

The methodology consists in an interactive process with three main stages, where the first refers to context analysis and the remaining corresponds to conception process (prefabricated module) and local adjustment (complemented local materials) in order to achieve optimal wall-module. The methodology

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outputs refer to an optimal module, complemented with local materials that constitute an adequate housing type (*Figure 1*).

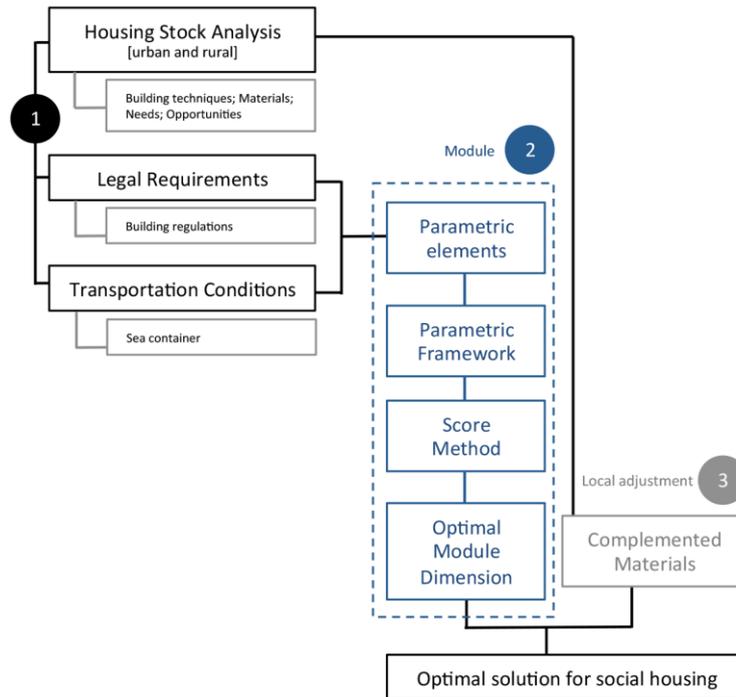


Figure 1. Research methodology.

The first stage corresponds to housing stock analysis, namely prevailing layouts, construction methods and applied materials. The analysis identified needs and regional features as well as common approaches to housing and the most adequate solutions according to territorial context. In this stage it is set out the relation between sustainable housing and traditional models.

This analysis also aims the study of applied materials, in rural and urban contexts, as well as common and traditional construction techniques that will permit the best options to complemented materials. Thereby, first stage main output is an inventory of the housing stock in terms of materials and techniques, able to complement the modular wall, as well as the prevailing housing types (layout) i.e. adequacy parameters for housing.

Stage one also envisages the analysis of legal requirements for housing and transportation premises. This analysis is determinant because will define and ensure not only quality but also the model optimal dimensioning. In one hand, legal requirements establish the minimum dimension for housing, which is related to the module composition (quantity and joint accessories). On the other hand, transportation requirements will defined the optimal dimension in order to transport maximum number of the modules in a sea container. The outputs from this stage refer to the most conservative requirements for housing and the capacity of a sea container to transport the modules i.e. dimensional parameters for module formulation.

Second stage is the most important research phase and performs the parametric framework for module optimal dimensioning. Through a score method, that interacts the parameters resulted from stage 2, it was able to build a framework for the optimal module solution (height and length). It is important to refer that the optimal thickness was achieve through mechanical tests to compression and traction made with samples.

In order to maximize the solution adequacy, the last stage (stage 3) proposes complemented materials, whose selection resulted from the context analysis and inventory performed in first phase.

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Methodology output refers, therefore, to a parametric framework that combines and interact the identified parameters of each research phase, resulting in an optimized module able to perform sustainable social housing solutions and presenting an adequacy in terms of social, economic and environmental criteria.

RESULTS AND DISCUSSION

The housing stock analysis focused in Cape Verde, Angola, Guinea-Bissau and Mozambique and provided not only a diagnosis of the housing conditions but also an inventory of commonly used/available materials and building techniques.

The analysis considered both urban and rural areas and it is important to refer that the urban models are similar in four case studies, where houses are constituted by one/two rooms and built with cement bricks and covered with zinc sheets. This is an important fact related to available materials: in rural areas, the architecture is richer due the diversity of natural available materials and therefore it is possible to observe houses made with wood, sticks and straw, rammed-earth, adobe bricks or basaltic stone (this last only in Cape Verde); urban areas, due the access to low-cost industrial/composite materials and lack of another options, show the same pattern in all case studies.

In terms of needs and deprivations, the urban models observed the most severe situation. While the rural housing showed an adequate performance to territorial and environmental conditions due the adoption of local and natural materials adapt to the site, urban models presented problems in terms of overheating and overcrowding. This is also related to the gross areas whose difference between urban and rural areas is significant: the average housing dimension in rural areas is about 24m² while in urban areas is much smaller, with an average of 14m² (**Table 8**).

Table 1. Summary of housing stock analysis

Parameter	General characteristics: Context analysis
Housing dimension (average)	Rural areas: 24m ² Urban areas: 14m ²
Housing layout	Rectangular or circular only/two one room Cooking area outside No sanitary facilities/outside sanitary facilities Porch Courtyard
Building techniques	Wood structure Bamboo structure Palm tree stems Sticks/canes structure Rammed earth Masonry
Wall materials	Straw Thatch/palm leaves Clay and rice shells Earth Mud

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	Adobe bricks Basaltic stone (only in Cape Verde) Zinc sheets Cement bricks
Roof materials	Straw Clay and leaves Palm tree leaves Asbestos-cement Zinc sheets
Alternative materials for construction (complements or aggregates)	Sisal Sugar cane wastes (food industry - industry waste) Corn wastes (food industry - industry waste) Rice shells (food industry - industry waste) Chesnutt shells (food industry - industry waste)

In terms of layout and housing disposition, the service areas (cooking area and sanitary facility) are located outside or, in severe cases do not exist. This option results, mostly, from two main reasons: the sanitary facilities are located outside due health concerns associated to absence of sewage infrastructure and are commonly attached to a septic tank; the cooking area is far from housing walls due fire risk but mainly because of the heating produced by a cooker or fireplace that compromises indoor thermal comfort.

The four countries mentioned above were also studied in terms of legal requirements related to buildings in order to constitute dimensional standards for housing:

- General Regulation for Construction and Urban Housing of Cape Verde (RGCHU) – Official Bulletin of 28th February of 2011;
- General Regulation of Urban Buildings of Angola (RGEU) – Executive Decree n°13/07 of 26th February of 2007;
- General Regulation of Urban Buildings of Mozambique (RGEU) – Legal Diploma n°1976 in Official Bulletin n°19, 1st series of 1st May of 1960;
- General Regulation of Urban Buildings of Guinea-Bissau (RGEU) – Decree n° 1228 in Official Bulletin n°13 of 28th March of 1960.

The above-mentioned legislation was the only found so far in these territories. However, local entities have informed that the current new buildings are also applying legal requirements from Portugal and South Africa (this last is significant in Mozambique).

The consideration of these parameters ensures quality and functional requirements, namely in terms of health, thermal comfort and fitness-for-use criteria, performing a main basis for module dimensioning and marking the minimum standards. The following table presents the legislation survey related to social housing in focus territories.

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Table 2. Legal requirements for a two-bed social house.

Country	Floor height [m]	Bedroom area [m ²]	Living room area [m ²]	Kitchen area [m ²]	Sanitary installation area [m ²]	Fenestration area [m ²]	Total area - two bedroom [m ²]
Cape Verde	2,6	10,5	14	6,5	4,5	1	52
Angola	2,8	10,5	10	6	-	1,08	52
Mozambique	2,8	9	12	-	-	1	-
Guinea-Bissau	2,8	9	12	-	-	1	-

Transportation parameters were also considered in order to provide an efficient and sustainable operation for the module implementation in different geographies. Thus, it was considered a sea container High Cuba 40' with 12,36m in length, 2,34m in width and 2,68m in height.

The studied criteria performed the parametric elements for optimal module dimensioning.

Module dimensional parameters

It is important to primarily refer the concern about the module structural function, besides its optimal dimensions or characteristics. However, this structural efficiency must be also related to economic and environmental aspects. In order to provide a durable and structural solution, the module is made in concrete. Through this option it is possible to ensure structural safety, identify as one of the main problems in precarious housing, and durability in order to reduce maintenance costs. The selected components materials for the module are commonly used in current constructions and as such, are easily available and affordable: concrete C25/30 or C30/37; structure class A500, type NQ50; steel profiles class S280GD+Z, U shape.



Figure 2. Standard concrete sample of the module.

However, it is recognized that use of concrete has several environmental impacts (that must be articulated, although, with its durability) due embodied energy of cement ¹³. In order to reduced this impacts, several tests were develop, namely by adding earth (soil) to concrete mixture, in an attempt to reduce cement percentage. The tests showed physical and mechanical behavior of several samples with different cement/soil percentages, comparing to current concrete with cement aggregates.

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Figure 3. Module composed sample type A 1:3:1 (cement; earth; gravel).

The module optimization in terms of dimension and characteristics was achieved due a parametric framework that interacts the previously mentioned variables. These variables are related to sustainability principles, focusing in low-cost housing, namely social, economic and environmental aspects. All these parametric elements have direct impacts in these fields:

- Minimum legal requirements for housing, that integrates the minimum areas for dwellers, room areas, floor height and fenestration width will provide a minimum level of quality, ensuring article 25 from Human Rights: “(...) everyone has the right to a standard of living adequate for the health and well-being of himself and his family.”¹⁴ This parameter is directly associated to social aspects by providing decent housing to the poorer but also to economic and environmental aspects: economically, the adoption of minimum areas reduces housing construction and thus its costs, making it affordable; environmentally, the implementation of minimum areas able to serve human activities (“(...) the minimum of space, air, light and heat necessary to men for developing their own vital functions without restrictions due the lodging.”¹⁵), shows a concern about resource management (no wasted space).
- Assemblage is a decisive parameter for assisted self-construction, which has also direct impacts in terms of social, economic and environmental premises. Besides of being a natural capacity of informal settlements population, building their own houses with technical guidance provide sense of community and social cohesion that is fundamental for low-income population development. Assisted self-construction also improves community skills and capacities, increasing the possibility to acquire a formal job later. In economic terms, this process naturally reduces costs by using local labour instead of specialized imported workforce. Environmentally, it reduces energy consumption by using mostly human labour rather than machinery.
- The optimization of the number of module’s joints and connectors has direct impacts in construction costs but also in resource management, namely the quantity of material used (specially considering metallic connectors that show high levels of embodied energy).
- At last, transportation requirements are fundamental to reduce housing costs and energy consumption by optimization of export procedures (the transportation of a larger quantity of modules in less trips).

This framework defined the set that compound the standard modular solution, constituted by three variants: wall module, window module and door module.

Thus, methodology considered the following parametric elements that result in several dimensional options (Figure 4).

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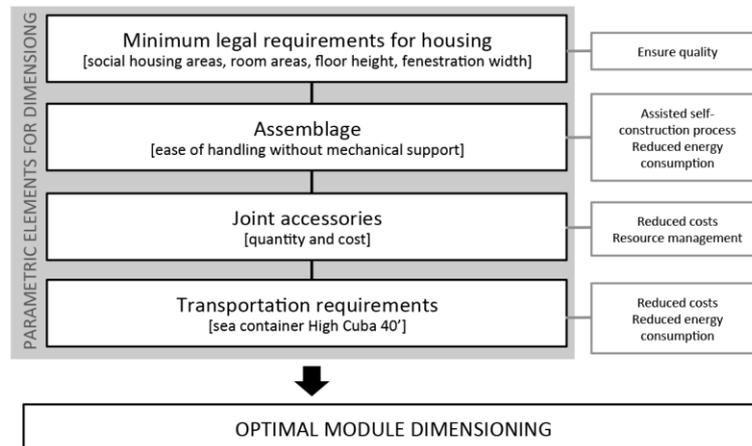


Figure 4. Parametric framework for module dimensioning.

The first task was the definition the minimum legal requirements by considering the most conservative values. This will enable the module application in all four studied countries, ensure official quality levels and also respect legal mandatory issues (Table 3).

Table 3. Minimum dimensions for two-bed housing.

Floor height [m]	Bedroom area [m ²]	Living room area [m ²]	Kitchen area [m ²]	Sanitary installation area [m ²]	Fenestration width [m]	Total area - two bedroom [m ²]
2,8	10,5	14	6,5	4,5	0,90	52

Through definition of minimum standards it was calculated the module height with 2,8m, according to the minimum floor height required. The module width resulted from assemblage considerations (ease of handling by user within an assisted self-construction process). Thus, eleven possible widths were selected and combined into a score method that considers: module width; number of modules in x and y (room sides), resulted dimension of x and y; resulted room area; number of joints needed to perform the room; final score considering economic and environmental premises (*Figure*).

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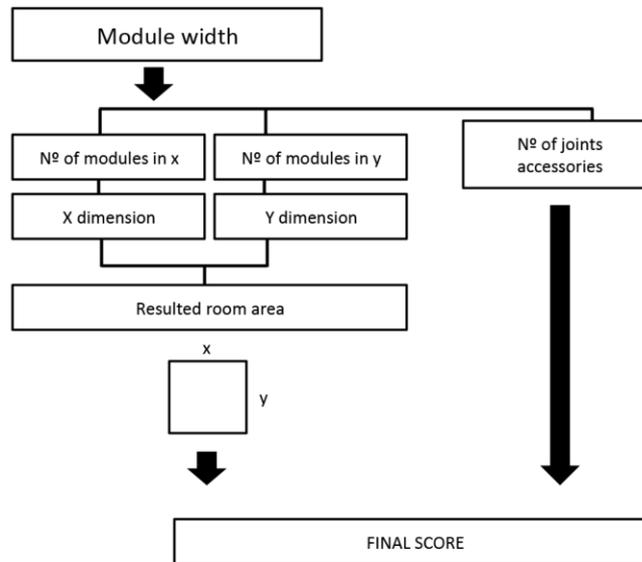


Figure 5. Score methodology for optimal module.

The following tables 4-7 present the score methodology for each room.

Table 4. Score table for bedroom: module optimization.

Module width [m]	Nº of modules in x	Nº of modules in y	X dimension [m]	Y dimension [m]	Resulted room area [m]	Nº joint accessories	Score
0,5	6	7	3	3,5	10,5	26	11
0,6	5	6	3	3,6	10,8	22	10
0,7	5	5	3,5	3,5	12,25	20	7
0,8	4	5	3,2	4	12,8	18	6
0,9	4	4	3,6	3,6	12,96	16	4
1,0	3	4	3	4	12	14	8
1,1	3	3	3,3	3,3	10,89	12	9
1,2	3	3	3,6	3,6	12,96	12	5
1,3	3	3	3,9	3,9	15,21	12	1
1,4	2	3	2,8	4,2	11,76	10	3
1,5	2	3	3	4,5	13,5	10	2

Table 5. Score table for living room: module optimization.

Module width [m]	Nº of modules in x	Nº of modules in y	X dimension [m]	Y dimension [m]	Resulted room area [m]	Nº joint accessories	Score
0,5	7	8	3,5	4	14	30	11
0,6	6	7	3,6	4,2	15,12	26	8
0,7	5	6	3,5	4,2	14,7	22	9

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0,8	5	5	4	4	16	20	5
0,9	4	5	3,6	4,5	16,2	18	4
1,0	4	4	4	4	16	16	6
1,1	3	4	3,3	4,4	14,52	14	10
1,2	3	4	3,6	4,8	17,28	14	3
1,3	3	3	3,9	3,9	15,21	12	7
1,4	3	3	4,2	4,2	17,64	12	2
1,5	3	3	4,5	4,5	20,25	12	1

Table 6. Score table for kitchen: module optimization.

Module width [m]	N° of modules in x	N° of modules in y	X dimension [m]	Y dimension [m]	Resulted room area [m]	N° joint accessories	Score
0,5	5	6	2,5	3	7,5	22	8
0,6	4	5	2,4	3	7,2	18	10
0,7	4	4	2,8	2,8	7,84	16	4
0,8	3	4	2,4	3,2	7,68	14	6
0,9	3	3	3,2	2,7	7,29	12	7
1,0	2	3	3	3	9	12	2
1,1	2	3	2,2	3,3	7,26	10	9
1,2	2	3	2,4	3,6	8,64	10	3
1,3	2	2	2,6	2,6	6,76	8	11
1,4	2	2	2,8	2,8	7,84	8	5
1,5	2	2	3	3	9	8	1

Table 7. Score table for sanitary installation: module optimization.

Module width [m]	N° of modules in x	N° of modules in y	X dimension [m]	Y dimension [m]	Resulted room area [m]	N° joint accessories	Score
0,5	4	5	2	2,5	5	18	9
0,6	4	4	2,4	2,4	5,76	16	6
0,7	3	4	2,1	2,8	5,88	14	5
0,8	3	3	2,4	2,4	5,76	12	7
0,9	2	3	1,8	2,7	4,86	10	10
1,0	2	3	2	3	6	10	4
1,1	2	2	2,2	2,2	4,84	8	11
1,2	2	2	2,4	2,4	5,76	8	8
1,3	2	2	2,6	2,6	6,76	8	3
1,4	2	2	2,8	2,8	7,84	8	2
1,5	2	2	3	3	9	8	1

The score criteria was based efficiency and cost degree i.e. the maximum score was attributed to modules that perform the nearest resulted area to minimum dimensions defined in **Table 3** and thus the most efficient dimension in terms of costs. In different modules cases width achieve equal areas,

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the option that shows less joint accessories was preferable i.e. got higher score. The optimal module was achieved through a comparison between the scores of the different module width per room (**Table 8**).

Table 8. Score table for kitchen: module optimization.

Module width	Score for width of each room				Σ score	Rank
	Bedroom	Living room	Kitchen	Sanitary Installation		
0,5	11	11	8	9	39	2°
0,6	10	8	10	6	34	3°
0,7	7	9	4	5	25	5°
0,8	6	5	6	7	24	6°
0,9	4	4	7	10	25	4°
1,0	8	6	2	4	20	8°
1,1	9	10	9	11	39	1°
1,2	5	3	3	8	19	9°
1,3	1	7	11	3	22	7°
1,4	3	2	5	2	12	10°
1,5	2	1	1	1	5	11°

Table 8 shows that 1,1m module had the best performance according to the parametric framework: achieve the minimum housing areas through a balance between assemblage, modules quantity and number of accessories needed. This dimension enables the incorporation of windows (variant B and C) and doors (variant C) according to the current standards, performing the three variants mentioned above (**Figure 3**).

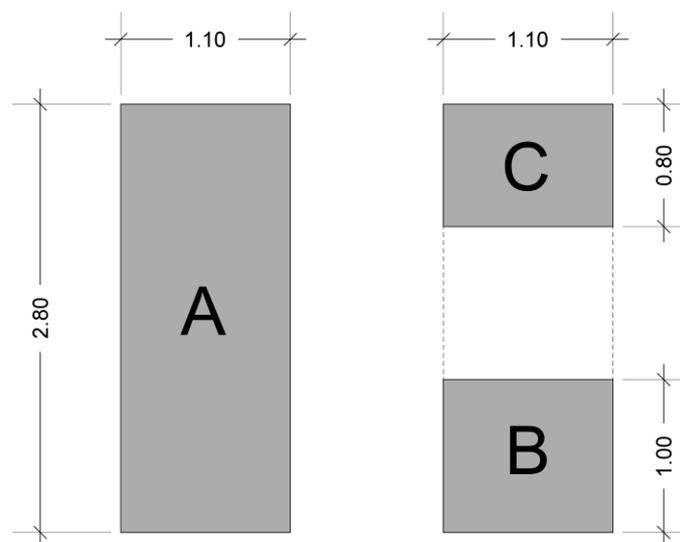


Figure 3. Optimal module dimension (m) and its variants.

The selected module shows also a good performance according to transportation parameters. Considering the sea containers High Cuba 40', it is possible to transport four modules rows in length. However, the quantification of modules to transportation depends also from module thickness. This was calculated through its mechanical resistance considering the layer that covers the module internal

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structure. Thus, knowing that the distance between this internal structured and the cover layer should not be less than 3cm, the required minimum thickness was fixed in 7cm. In order to validate these values, several simulations were made. Another issue to be considered was the section asymmetry: the module thickness is displaced from its centre in order to allow the application of complemented materials *in situ*, making the module strictly structural (**Error! Reference source not found.**). These metallic profiles, in U shape, with 100mm x 50mm x 3mm and it is place in the middle of the module, leaving 65mm for complemented covering material. Thereby, these structural metallic profiles have simultaneously the function to provide the connection between modules but also between modules and complemented materials.

This modular solutions enables flexibility in housing layout, namely through expansion and retraction possibilities, because all the connections and joints work mechanically and are able to be easily handle by occupants in an assisted self-construction perspective. Within this solution, and considering the African household dynamic and tendency to incremental informal processes, it is possible to provide a housing core that provides shelter and the main infrastructures, able to be evolved according to occupants' needs and financial capacity.

Module local adjustment

The local adjustment is achieved through complemented local materials. The module provides a universal solution that is subject to an adequacy procedure through finishes and coverings made with local materials and built *in situ*, in an assisted self-construction context. The material selection is provided by first stage referring to context analysis where available and commonly used materials are identified. The main principles for materials selection are economic viability, social/cultural adequacy and low environmental impact. Thereby, the module is complemented with local and durable materials that address the following advantages:

- Contribution to local economy by providing employment and stimulate local material enterprises and local craftsmen ¹⁶;
- Propitiate social/cultural adequacy through the application of local architectural imagery, reinforcing collective identity and social cohesion;
- Reduces environmental impacts due less harmful emissions associated to transport and production.

Due the context analysis, the present research considers the application of earth blocks masonry – compressed earth blocks (CEB) - as external covering and wallpaper as internal finish.

According to the housing stock analysis previously made, earth blocks are commonly used within the four case studies and meet premises of economical viability and cultural expression. They can be seen in vernacular architecture and show a good thermal and durability performance besides being an abundant raw material and thus adequate to social housing solutions. Its natural and ecological proprieties and manufacture processes demonstrate low embodied energy (energy consumption in whole process, including transport and production) but, most important, provides an important contribution to thermal comfort ¹⁷.

This last aspect is important to refer i.e. energy efficient housing represent less energy costs as well as less energy consumption for cooling and ventilation, which directly reverts to household budget. In this context, several tests were made to a set of samples with different compositions in order to assess the best solution. The samples were produced with different types of soils and additions, namely low percentages of mineral binders as cement or hydraulic lime, construction and demolition wastes

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(CDW) and other types of non-dangerous wastes, giving a new usage to these types of materials. They were also cured through different manners, which have consequences in durability and thermal performance.

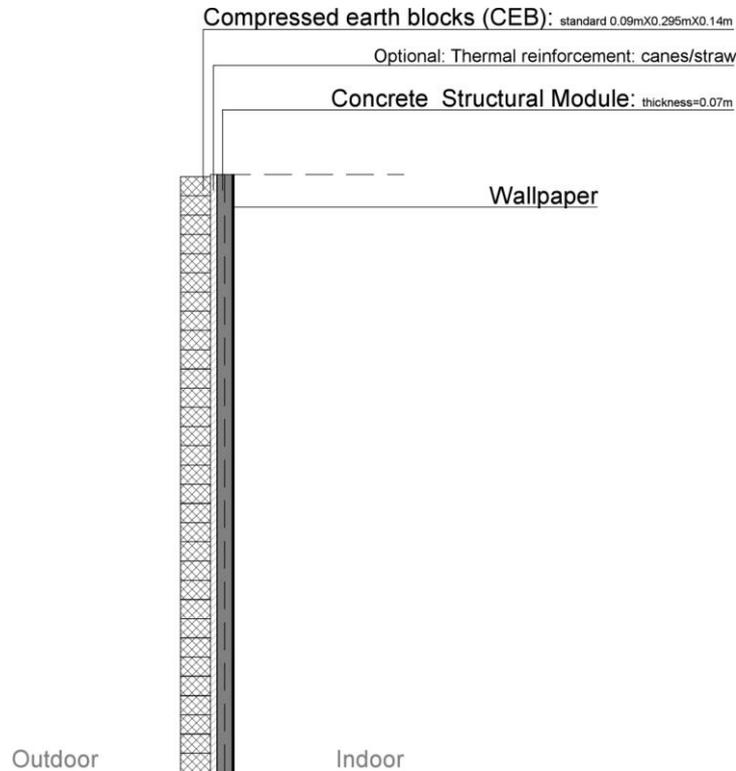


Figure 7. Solution section.

The tested samples used soil from different geographies in order to compare and analyze the different properties according to different type of soil. These samples were subject to the current standard tests and procedures: tensile strength; compressive strength; resistance to wear by dry abrasion; water abrasion resistance; dimensional stability to temperature variations and relative humidity; water absorption by low pressure; water absorption by capillarity; and drying capacity¹⁸.

Aiming the thermal improvement of the complemented solution module, the application of an extra layer between CEB masonry and the structural module in concrete was considered. Once more, the housing stock analysis provided available materials for this purpose, namely the possibility to implement a straw or canes layer as a thermal reinforcement.

For internal finish, the research aimed the application of a low-cost ecological material that would not compromise housing affordability. Thus, it is proposed the application of recycled wallpaper composed by agricultural wastes that can be produced locally and also improve wallpaper blending aggregation and its mechanical performance. However, the paper production should be supported by reforestation strategy i.e. paper production needs to be supported by production forests. If so, paper becomes an inexhaustible raw material and thus, economically viable and environmental adequate.

However, the sustainability of wallpaper should also considers not only the blending itself but also its application in inner walls where glue, pastes or another kind of chemicals are commonly used which can compromised its sustainable and ecological aspect. These chemicals are usually present in binders,

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glues and pigments, invalidating, in some cases, paper recycling process and generating harmful emissions not only for environment but also for inhabitants.

In order to provide a full recycling process and improve the ecological premises for the solution, it is proposed a natural-based glue made with wood pulp and water – *Methyl Cellulose*. Apart from being a organic compost, this component does not present health risk nor environmental threats i.e. it is non-allergic and non-toxic ¹⁹. *Methyl Cellulose* is a natural powder that dissolves in cold water (between 40°C and 50°C) and get adhesive properties, which means that does not required much energy consumption for its production and thus, less associated costs. Besides its adhesive properties, this material is also an emulsifier that can be added to paper blending, improving its water absorption resistance ²⁰.

CONCLUSIONS

The fast development, population growth and consequent slum formation and expansion in developing countries calls for an urgent solution for housing that should be integrated in a social, economical and environmental long-term strategy. The research presents a possible solution for housing deficit in developing countries that simultaneously contributes for sustainable development. The research focused in four case studies - Angola, Cape Verde, Mozambique and Guinea-Bissau. Therefore, a housing stock analysis and the identification of legislation related to buildings were made in order to identify needs, potentials, opportunities and quality standards.

The methodology refers to a framework for the calculation of an optimal module for social housing supported by parametric elements such as the legal requirements related to housing, assemblage premises, number of accessories needed and transportation conditions. All these parametric elements are directly related to social, economic and environmental factors. Through a score method it was possible to compare several possibilities and thereby support the best option for module dimension.

The combination of parametric elements resulted into a structural module with 1,1m in width, 2,8m in height and 0,07m in thickness, able to be complemented with local materials *in situ*. The selected materials resulted not only from the housing stock analysis of each country but also from ecological premises. Thus, the research showed the potential of CEB as external covering and wallpaper as internal covering. For the first, there were made samples with different soils types and aggregates that were subject to a set of standard test in order to achieve the better solution. The local adjustment through natural and locally produced materials shows almost no transportation efforts and low embodied energy, presenting economic and environmental benefits. It has also socially consequences through the creation of housing whose imagery is associated to community identify, making it easier its acceptance by population within a (re) housing context.

In order to support the wall thermal performance, several tests will be made through software simulations in the next phase. Further research will also consider life cycle analysis (LCA) of wall components (concrete module, CEB and wallpaper) within a Cradle-to-Grave scheme (impacts from raw material extraction to recycling/disposal). Both approaches will validate the environmental component but also economic aspects namely due thermal performance.

The modular solution aims its application within an incremental housing process supported by assisted self-construction, compatible with the population culture and knowledge, which performs an affordable approach to (re) housing in developing countries.

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ENDNOTES

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 - ² John Beardsley, “A Billion Slum Dwellers and Counting” *Harvard Design Magazine*, 2007.
 - ³ United Nations, “*Millennium Development Goals 2014*” (New York: United Nations, 2014).
 - ⁴ Mike Davis, *Planet of Slums*, 1st ed. (New York: Verso, 2006).
 - ⁵ United Nations, “*Millennium Development Goals 2014*” (New York: United Nations, 2014).
 - ⁶ Lejone John Ntema, “Self-Help Housing Policy in South Africa: Paradigms, Policy and Practice” (PhD Thesis, University of Free State, 2011).
 - ⁷ Edmundo Werna, “Shelter, Employment and the Informal City in the Context of the Present Economic Scene: Implications for Participatory Government,” *Habitat International* 25, no. 2 (2001): 209–27.
 - ⁸ Melanie Stallen and Yves Chabannes, “Potentials of Prefabrication for Self-Help and Mutual-Aid Housing in Developing Countries,” *Habitat International* 18, no. 2 (1994): 13–39.
 - ⁹ *Ibid.*
 - ¹⁰ Ntema, Lejone John. “Self-Help Housing Policy in South Africa: Paradigms, Policy and Practice.” PhD Thesis, University of Free State, 2011.
 - ¹¹ Margarita Greene and Eduardo Rojas, “Incremental Construction: A Strategy to Facilitate Access to Housing,” *Environment and Urbanization* 20, no. 1 (April 1, 2008): 89–108.
 - ¹² Wijitbusaba Ann Marome and Supreede Rittironk, “Thai Incremental Housing Experience,” in *Global University Consortium: Exploring Incremental Housing* (5th UN World Urban Forum, Rio de Janeiro: UN-HABITAT, 2010).
 - ¹³ Paulina Faria et al., “Caracterização de Betão Com Terra Para Aplicação Em Construção Modular Prefabricada,” in *2º CIHEL - Congresso Internacional Da Habitação No Espaço Lusófono (2º CIHEL - Congresso Internacional da Habitação no Espaço Lusófono, Lisboa, 2013)*.
 - ¹⁴ UN-HABITAT, “The Right to Adequate Housing” (Geneva: UN-HABITAT, n.d.).
 - ¹⁵ Marco Giorgio Bevilacqua, “Alexander Klein and the Existenzminimum: A ‘Scientific’ Approach to Design Techniques,” *Nexus Network Journal* 13, no. 2 (2011): 297–313.
 - ¹⁶ Werna, Edmundo. “Shelter, Employment and the Informal City in the Context of the Present Economic Scene: Implications for Participatory Government.” *Habitat International* 25, no. 2 (2001): 209–27.
 - ¹⁷ Fernando Pacheco Torgal and Said Jalali, “Earth Construction: Lessons from the Past for Future Eco-Efficient Construction,” *Construction and Building Materials* 29 (2012): 512–19.
 - ¹⁸ Miguel Amado et al., “Eco-Wall Modular Solutions for Buildings,” in *9th International Mansory Conference 2014 (9th International Mansory Conference 2014, Guimarães, 2014)*.
 - ¹⁹ José A. Rabi et al., “Agricultural Wastes as Building Materials: Properties, Performance and Applications,” *Nova Science Publishers, Inc*, 2009;
 - ²⁰ Dhani Bogati, “Cellulose Based Biochemicals” (Bachelor Thesis, Saimaa University of Applied Sciences, 2011).

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