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Construction Technologies for Sustainable Affordable Housing within Fragile Contexts: Proposal of a Decision Support Tool

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Abstract: The topic of sustainable affordable housing in developing countries is gaining increasing importance within international debates. The challenge is to find a balance between the concepts of sustainability and affordability in building construction within fragile contexts, overcoming basic self-made shelter solutions towards the creation of sustainable durable housing. In particular, concerning the selection of constructive technological solutions, the goal is to shift from the current decision-making process based only on economic factors to a more holistic approach based on a triple bottom line perspective, integrating economic, environmental and social sustainability. With this aim, this paper proposes a decisional support tool for contexts characterized by poor information to sustain decision-makers in identifying suitable technological solutions. The tool is based on a set of key indicators, articulated into the three pillars of sustainability. The proposed tool, conceived as scalable and replicable, is finally applied to the specific context of Mogadishu (Somalia), since it is representative of the uncertain social, political and economic nature of fragile contexts.

Keywords: sustainable housing; affordable housing; East Africa; decisional support tool; construction technologies

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1. Introduction

Over recent years, sustainable affordable housing has been at the core of international debates, especially with regard to developing countries. Today, this topic still represents an open issue that is faced by several bottom-up and bottom-down projects and initiatives dealing with housing sustainability and affordability. The present paper is part of one of these projects, namely, BECOMe, "Business ECOsystem design for sustainable settlements in Mogadishu: affordable housing, local entrepreneurship and social facilities", a two-year project funded by the PoliSocial Award 2018 and developed at Politecnico di Milano by an interdisciplinary research team, including experts in architectural technology, urban planning, technical physics and management engineering. The project also involves contracts with local experts, such as engineers, architects and construction companies, and it has been supported by a constant and continuous relationship with the University of Mogadishu. The focus is the analysis of the dynamic and fragile Somali context and its housing sector with the aim to mitigate the risk of the occurrence of accelerated growth, proposing alternative models in line with the Sustainable Development Goals [1] promoted by the United Nations in the 2030 Agenda (e.g., Goal 1—end of poverty; Goal 3—good health and well-being; Goal 7—affordable and clean energy; Goal 11—sustainable cities in communities). In particular, the goal is to deliver an integrated development plan for a new business ecosystem design model oriented towards new sustainable settlements in Mogadishu (Somalia), involving local entrepreneurship, social facilities and renewable energies. Going beyond basic shelters, the challenge is to build a social community and create sustainable durable settlements in a context such as Mogadishu, which is characterized by fragile and uncertain social, political and economic backgrounds. Indeed, access to adequate and affordable housing is a key and increasing problem in developing countries such as Somalia, given the high urbanization rate of households [2] and the large share of the population that currently lives in slums or partially destroyed buildings [3]. This housing emergency is determined by the overlap of multiple factors: the intense growth of the population, the high levels of poverty, the destruction of building stock caused by civil war, the displacement of the population and the insecurity in conflict areas. Nowadays, poverty affects about 61% of the population, and the per capita income is only USD 435 [3]. The concurrence of these factors actually results in sudden and uncontrolled growth with consequent risks of speculation as well as purely economic strategies that fail to take into account social and environmental sustainability aspects. To encourage the stability of the country, the main need is to promote construction housing programs designed to build durable neighborhoods and not temporary camps [3], commonly characterized by accommodations of poor standards with little consideration of inhabitants' well-being and livelihood. New construction development plans have to be conceived not only to provide adequate housing but also to reduce the high carbon footprint and negative environment impacts derived from rapid and unplanned urban development. In fact, urban settlements in Somalia significantly fall short of the Millennium Development Goals relating to shelter, water and sanitation topics [1]. In this context, the provision of adequate and affordable housing remains a key priority [4]. Concerning housing design and construction, one of the major weaknesses lies in the fact that in such fragile contexts as that of Mogadishu, decision-makers often only take into consideration economic issues when choosing constructive technological solutions. However, due to the peculiar dynamic nature of fragile contexts, it is crucial to ground such decisions by adopting a more holistic and systemic approach, which, aside from economic sustainability, includes environmental and social sustainability, thus stressing a triple bottom line perspective. For this reason, particular attention has been paid to social, commercial and productive issues in relation to the specific vocations of the territory, performing field surveys through dialogue with local stakeholders (political, business and research subjects) and the enrolment of local practitioners.

In particular, this paper focuses on construction technologies, and it proposes—as one of the results of the BECOMe project—a decisional support tool for contexts characterized by poor information to sustain decision-makers in the choice of the most suitable technological solutions according to a multicriteria analysis. This tool aims to seek a balance between sustainability and affordability when dealing with the selection of construction technologies, involving both direct and indirect beneficiaries. In particular, direct beneficiaries are all stakeholders of the AEC sector, such as construction and manufacturing firms, SMEs, medium and small social cooperatives, developers, architects, engineers, policymakers and institutions. Indirect beneficiaries are the citizens, including displaced people, the middle and lower classes—as they are the end users of the sustainable affordable housing—and workers looking for new job opportunities in the field of sustainability construction.

2. Construction Sector in Somalia: Features and Needs

Somalia and, in particular, the city of Mogadishu represent a very dynamic context with respect to manufacturing and construction practices. They are now witnessing increasing growth in the construction industry, to the extent that new construction projects are expected to be increasingly in demand in the coming years [5]. With the aim to allow the construction industry to contribute toward the economic and social growth as well as the sustainable development processes of the country, it is essential to gain insight into both the manufacturing and construction sectors, analyzing their main features, dynamics, processes, activities and involved stakeholders and highlighting their main weaknesses and strengths.

In examining the manufacturing sector of Mogadishu [3,4,6], it is possible to highlight two main issues: (i) the geographic origin of materials, components and products and (ii) their quality and variety. Indeed, Mogadishu is more and more interested in increasing its supply of imported building materials (mainly from China, Turkey, the UAE and India), which limits the growth of local manufacturing production [7,8]. This addresses the majority of construction materials, including cement, concrete, steel, wood and ceramic, that are imported from foreign countries through international trade routes [7,8]. According to both the Observatory of Economic Complexity and International Trade Center data, in Somalia, the largest share of imports dedicated to construction materials consists of metal (USD ~110 M) and cement (USD ~30 M) [9,10]. Metal turns out to be imported from China, India and the UAE, while cement and concrete are imported from Oman, Iran and the UAE [9,10]. Even the amount of imported ceramics and wood is noticeable and derived primarily from China and the Middle East [9,10]. In addition, the market of finishing components, such as tiles, windows, doors, plumbing and sanitary, appears to be covered only by international trade without any evidence of local production, despite the fact that these particularly affect the final price of buildings. Moreover, an evident critical issue is that the majority of imported construction products, components and materials provide a reduced variety of choice and poor quality in favor of an easy supply chain and, above all, very low and competitive costs, which encourage their widespread use. In this context, it is possible to emphasize two main emerging needs: on one hand, the promotion of local production of building components, together with the identification of drivers for investments in local manufacturing and, on the other hand, an increase in awareness of building quality among the involved local stakeholders.

With respect to the Somali construction sector, analysis of the current construction market highlights the presence of more than 20 construction firms that are now active in the territory. In particular, surveying construction firms operating in Mogadishu, it is possible to identify different typologies of construction companies: small local firms, medium local firms and international medium firms based on a joint venture model (e.g., groups of companies based on foreign management and headquarters but using a local workforce), which differ in terms of the involvement of foreign companies, number of employees, average annual turnover and geographic area of the market.

Concerning construction procedures and methods, medium-size firms in Mogadishu employ both ready-to-use materials imported to Somalia and on-site production materials for basic building components (i.e., concrete blocks and concrete load-bearing structures). This is achieved either by using manual or semi-automated machinery. On the contrary, local firms install imported building materials (from China or India), but they use fully manual procedures for building material production. It has also been observed that semi-advanced construction types of machinery (excavators, telehandlers, bulldozers, etc.) exist in Somalia, specifically in Mogadishu; however, they require skilled laborers, craftsmen and technicians whose level of experience must be carefully evaluated in the field. In summary, it is possible to state that the three existing typologies of construction companies, although different in terms of construction methods (manual or semi-automated) and origin (local or international), demonstrate good production and construction skills, even if not supported by information tools aiming at finding more appropriate and sustainable organizational models and processes. Indeed, in order to increase the knowledge and know-how of construction operators and reach a better quality and sustainability of construction solutions, proper information tools are increasingly necessary.

3. Current Technological Solutions: Limitations and Perspectives

Interviews, questionnaires and focus groups with local construction companies were carried out in order to gain insights on construction technologies, commonly used products and materials, supply chain configurations, building site organization, construction machineries and employed workforce. The interviewed companies also made a set of documents available, including images of construction phases and construction techniques as well as bills of quantities of settled projects. As a result, the use of very simple technological solutions emerged, mainly based on basic concrete blocks for walls, concrete structures for columns/beams and wood frames with metal sheets for roofs (Table 1). Among these, the key construction technology is the concrete masonry unit (CMU), namely, a standard-size rectangular concrete block, widely adopted since it is simple and versatile in defining all shapes and size [11]. Concrete blocks are made from cast concrete, composed of Portland cement and aggregate (usually sand and fine gravel) for high-density blocks, while including industrial wastes (such as fly ash or bottom ash) as an aggregate for lower-density blocks [12]. Concrete masonry walls are built, as appropriate, un-grouted, partially grouted or fully grouted for enhancing their structural strength. Additionally, steel reinforcement bars (rebar) are used both vertically and horizontally inside CMU walls to maximize the structural performance, and grouting cells with rebars are used for enabling their bond to the wall [13]. The use of blockwork allows building structures in the traditional masonry style with layers of staggered concrete blocks, usually manufactured with hollow cores for reducing weight or improving insulation. Currently, CMU is mainly produced manually using compressing machines. Typically, cement is mixed with coarse sand and gravel with the ratio of 1:2:3, respectively, for the casting part [12]. Casts are fully filled with the concrete created on site and compressed using the machine. After compression, pieces of flat wood are placed under the concrete blocks as a support, allowing the operators to set them down (preferably under the sun) in order to let the blocks dry out for about 2 days. Afterwards, blocks are kept wet in order to provide enough compressive strength [12].

Table 1. Current construction technologies articulated according to building sub-systems. Source: interviews with local construction companies.

System	Sub-System	Description
Sub-structure	Foundations	Grade beams with concrete class M25 and steel bars (diam. 9 mm). Wooden formwork (25 mm thick). Plinth with concrete class M25 and steel bars (diam. 9 mm). Wooden formwork (25 mm thick).
Shell	Slabs-on-Grade	Concrete slab with concrete class M25 and steel bars (diam. 9 mm). Wooden formwork (25 mm thick). Finishing in ceramic tile flooring.
	Non-Structural Exterior Walls	Pillars in structural concrete (with steel bars of 9 mm diameter) and non-structural walls in concrete hollow blocks (400L × 300H × 200S). Finishing in painting over a plaster of sand and cement.
	Structural Exterior Walls	Structural concrete hollow blocks (400L × 300H × 200S) reinforced with steel bars of 9 mm diameter. Finishing in painting over a plaster of sand and cement. Cement imported from China and Turkey.
	Exterior Windows	PVC profiles with single glass. Aluminum profiles with single glass.
	Exterior Doors	Aluminum-framed entrances.
	Roof Construction	Wood structure and aluminum corrugated sheet.
Interiors	Floor Construction	Concrete slab with concrete class M25 and steel bars (diam. 9 mm). Wooden formwork (25 mm thick). Finishing in ceramic tile flooring.
	Interior Partitions	Walls in concrete hollow blocks (400L × 300H × 200S). Finishing in painting over a plaster of sand and cement.
	Interior Doors	Hardwood timber (220L × 100H).
	Stairs	Stair structure with concrete class M25 and steel bars (diam. 9 mm). Wooden formwork (25 mm thick). Finishing in painting over a plaster of sand and cement.

The recurrent set of construction technologies was confirmed by a series of interviews with the construction companies, in which the economic dimension turns out to be the key driver for the selection of the lowest possible price solution. As a result, the standard technological solutions appear of poor quality and not appropriate for the local climate context. Indeed, construction companies often choose the cheapest solutions without taking into consideration the cost/benefit ratio in the assessment process of suitable technological solutions. Hence, the aim of the present paper is to propose a tool supporting the identification and choice of high-quality and low-price solutions, improving the variety of construction technologies towards more sustainable alternatives.

In particular, in recent years, alternative building technologies (ABTs) have been promoted by several contributions [14–16] in order to reduce construction costs (including shortened time for construction and thus labor reduction) and increase environmental sustainability (using the most sustainable materials, increasing the efficiency and quality of production processes, reducing waste, etc.), leading to affordable [3] and sustainable housing.

There are several classifications of ABTs in the literature [14–16]; however, the most suitable ones with respect to the specificity of the application context appear to be the following:

- High technology: processed materials, manufactured products or systems, industrialized production;
- Intermediate (or adapted conventional) technology: hybrid approaches that replace some conventional or high-technology materials and products used in construction (especially walling and roofing components) with recycled and/or other "found" materials;
- Low technology: traditional materials and usually owner-built methods (mostly used in rural settings, but often also "informal" peri-urban/urban areas).

The transition from low to high ABTs in developing countries or low-income cities such as Mogadishu is not an instantaneous process, and it requires significant efforts. Due to the fragile nature of such context, this transition must follow a gradual process of improvement and innovation. In particular, this paper proposes the following paradigm shifts as transition goals towards sustainable and affordable construction solutions:

- From imported to local raw materials;
- From manual to semi-automated or prefabricated construction;
- From "doing" to learning-by-doing and cross-fertilization (cooperation between firms).

Focusing on the first shift, according to National Master maps [17] on the presence of existing natural resources in Somalia, it is possible to observe that the country holds deposits of bauxite, copper, iron, kaolin, limestone, quartz, granite, silica, sandstone and sand [18,19]. Nevertheless, today, most of the mineral deposits still remain unexploited [10], and data on mineral production are not available, as a result of the lack of fully functioning central management. It is necessary to underline that this shift from imported to local raw materials implies the construction of new supply chain configurations which depend on the achievement of a greater awareness, the definition of new viable business strategies and the political will to activate training programs, financial support and marketing actions.

Regarding the second shift, there is the potential to implement automatic machineries [20–22], mainly imported from different countries with an average price that depends on the level of automation in operation and variation of possible materials (i.e., concrete, clay or soil) used for different types of blocks and panels. The machine specifications create various scenarios in terms of final product cost. Moreover, there is also the possibility of on-site production if quantity is resalable. Both on-site semi-automatic production machines [21] and factory automatic production machines [22] are currently used in local construction processes and could be improved by the strengthening of local commercial policies.

For what concerns the third shift, it is possible to mention recent international and national initiatives [1,2,23] that involve the opportunity of both cross-fertilization (collaboration and cooperation) among construction companies (local and not) and training of local workforce. These initiatives set the ground for the creation of solid partnerships among companies as well as the creation of joint ventures, improving skills and know-how and reaching competitive advantages.

The three paradigm shifts introduced above lay the foundations both for the identification of more sustainable alternative technological solutions (at competitive prices) and for the definition of a decision support tool that is able to take into account, in a holistic way, the issue of sustainability (not only economic but also environmental and social) useful for assisting stakeholders towards affordable and sustainable construction solutions.

4. A New Approach to Technological Solution Selection towards Sustainability and Affordability: Proposal of a Decision Support Tool

In order to allow the construction industry to contribute, in the near future, to economic and social growth and to the sustainable development of emerging countries, this paper proposes a support tool for the identification of the most appropriate technological and construction solutions. The goal is to shift from the current decision-making process related to the identification of suitable technological solutions that is often based only on economic factors towards a more "holistic" approach. From the field analysis, the need for a simplified qualitative tool to gain a wider awareness about the role of some fundamental sustainability key issues, consisting of basic indicators able to fill the gap over the limited availability of reliable quantitative data, emerged.

Over recent decades, several methodologies and tools were developed to perform sustainability assessment analyses, focusing on different scales (micro/macro), scopes (one or more pillars) and purposes [24–26]. Taking into consideration the current lack of information of the context, this research proposes a simplified tool based on a triple bottom line (TBL) approach [27–29]. The objective of the tool is to find a balance between the three pillars of sustainability and not to weigh the indicators in order to reach a final grade. The tool aims to support decision-makers in analyzing the performance of each solution with respect to the proposed indicators, without providing a direct quantitative comparison of grades. Moreover, it follows a principle of gradualism, being enriched over time in relation to new knowledge and information that will become available. The tool is based on a set of key indicators, articulated into the three pillars of sustainability (economic, environmental and social), assuming as a scope the technological solutions and the related underlying production, logistics and construction processes. According to this viewpoint, the selection of indicators takes advantage of in-depth reviews of the literature, business white papers and NGO reports [27,30–36]. The proposed set of indicators was validated by a panel of experts belonging, on one hand, to academia in the fields of technology of architecture, sustainable architecture, economics and management engineering and urban planning, and, on the other hand, to Italian and Somali practitioners, including architects and engineers, construction companies and trade associations and NGO representatives. Economic sustainability is conceived following a life cycle perspective, thus taking into account the whole building process, from the production phase to the end-of-life phase. All resulting indicators (Table 2) refer to costs of production (cost of raw materials, cost of production machineries, etc.), construction (cost of construction machineries, cost of labor for construction, cost of energy and utilities in construction, etc.) and building management (e.g., cost for maintenance and replacement processes). Besides costs, sell prices are also included as representative indicators, both in relation to the construction products available on the market and to the impact of technological innovation in terms of an increase in the final building sell price.

Table 2. Decision support tool for technological solution selection—set of indicators.

Pillar	Indicator	M.U.
Economic sustainability	Cost of raw materials	$
	Cost of production machineries	$
	Sell price of product	$
	Cost of material transport	$
	Cost of material storage site/s	$
	Cost of construction machineries	$
	Cost of labor for construction	$
	Cost of energy and utilities in construction	$
	Economic share of solution on building sell price	%
	Cost of procurement/distribution	$
	Cost for maintenance/replacement processes	$
Environmental sustainability	Use of local raw materials	%
	Use of natural raw materials	%
	Use of raw materials of fossil origin	%
	Emissions of production process (EPD)	CO_2
	Emissions for material transport	CO_2
	Recycled content of product	%
	Recyclability of product	%
	Presence of hazardous waste	%
	Durability of product	Years
Social sustainability	Involved local workforce in construction	n°
	Involved non-local workforce in construction	n°
	Diffusion of local workforce training programs	n°
	Cross-fertilization among construction companies	n°
	Spread of local market network	n°
	Local value creation for new technological solutions	%
	Social acceptability	%
	Health and safety in construction	%
	Employment opportunity	%

Environmental sustainability is also assessed along the entire building life cycle (Table 2), including product manufacturing (use of natural raw materials, emissions of production process, etc.), product in use (e.g., durability of product) and product end of life (recyclability of product, presence of hazardous waste, etc.).

Lastly, social sustainability involves indicators (Table 2) according to three main scales of increased levels of aggregation: workforce in construction (involvement of local/non-local workforce during construction, health and safety of operators, employment opportunity, etc.), construction companies (e.g., training and cross-fertilization among construction local/non-local companies) and network (spread of a local market network, social value and acceptability, etc.).

For what concerns the applicability of the proposed decision-making support tool, it is worth mentioning that it strictly depends on the set of information available to decision-makers. Indeed, in the case of information availability, all indicators are directly measured, expressing numeric values according to the representative unit of measurement. By contrast, in the application context of developing countries such as Somalia and, in particular, the city of Mogadishu, strongly characterized by a lack of information references and sources, the proposed tool needs to be adjusted both in quantitative terms, i.e., minimum number of representative indicators for each sustainability category, and in measurement terms, i.e., methods and criteria to evaluate indicators in the absence of data for assessing them in an alternative way.

This process of adjustment of the tool was supported and validated by the above-introduced panel of experts through periodic brainstorming sessions and focus groups. The involved stakeholders raised the need to narrow the set of indicators to a minimum number, not following the criterion of representativeness (namely, indicators selected based on their importance to define the sustainability categories) but in relation to their propensity to be estimated (namely, indicators selected based on the possibility to define a method for their qualitative assessment in the absence of quantitative data). In particular, the panel of experts was asked to select the indicators useful for the context of Mogadishu from the complete set, mainly taking into account their measurability. Consequently, the authors reviewed the set of selected indicators and their measurement methods in accordance with the experts' opinions.

To this end, three ranges (low, medium and high) were defined for the estimation of the selected indicators suitable for fragile and dynamic contexts, such as the one of Mogadishu. In addition to these three ranges, the involved stakeholders found it necessary to also include the option "no information" in order to stress the importance of missing information. Indeed, the absence of certain information may represent an alert for decision-makers, clearly showing how their choices could be based on a partial vision due to the presence of key missing information. Hence, the proposed tool highlights those crucial missing data that should be retrieved for making, in the near future, informed decisions on technological solutions from a triple bottom line perspective within vulnerable and emerging application contexts.

Below, an overview of the selected indicators for each sustainability pillar is provided along with methods and criteria for the description of the three qualitative ranges.

As regards economic sustainability (Table 3), the selected indicators total four. Two of them refer to the cost of machineries for production and construction, both assessed according to the degree of automation of the equipment used for building processes. Then, the cost of material transport is evaluated by the combination of the following factors: geographical distance between the production plant and the construction site, presence of consolidated market channel and infrastructure coverage. Lastly, the cost of labor for construction is derived from the arrangement of the timeframe of the construction process, the use of automated/manual machineries and the skills of the involved operators.

Table 3. Economic sustainability—indicators and assessment criteria.

Code	Indicator	Range	Description
EC1	Cost of production machineries	High cost	Fully automated complex equipment.
		Medium cost	Semi-automated equipment.
		Low cost	Manual equipment.
		No info	
EC2	Cost of material transport	High cost	Long distance (extra-continental) with new and unconsolidated trade channels; or short distance (Africa) but poor infrastructural coverage.
		Medium cost	Long distance (extra-continental) with consolidated trade channels.
		Low cost	Local materials (Somalia, Kenya, Ethiopia); short distance (Africa) with infrastructure coverage.

Table 3. *Cont.*

Code	Indicator	Range	Description
		No info	
EC3	Cost of construction machineries	High cost	Fully automated complex equipment.
		Medium cost	Semi-automated equipment.
		Low cost	Manual equipment.
		No info	
EC4	Cost of labor for construction	High cost	Construction process characterized by short timeframe, automated equipment and specialized workers at high hourly rate.
		Medium cost	Construction process characterized by medium timeframe, semi-automated equipment and non-expert workers at low hourly rate.
		Low cost	Construction process characterized by long timeframe, manual equipment and unskilled workers at low hourly rate.
		No info	

Environmental sustainability has four indicators (Table 4) related to the main features and properties of the technological solutions. They concern, for instance, the presence of local raw materials and the content of raw materials of fossil origin expressed as a share (entirely/partial/none) of the whole construction product. Another indicator involves the estimation of the emissions for product transport taking into account the combination between the distance and the means of transportation (via air/sea/road). Lastly, the end-of-life scenarios are also considered in relation to the recyclability of products (entirely/partially/not recyclable).

Table 4. Environmental sustainability—indicators and assessment criteria.

Code	Indicator	Range	Description
EN1	Use of local raw materials	Medium-high content	The solution consists entirely of local raw materials.
		Low-medium content	The solution is partially made up of local raw materials (only at component level).
		No content	The solution consists entirely of imported materials, without use of local raw materials.
		No info	
EN2	Use of raw materials of fossil origin	Medium-high content	The solution consists entirely of fossil origin materials.
		Low-medium content	The solution is partially made up of fossil origin materials (only at component level).
		No content	The solution does not contain fossil origin materials.
		No info	

Table 4. *Cont.*

Code	Indicator	Range	Description
EN3	Emissions for material transport	High emission	Long distance (extra-continental) and use of means of transport by sea/air and road.
		Medium emission	Medium distance (Africa) and use of means of transport by road.
		Low emission	Short distance (Somalia, Kenya, Ethiopia) and use of means of transport by road.
		No info	
EN4	Recyclability of product	Medium-high	The solution is potentially fully recyclable.
		Low-medium	The solution is partially recyclable (only at component level).
		No	The solution is not recyclable.
		No info	

Social sustainability includes four indicators (Table 5) able to assess the social development of the local building sector. The first indicator regards the number of local workforces involved in construction, and it is assessed by looking at the origin of the company (local or foreign). Another indicator concerns the diffusion of local workforce training programs, defined on the basis of the educational offer (courses and workshop/internship/none) aimed at enhancing labor skills. Moreover, the cross-fertilization among construction companies is evidenced as a key indicator, estimated by defining the level of cooperation and interaction among local and foreign companies (high and constant/limited and occasional/none). Finally, the last indicator regards the spreading of local market networks, assessed by looking at the localization and capillarity (local/national/none) of product sellers in the territory.

Table 5. Social sustainability—indicators and assessment criteria.

Code	Indicator	Range	Description
SO1	Involved local workforce in construction	Medium-high	Completely local workforce (Mogadishu construction companies).
		Low-medium	Limited number of local workforces collaborating with foreign companies.
		No	Completely non-local workforce (solution imported by foreign construction companies).
		No info	
SO2	Diffusion of local workforce training programs	Medium-high	Company offers academy with workshops, training courses, apprenticeship/internship, etc.
		Low-medium	Company offers apprenticeship/internship courses.
		No	Company does not offer training courses.
		No info	
SO3	Cross-fertilization among construction companies	Medium-high	Non-local company in collaboration with local companies for construction works.
		Low-medium	Non-local company with occasional collaboration with local workforce.

Table 5. *Cont.*

Code	Indicator	Range	Description
		No	Absence of cross-fertilization between companies.
		No info	
SO4	Spread of local market network	Medium-high	Product sellers in Somalia, Kenya and Ethiopia.
		Low-medium	Product sellers in Africa but not in Somalia, Kenya and Ethiopia.
		No	Lack of local sellers of materials/products/solutions.
		No info	

5. The Case of Mogadishu: Application of the Decision Support Tool to Identify Suitable Technological Solutions

Following the paradigm shifts introduced in Section 3 (from imported to local raw materials; from manual to semi-automated or prefabricated construction; from "doing" to learning-by-doing and cross-fertilization), a set of technological solutions suitable for the Mogadishu context was identified in performing an extensive and widespread analysis. This paper focuses on exterior walls by way of example; however, the proposed tool is extended to all the technological sub-systems (roof, floor, partitions, etc.). The identified exterior wall solutions include two main types: on one hand, block walls, i.e., concrete hollow block wall and compressed earth-stabilized block walls, and, on the other hand, panel walls, i.e., bamboo sandwich panels and concrete sandwich panels.

Concrete hollow block walls and bamboo sandwich panels are representative of the first paradigm shift. To date, cement is mostly imported from Turkey and China, while bamboo is imported from China. However, it is reasonable to envision the activation of a local supply chain, exploiting the resources already existing in the territory. Following this approach, the use of local cement and bamboo allows increasing local small-medium businesses, strengthening Somali supply chains.

Concrete sandwich panels with internal polystyrene represent the second shift, since they are partially constituted by prefabricated elements (e.g., EPS core and metal frame) and completed with concrete poured in situ through imported automated machineries. On one side, this solution considerably reduces the construction timeframe, resulting in being highly competitive in terms of construction costs that further decrease once consolidated trade channels are established. On the other side, taking advantage of prefabricated techniques, the solution limits the needed workforce, cutting down the number of workers with specialized skills, and highlights environmental sustainability issues in relation to some materials used in the process.

Compressed earth-stabilized block walls, as a result of cooperation between local and foreign companies, meet the third paradigm shift since, for their production and installation, cross-fertilization processes are involved.

An example of the application of the proposed tool is represented in Figure 1, focusing on concrete hollow blocks and bamboo sandwich panels (in this example, all the information is covered, so "no information" does not appear). The evaluation of the indicators is performed analyzing the solutions considering equal performances, in terms of thermal capacity, maintenance costs and lifespan. The product information and data needed to evaluate indicators are retrieved primarily from technical product sheets and online sources (website, reports, etc.) and, where appropriate, through interviews with manufacturers and construction companies. The resulting diagrams do not intend to define the best technological solution but only to provide, for each case, an overview of the indicator assessment according to the three pillars of sustainability. It supports, for each solution, the performance analysis with respect to the proposed indicators, without providing a direct quantitative comparison (no weights and no final grades are expected at this stage).

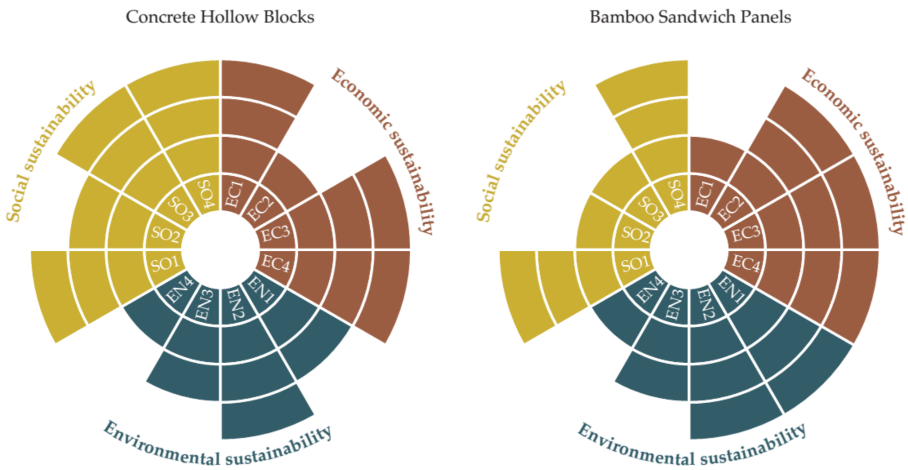

Figure 1. Example of application of the decision support tool to alternative technological solutions for Mogadishu—diagrams.

6. Conclusions

With reference to the selection of technological solutions, the proposed tool supports different stakeholders along the construction supply chain to reach a systemic vision based on a triple bottom line perspective. The goal is not to propose a theoretical and sophisticated model but to provide a simplified tool, extremely adherent both to the local specificities analyzed in the field and to the emerging needs raised from the dialogue with local stakeholders.

The tool, integrated within an IT system or alternatively developed as a simplified Excel file, addresses multiple stakeholders, including policymakers, designers, construction companies and clients. In particular, the tool assists policymakers in including topics such as environmental sustainability and social sustainability in current strategic development tools and plans, favoring the enhancement of local employment and business towards a more sustainable growth of the country by decreasing social disparities. The tool also sustains designers and construction companies by promoting the enlargement of their ranges of offered technological solutions, preferring local materials and inclusive approaches to building construction. Moreover, the tool highlights the key role of workforce training as an opportunity to increase the added value and competitive advantage of local companies. Lastly, the tool enables clients to increase their awareness on building constructive solutions by taking into account their effects, looking beyond the mere economic evaluation and pursuing a more holistic approach, also encompassing aspects such as product supply sustainability, environmental impacts of products and local employment.

Despite these benefits, it is possible to observe some weaknesses that need to be properly and carefully discussed and handled. First of all, it is worth mentioning that the proposed tool does not identify the best technological solution but has the sole purpose of opening the "black box" of the decision process, investigating the quality of the possible techniques and products from various points of view and according to various indicators. The final evaluation is in the hands of the decision-maker, and it depends on the priority attributed to each of the three pillars of sustainability and their related key indicators. It is essential to stress that the tool is not able to address a long-term perspective, not showing future potentialities of solutions in relation to the development of the socio-economic context. Moreover, it should not be underestimated that the tool is conditioned by the availability of information, and it follows a principle of gradualism, being enriched over time in relation to new available knowledge and information. In addition, its applicability and trustworthiness strongly depend on the specific features of the application context, seeking to include the complete set of indicators. To this end, a structured approach to information management is necessary to lay the foundations for integrating assessment with environmental and social issues.

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