Journal of Scientific Research & Reports
3(1): 17-96, 2014; Article no. JSRR.2014.002

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A Decision Support System for the Selection of Low-Cost Green Building Materials

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Authors' contributions

This work was carried out in collaboration between all authors. Author OCBI managed the literature searches, designed the study, performed the statistical analysis, wrote the protocol, and wrote the first draft of the manuscript. Author YJL supervised the analyses of the study. All authors read and approved the final manuscript.

Research Article

Received 7th July 2013
Accepted 15th September 2013
Published 9th October 2013

ABSTRACT

Background: For the past ten years, researchers have sought effective ways of exploring the possibilities of constructing homes more efficiently by using low-cost green building materials and components, as they produce less toxic waste and also perform very well in terms of cost and energy reduction in use, over their life cycle. Yet, despite these efforts and the benefits that associate their use, the patronage in housing construction appears to be relatively low when compared to conventional building products. The analysis of the literature study showed little evidence to justify the assumption that there are tools of demonstrable reliability for designers to assess the sustainability of such materials or their applicability and utility in the design of low-cost green housing projects. Nevertheless, questions remain regarding how designers should evaluate their relative impacts in the presence of multidimensional factors; hence underscores the need to investigate how informed decision-making in the material selection process could reduce decision-making failures, and encourage greater industry acceptance during the planning and design stage(s) of residential housing projects.

Aims: This article set(s) out to determine how the understanding of the principles of best practices associated with the impacts of low-cost green building materials could be improved to fulfill the objective of their greater use in mainstream housing. To achieve this aim, a DSS is presented in this paper as a means to aid and inform design and building professionals in their choice of materials for low-cost green residential housing projects.

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Study Design: The study employed exploratory study design approach using literature reviews, and networking with domain experts and practitioners. This was followed by a series of questionnaire surveys and knowledge-mining interviews.
Place and Duration of Study: This study was carried out in some selected housing construction firms in the UK over a two-month period of March and April 2012.
Methodology: The study conducted in-depth interviews that consisted of 10 participants, involving a sample of practicing architects, engineers, material specifiers, and a host of building professionals that influence material choice decisions in the UK housing construction industry. In order to elicit the ‘‘most important’’ factors, a semi-structured questionnaire survey was conducted among 480 executives of some selected expert builder and developer companies, with an overall response rate of 52.1%.
Results: The analysis of the questionnaire survey provided a list of ‘‘most important’’ decision factors having significant impacts on the process of material selection for low-cost green residential housing development. The value for Cronbach’s alpha was estimated at 0.781, showing strong evidence that all reliability coefficients of 55 out of 60 factors were acceptable, and internally consistent.
Conclusion: This study posits that an improved approach for integrating data associated with the impacts of low-cost green materials from heterogeneous databases and other information sources may likely reduce decision-making failures in the selection process; hence engender their wider-scale use in mainstream housing.

Keywords: Analytical hierarchy process (AHP); decision support system (DSS); low-cost green building materials; material selection factors.

DEFINITIONS

For clarity, several definitions have been included. For the purpose of this study:

Low-cost green building materials or components are defined as materials or components with lower cost and energy requirements across their life cycle, when compared to competing products that serve the same purpose. In this study, the term locally sourced and recycled green building materials or components will be used to refer to either low-cost green building materials and components or low-cost green construction materials and components. In the same vein, the term low-cost housing will be used to refer to reduced cost housing where applicable.

Low-cost green housing is defined as; “buildings that are specifically designed or constructed by utilising a large proportion of locally sourced and recycled green building materials or components more harmoniously—with regard to the likely impact of the key-influential factors or variables proposed, to effectively address a range of issues specific to the population they intend to serve during their life-cycle”.

However, low cost housing being a relative concept that may vary between regions will in this study refer only to housing which may be reasonably affordable to the poor, and required to specifically address the economic issues of the population that it will serve [7]. It is therefore, not similar in definition to low-cost green housing as given above, which rather satisfies a set of building regulations, codes and standards which not only determines the quality and cost of housing, but also deals with a broader range of issues including political, environmental, social-cultural, technical, legal, as well as energy-related issues. Though it is *designed to cater more widely for the needs of the poor, it is however, not synonymous with 'social' or low-income housing.*

1. INTRODUCTION

The limited number of building materials available and poor structural frameworks of existing housing delivery schemes have widened the deficit of housing in almost every urban city of Less Developed Countries-LDCs [1,2]. With population growth and industrilisation consequently indicating strong potential for continuing growth in housing demand and in the materials that it uses, various governments of the LDCs have been active in urging the housing construction industry to explore the possibilities of constructing homes more efficiently, by using building materials that significantly contribute towards minimising CO_2 emissions, in order to improve the quality of the housing stock [3,4,5]. The Report Emissions of Greenhouse Gases in the United States [6] indicates that widespread demand for comparative environmental performance of building products coupled with considerable reduced production cost have afforded the opportunity of using low-cost green building materials, as they possess features that can help to mitigate climate change, given their lower cost and energy requirements [6,7,8].

Despite the potential benefits that associate the use of such materials, research conducted by Oruwari et al. [9] and Ashraf [10] yet, indicate a rather decreasing emphasis on their wider-scale use in housing construction. They claim that limited use of low-cost green building materials in the housing construction industry indicates that building practitioners have little experience that could allow effective decision-making, and vague understanding of best practices in using them. They added that this lack of knowledge has resulted in the industry operating at a low capacity, hence, compromising low-cost green building material market expansion. They further expressed serious concerns over limited access to adequate information as a seeming good reason for the limited knowledge and experience amongst building professionals and designers, and their reticence in the use of such materials for housing construction. They suggest that existing data for selecting such materials originate from varied sources and are not organised in a format that decision makers can readily use to derive any meaningful information.

In the growing housing construction industry where new technology, products and materials with differing properties are continuously being introduced, the choice of materials and the manner in which they are put together to form building elements depend largely upon, and are determined by numerous preconditions, decisions and considerations, relative to their environmental requirements and life-cycle performance [11]. In design environments where ecological, health, and ethical impacts are increasingly important, often the only way to choose from many different material alternatives is by relying on unquantified professional judgment or past experience [12]. This is particularly pertinent as inexperienced designers still engage the traditional mode of relying on subjective individual perceptions of values and priorities in the material selection process, which rather than facilitate or drive their design ideas, appears to do the opposite, thereby limiting creativity and sometimes resulting in considerable frustration. This means that designers or architects are constantly faced with the complex decision of selecting appropriate materials [12,13]. The process of selecting appropriate materials however, involves an understanding of: the nature and characteristics of a number of materials; the methods to process them and form them into building units and components; structural principles; stability and behaviour under load; building production operations; and building cost. Hence, a better understanding of the impacts of low-cost green materials (consisting of locally-sourced and recycled building products), and their method of selection is needed to allow them to be used more efficiently and effectively [13].

While a complete understanding of the properties of low-cost green building materials could enable designers to design energy efficient and cost effective buildings, Wastiels et al. [14] noted that the material selection process is influenced by numerous factors. They further remarked that the material selection process depends largely on a number of other factors that are not usually considered in the traditional mode of selection, as this further complicates the decision-making process of determining whether or not a particular material or component is appropriate for the intended task. Quinones [15] asserted that some recycled products, for example, contain high embodied energy that leads to ecological toxicity and fossil fuel depletion impacts during their manufacturing phase, and thus may have severe consequences on the overall performance of the building, if the relevant factors are not properly considered.

Moreover, Seyfang [12] and Trusty [16] have argued that providing useful and explicit information in order to derive conclusive evidence of the differing impacts of various material alternatives is a strategic decision-making process that requires careful analysis of a wide range of data. They observed that data available for low cost green materials are usually very large, complex and not organized in a suitable format helpful to decision makers for extracting any meaningful information without the help of database technicians. They further noted that the available data on such materials are normally stored in various operational databases that are not easily accessible to decision makers in usable forms and formats. In this event, decision-making failures during planning and design stage(s) of housing projects hinders their use of such products in terms of their industrial capacity utilisation in the housing industry [17].

To improve best practice associated with the use of low-cost green building materials, Trusty [18] suggests that a system capable of retrieving data from different databases and information sources is needed to provide useful and explicit information that will aid designers in making quick and informed decisions during crucial material selection process at the design stage.

Recent material assessment tools, such as Building Research Establishment Environmental Assessment Methods (BREEAM), ATHENA, and the Leadership in Energy and Environmental Design (LEED), have shown great promise for guiding evaluations of material predictor performance [19]. Implications emerging from the main research study however criticized and noted the flawed existing support systems for being partially objective and fraught with problems of fairness. It revealed that many tools are only applicable to the situation studied, rather than being generalisable to a wider range of issues. The analysis of the study further showed little evidence to justify the assumption that design and building professionals are well informed in terms of knowledge of the basic standards of best practices in applying low-cost green materials to building projects. The study therefore recommended that decision makers need more informed knowledge to develop a better understanding of the strengths and weaknesses of the different material alternatives and selection strategies, when specifying such products.

Seyfang [12] further noted that any potential Decision Support System (DSS) for such products should be developed with the condition that they are tailored for the specific markets that they are to be used. She argued that while there seem to be a growing momentum across many municipal jurisdictions in LDCs and even developed regions to use low-cost green building materials on a permanent basis for low-cost housing community-based projects, there are limited decision support tools available to assess the suitability of such materials or products for their potential use.

More importantly, she observed that much of the current research and information on material selection of low-cost green materials offer generalised guidance, which are neither supported by quantitative nor qualitative data, and have proven difficult for designers to interpret or adopt. She strongly recommended that strategies and technologies that will enable design professionals to have easy access to relevant and adequate information on the available options, hence, making the selection results more reasonable and bringing more standardization to the material selection decision-making process at the design stage, could be a better option to promote greater use of such materials in mainstream housing.

Consequently, to improve the understanding of relevant data associated with the impact of low-cost green building materials and components, this paper introduces the development of an interactive Decision Support System (DSS) that helps retrieve and analyse data from different databases and information sources, to aid informed decision-making in the choice of materials, from conceptual to detailed design stage of residential housing development. The prototype DSS model is intended to provide useful and explicit information that will aid designers in the material selection processes. Several materials selection-related factors and information from manufacturer and supply companies were incorporated in the model. The MSDSS model utilizes macro-in-excel application and employs the AHP technique in order to narrow a vast list of available materials alternatives down to a manageable short list of a few technically feasible options. A step-by-step methodology is presented to illustrate the different stages of the DSS model development. The material selection data warehousing schemas and their architecture are discussed with reference to the particular DSS design reported in this paper. Finally, the application of the prototype DSS for selecting appropriate floor material for a residential project in the London Borough of Sutton is presented. The final section concludes the study and suggests areas for further studies.

In the following section, the review of existing green building material assessment tools are summarised and the main findings and themes to emerge from the literature review and the fieldwork seminars and interviews are reported.

2. A REVIEW OF EXISTING MATERIAL SELECTION SYSTEMS

The field of building construction has witnessed a rapid increase in the number of building environmental assessment methods either in use locally or being developed worldwide [20]. There are little doubts that building environmental assessment methods have contributed enormously to furthering the promotion of higher environmental expectations, and are directly and indirectly influencing the performance of buildings [21]. Widespread awareness of environmental issues has created the critical mass of interest necessary to cement their role in creating positive change. Cooper [22] however, argues that the contexts in which building environmental assessment methods now operate, and the roles that they are increasingly playing, are qualitatively different than earlier expectations. While there is clearly an urgent need for new technologies to optimise the use of low-cost green building materials, it is also true that there are many technologies or systems, already in use [23].

The Building Research Establishment's Environmental Assessment Method (BREEAM) was the first set of assessment tools developed in the United Kingdom in 1990, and is the building environmental assessment method with the longest track record [23]. The BREEAM tool assesses the environmental impacts of over 150 various materials and components most commonly used in home construction. The tool takes environmental issues into account, then adds measurements and user-defined weighting to arrive at environmental impacts, measured as “Eco-points” for each building material being assessed.

Twelve different environmental impacts are individually scored, together with an overall summary rating, which enables users to select materials and components according to overall environmental performance over the life of the building. This scientifically accepted program however, focuses only on the environmental performance of products rather than environmental, social and financial considerations going hand in hand as parts of the material evaluation and selection process.

In 1998, the U.S. Green Building Council developed the Leadership in Energy and Environmental Design (LEED) building rating tool, which places certain values on building products [6]. Focusing on the LEED system, Keysar and Pearce [24] conducted a detailed evaluative study comparing the effectiveness of five different relative importance indices for selecting appropriate material selection tools such as: relative advantage; compatibility; complexity; trialability; and observability, with the goal of improving the sustainability of materials for capital projects. Here, materials such as; regionally manufactured materials, materials with recycled content, rapidly renewable materials, salvaged materials, and sustainably forested wood products are selected based on credit scores. Analyses of their study however, revealed that the LEED model for example specifically requires an energy model, a task often handled by a specialist within a design firm or outsourced to a third party specializing in energy modeling.

Due to the inflexibility inherent in the application of first generation tools, many different tools of the second-generation group have also been launched to address these limitations. Among this category is the ATHENA estimator. This has been one of the most popularly used material data-analytic models that analyze over 1,200 building material and assembly combinations [25,26]. It allows the users to look at the life cycle environmental effects of a complete structure or of individual assemblies and to experiment with alternative designs and different material mixes to arrive at the best scenario. Bayer et al. [27] noted that the major drawbacks to this tool are the fixed assembly dimensions, software cost, the cost and required skills to use it, the limited options of designing high-performance assemblies, and the overall incomplete assessment of whole buildings environmental impacts.

With the identified setback associated with ATHENA estimator, The National Institute Standards and Technology (NIST) developed the Building for Environmental and Economic Sustainability (BEES®) 4.0. This model provides a cradle-to-grave product-to-product comparison of over 230 building products based on manufacturer and supply company information [27]. The impact categories are weighed, normalized, and merged into a final environmental performance score, to generate a single measure of desirability for product alternatives by combining qualitative and quantitative data. The BEES 4.0 model is however, not capable of providing data for a full LCA of a complete building product, as it only produces data for a limited amount of building materials and evaluative factors [27]. These single-attribute claims ignore the possibility that other life-cycle stages or environmental impacts can yield offsetting impacts. Other limitations include; limited product options, limited use for local/regional impact materials and devaluating weighing process [27,28].

Trusty [28] argued that these sets of first and second-generation tools less often consider any of the Multi-Criteria Decision Methods available to solve MCDM problems, adding that some systems do not even consider Life Cycle Cost (LCC) and other performance criteria simultaneously or completely. Moreover, he claimed that the existing performance requirements/criteria approach used in such tools tend to rely on immeasurable characteristics in demonstrating the extent of sustainability in a product, which makes them over-burdensome to implement and communicate.

Since the highlighted material assessment tools were developed primarily to be used in different countries, and the data sources used by each tool differed, further efforts have been undertaken to develop knowledge-based or expert DSS for assistance in material selection.

For instance, Rahman et al. [29,30] developed an integrated knowledge-based cost model for optimizing the selection of materials and technology for residential housing design using Technique of ranking Preferences by Similarity to the Ideal Solution (TOPSIS). The system is developed to assist architects, design teams, quantity surveyors and self house builders to make decisions for the design from early stage to detailed design stage by ranking the performance and cost criteria of technologies and materials. Their tool however, provides partial assistance in the material selection process of the whole building design as it only considers the cost of roofing materials. Florez et al. [39,40] argue that the material selection process depends on a number of other factors such as the location, zoning and environmental regulations, demographic characteristics, etc. that are not considered in their system. They noted that the TOPSIS approach adopted does not only lack the ability to eliminate bias in the selection process but also unable to allow fairer trade-off process.

Loh et al. [31] developed an environmentally focused decision support system in the form of an Environmental Assessment Trade-off Tool (EATT), which supports the development of the ideal building design and materials combination that meets stakeholders‘ requirements. It is designed to assist users select the most appropriate material among a set of candidate materials based on the analytical hierarchy process (AHP) concept of decision-making, since AHP technique has the robust ability to handle the complexities of real world problems, and to deal formally with judgment error, which is distinctive of the AHP method. The system rank orders a set of preselected, technically feasible materials using different decision factors with and without tangible values, such as a clients favour over a particular building design, publicity potential of the building design, life cycle cost, capital cost and energy performance of different materials and building layouts. They emphasise the strategic selection of sustainable materials and building design prior to the building construction as crucial to increasing building life cycle energy performance. They argue that stakeholders involved in the early design process often have conflicting priorities for both building design and construction materials. It was however argued that the approach adopted by Loh et al [31] lacked in robustness as it does not take into account the full-life cycle impacts of newly-accepted building products, and did not specify the sort of materials under studied.

Zhou et al. [32] developed a decision support multi-objective optimization model for sustainable material selection. The material selection tools and material data sheets provide extensive information that includes factors such as cost, mechanical properties, process performance and environmental impact throughout the life cycle based on expert knowledge. Wastiels et al. [16] confirmed that the tool, however, lacked the considerations or descriptions to evaluate the intangible aspects of building materials, which are important to architects. They also criticised the selection methodology for being highly restrictive to a limited range of factors and incompatible with other stakeholders.

Wastiels et al. [14], proposes a qualitative and quantitative framework to support informed decisions based on physical aspects' and 'sensorial aspects' of building materials, but without the tools integration and computerisation as done by Zhou et al. [32]. In the presented framework, no pronouncement is made upon how sustainable considerations from these different categories of factors could influence each other in the material selection process, and what Multi Criteria Decision Method (MCDM) could possibly be used if developed.

A similar study by Ding [33], developed a comprehensive assessment decision support system that measures the environmental characteristics of a building product using a common and verifiable set of criteria and targets for building owners and designers to achieve higher environmental standards. Upon analysis it was found that the assessment for her study focused heavily on environmental issues rather than the broader social, cultural, technical and economic aspects of sustainable green construction.

Keysar and Pearce [24] cited extensive research literature describing how material selection tools facilitate the innovation diffusion process and radical decision-making transformation. They however, note that most of the examined models make choices that result in "fabricated assemblies of standardized performance attributes", implying that they do not choose for materials but rather for 'material systems'.

Hopfe et al [34] conducted a study that assessed the features and capabilities of six software tools to screen the limits and opportunities for using BPS tools during early design phases. The tools classification was based on six criteria namely the capabilities, geometric modeling, defaulting, calculation process, limitation and optimization. However, the authors did not report what methodology was used to compile these criteria.

Other influencing reviews within the scope of this study include Mohamed and Celik [35] who proposed a computerised framework that is responsible for materials selection and cost estimating for residential buildings where users are able to choose their preferred one from list of materials without evaluation and synthesis of multiple design criteria and client requirements. No mention was made as to the MCDM technique used for evaluating the list of materials selected and their respective quantities.

A cost modeling system for roofing material selection was further proposed in Perera and Fernando [36]. Several factors were identified and considered in the selection process. Results demonstrated large inconsistency in the evaluation process. No particular reference was made to the selection methodology.

Mahmoud et al. [37] suggested a method for the selection of finishing materials that covered floors, walls and ceilings and integrates cost analysis at the appropriate decision points, but without the selection information requirements or methodology as proposed in this study.

Lam et al. [38] carried out a survey on the usage of performance-based building simulation tools. His study examined the relative impacts and limitations of knowledge-base tools in decision-making. Murray [59] argues that while there is a natural tendency for design and building professionals to focus on the scientific and technological aspects of green and sustainable construction, their approach does not necessarily maximise the positive contributions professionals have to offer if tools are designed to replace professional judgment in the choice of materials. Murray [59] suggests that this is because tools cannot address the intrinsic motivations people need if they are to embrace the positive changes sustainability requires. He continues that limiting the assembly of buildings to the specification of systems would impede the discovery of design opportunities inherent in materials themselves. Similar patterns of consistency, and lack thereof, have also been obtained [for detailed reviews see 39, 40, 41, 42].

Having reviewed the different sets of green building material assessment tools, it can be deduced that existing tools are dispersed and based on individual initiatives without a unified consensus based framework [39,40]. A key question therefore, is whether current assessment methods that were conceived and created to specifically evaluate the environmental merits of conventional building materials can be easily transformed to account for a qualitatively different product. In order to respond to the foregoing question, the following section conducts an appraisal of existing decision support systems.

2.1 A Critique on Reviewed Material Selection Decision Support Systems

Attempts to address the use of existing tools for local and recycled building products have been proposed separately by many researchers [9,10]. However, in the context of universality, each of these indices applied to deal with issues associated with the impacts and performance of low-cost green materials have proven unsatisfactory [12,13].

Giorgetti and Lovell [43] for instance have reported the sub-optimal performance of existing tools. They noted that many existing material-selection decision support tools particularly from the developed regions do not, by design, address social issues, other designated priorities relevant to the developing nations or even relate to their current building codes. They remarked that most of the existing material selection decision support systems have been designed by countries with more developed economies such as the UK, where the scale of social issues and lack of access to resources is simply not as critical as observed in the developing nations.

In his study “Green Building Rating Tools in Africa”, Malanca [13] further remarked that developing countries currently have unique challenges regarding the use of green building decision support systems. In it, he specifically points out that the performance thresholds put forward in most material-selection decision assessment tools designed for developed nations are based on existing green building guidelines already in use in such countries, adding that their resource requirements could potentially pose obstacles in developing nations. He noted that the LEED and BREEAM environmental assessment and rating tools tend to focus on energy-related environmental impacts of design decisions. These tools he argued provide pragmatic approaches to integrating the assessment of environmental performance into design and material selection processes and predicting environmental performance, with little or no regard to the assessment of the ecological and human health impacts of design decisions. He argued that tools developed overseas may be more advanced and comprehensive in their scope and in their use, but such tools are not directly transferable to developing regions because they do not reflect the local environmental conditions, pressures or impacts of the region. This, Ellis [44] corroborates, creates market confusion since such tools are often not designed specifically for an environment characterised by mainly social and economic issues.

Separate studies conducted by Malanca [13], Ellis [44] and Kibert [45] revealed that the majority of the available systems to date are already perceived to have less relevance in the housing sectors of the developing countries, even though they have been effective in improving the performance of multi-unit residential developments in many developed countries. They contrast the credibility of existing decision support systems with what they describe as “overly comprehensive’, arguing that additional documentation to existing guidelines, as a way to prove compliance with social criteria in developing countries, could increase the perceived burden on housing.

They note that too many tools are being ‘pushed’ by outside interests, and too few locally developed (and more informal, or less expensive) approaches known. They disclosed that the assessment parameters of existing tools particularly of the developed countries are not consistent across product categories or different countries of origin, adding that some materials that are commonly used in buildings in the developed regions may not be affordable or available in developing countries.

Ellis (2009) further notes that most first generation tools (particularly those within the developed regions), take into account only the direct effects of single criterion and are unable to predict the actual performance of building products when considering multiple variables.

They added that existing DSS models suffer from similar problems in that materials analysed by single criterion cannot be unambiguously assigned to multiple variables, and therefore, suffer from inconsistency and imprecision in the evaluation process. She further suggests the need for new generation of tools associated with the impacts of low-cost green building products, by which design and building professionals, especially the inexperienced ones, must be adequately informed, to achieve energy efficient and cost effective design in the housing construction industry.

2.2 Summary of the Reviewed Literature

In summarizing the literature findings, it can be deduced that the contents of existing tools within the developed regions are not directly transferable to less developed regions, since they do not reflect the values, priorities, local environmental conditions and needs of such regions [14,15]. By highlighting the different LCA tools during the review, it became apparent that each tool had its own unique application. Moreover, Gluch & Baumann [46] note that different cultural factors and various regulations in different countries complicate the situation even further. While each tool could be called an LCA tool, there was little consistency in the methodologies used from one tool to another. Due to the various limitations of the reviewed systems, researchers [45,46] have suggested that potential tools for low-cost green materials consider broader yet critical underlying premises to overcome some of the challenges encountered by their predecessors. Trusty (2003) suggests that it is necessary for potential users to analyze the local situation and identify the adaptability of using any tool before applying a universal green building assessment tool to a specific country and region. He warned that some existing tools such as BREEAM, LEED, and Athena might potentially institutionalize a limited definition of environmentally responsible building practice at a time when exploration and innovation should be encouraged in another region.

However, in all the reviewed studies, no efforts to develop a DSS that associates with the corresponding attributes and performance characteristics of low-cost green building materials and components, starting from the broad list of available options in the database to the final selection of the most appropriate material, were found in the existing literature. The findings of the study revealed that there is not yet a uniform and clear methodology or outline to assess and define tools specifications and criteria for developers, practitioners and tools users dealing with issues associated with the informed selection of low-cost green materials.

It showed that each of the indices applied in developed regions to deal with issues associated with the impacts and performance of low-cost green building materials in other regions have proven unsatisfactory.

This finding is premised on the fact that most existing material selection systems have been designed by countries with more developed economies such as the UK, where the scale of social issues and lack of access to resources is simply not as critical as observed in the developing nations.

Hence, the study makes recommendations that there is need for tools associated with the corresponding attributes and performance characteristics of low-cost green building materials and components, which fit into the intrinsic way that design-decisions are made by architects, at the various stages of the design process. Therefore given the setbacks that associates the tools reviewed in this research, this study thus, highlights the opportunity for developing a Material Selection Decision Support System (MSDSS), to better address the specific needs and attributes specific to the use of low-cost green materials for tool adopters new to green housing.

The following section highlights the research aim and objectives of the study. It also describes specific methodology for each task in brief detail.

3. RESEARCH METHODOLOGY

To identify the key material selection factors or variables that formed the basis for the development of the prototype multi-criteria decision support system (DSS), suitable clusters of research approaches were considered in the research exercise, some of which include:exploratory literature reviews, networking with domain experts and practitioners, series of questionnaire surveys and knowledge-mining interviews. Table 1 provides an overview of the research aim, objectives and approaches undertaken in four major stages.

Table 1. Basic summary of the research methods

AIM	To develop a decision support system (DSS) that will provide designers with useful and explicit information associated with low-cost green building materials and components, to aid informed decision-making in their choice of materials for low-cost green residential housing projects.		
Stage	**Objectives**	**Tasks**	**Method**
1: Review	1. Examine current views on themes related to decision-making associated with the use of low cost green materials in the housing industry, to identify new ideas & issues arising from the study	**Step 1**. Reviewed relevant literature through synthesis and analysis of recently published data, using a range of information collection tools such as; books, peer-reviewed journals, and articles from libraries and internet base sources	AA,
	2. Review various DSSs currently	**Step 2**. Carried out a preliminary research study with leading researchers	AA,

	used at national and international levels for the selection of materials to identify knowledge deficits and the potential benefits associated with their use	who influence the selection of building materials in the field of housing construction	QS, INT
2: Data collection &synthesis	3. Conduct surveys and interviews with building professionals in the UK, to identify the potential factors or variables that influence the informed selection of low cost green building materials and components	**Step 3**. Conducted a pilot study, by deploying a test-questionnaire to a small sample of researchers who possess relevant knowledge on issues specific to the use of low cost green materials using the email addresses taken from the databases of recognised building construction companies and research institutions **Step 4**. Conducted the main survey, by administering the revised questionnaire through email contacts taken from databases of interested registered building professional groups, who influence the selection of construction materials from throughout the construction value chain **Step 5**. Conducted in-person interviews with interested building professionals who influence material choice decision in housing construction using audio recording system to avoid re-contacting the respondents or falsification of information **Step 6**. Carried out inspection on available expert systems most commonly used in building firms in the UK, USA, China etc. by interviewing experts, with years of experience in the industry, who have implemented or used such systems and directly observing how they function when in operation	AA, QS, INT
3: Data analysis	4. Evaluate and establish the weighted importance of the key factors or variables that will help to determine	**Step 7.** Analysed the information and report gathered from the survey exercise(s) using a suite of statistical analytical programs, and various quantitative data analytical techniques	AA, QS M

	the relative impacts of the different choices of building materials and components		
4: Development & application	5. Develop a system to integrate the necessary information appropriate to the informed selection of low-cost green building materials & components	**Step 8.** Assembled the key components by synthesising the relevant databases to be incorporated in developing the proposed DSS model. **Step 9**. Developed the main structure workflow of the proposed system by creating links among the various databases,	AA, QS, M
	6. Test the functionality of the proposed approach; and validate the effectiveness by applying it to a building material selection problems using a series of case study residential building projects in the UK	**Step 10**. Inputted relevant data to test the internal links to know what needed to be measured within the system, and checking the output of the results against easily calculated values	M
		Step 11. Conducted experts survey by deploying a sample of the prototype system via email of those who participated in the main survey, using feedback questionnaires as a quicker and cost effective means of assessing respondents' judgments about the system	QS
		Step 12. Made necessary changes based on the feedback from the survey	M
		Step 13. Validate the modified prototype system using a series of completed building projects in the UK, by comparing the outputs from the algorithms to monitored data from the completed building	M, CS

KEYS: AA (Archival analysis) INT (Interview) CS (Case study) QS (Questionnaire Survey) M (Modeling)

3.1 Results and Discussions from the Surveys

In order to build upon knowledge gained from the literature review, and recognising the limitations of the preliminary research survey in terms of examining current research thinking in respect of decision support systems for low cost green building materials and components, a mixed method (consisting of qualitative and quantitative techniques) was adopted for this study. In-person interviews were conducted to further clarify and elaborate on less detailed issues associated with the informed selection of low-cost green building materials. The in-depth interviews consisted of 10 participants, involving a sample of practicing architects, engineers, material specifiers, and a host of building professionals-who influence material choice decisions in the UK housing construction industry. This approach was used to examine the potentials of the proposed MSDSS, (being a tool for the assessment and evaluation of low-cost green materials). It further investigated the effectiveness of design and decision support tools, as well as identified requirements of Life Cycle Assessment (LCA) tools for design decisions at the various stages of the design process.

To get deeper insight upon any exceptional issues noted during the interview, and identify the potential and significant impact on the overall integrity of the proposed model, series of inspection(s) were carried out on some of the available expert systems most commonly used in three (3) building firms in the UK (as they have had the most uptakes in developed countries).

This involved interviewing experts, with years of experience in the industry, who have implemented or used such systems, by directly observing how they were constructed and how effective they were against some criteria such as comprehensibility, interoperability, ease of use, and flexibility, when in operation. The observation method provided essential triangulation of data gathered through reviews, questionnaires and interviews.

Consequently, a quantitative questionnaire was developed as the result of the analysis of the results from the literature, interviews and observatory studies. In order to elicit the ‘‘most important’’ factors, a questionnaire survey was conducted among the executives of some selected builder/developer firms. They were asked to rank order from a list of factors (compiled from existing literature on the topic and after initial consultation with some of the executives) based on their judgment and experience. The executives were also asked to indicate desired features they would like to have in a DSS for low-cost green material selection. Since the respondents were widely dispersed, and because it was anticipated that building professionals would be more likely to reply and cooperate with a less time-consuming research method, giving the constraints of time, wider coverage, and budget, it was therefore, decided that a questionnaire sent and returned by email would be the most convenient way of collecting the required data. The inclusion of qualitative open-ended questions provided respondents a chance to express their views more freely.

The target groups of respondents were also taken from a database or directory of building professionals provided by the UK, China, Canada, South Africa, Brazil and US Green Building Councils (GBCs). The selection approach followed the random sampling technique to ensure uniformity, consistency and quality of data [50]. The selection of South Africa and Brazil for the analysis was due largely to their great similarities in social, economic, and geopolitical terms, and likewise their developed counterparts. In a similar vein, the choice of building experts within the selected countries was as a result of their expertise and advancement in the use and development of green building tools (as they have had the most uptakes in both geographical regions and being part of an emerging market).

To receive a reasonably sized sample, 480 surveys were sent out by email, over a two-month period of March and April 2012. Using a progressive approach of data collection, a total of 250 respondents returned the completed survey, with an overall response rate of 52.1%. Respondents were also invited to post their ideas about current limitations or improvements that should be avoided or integrated in the development of the proposed MSDSS model at the later part of the questionnaire. The questionnaire also examined the adequacy/inadequacy between traditional manual approach of material selection and computer-aided decision support tools. One of the group’s participants commented that one of the hallmarks of good science is that a result can be tested independently and proven to be right or wrong using the latter method.

The analysis of the questionnaire survey and interviews provided a list of ‘‘key” decision-related factors having significant impacts on the process of material selection for residential development as shown in section 4.1.1. The results of the study however, revealed that:

- Many existing decision support systems in the developed countries do not have the appropriate performance threshold for addressing the most relevant issues specific to less developed countries;
- Current DSS models are unable to relate to matters associated with the informed selection of materials that are commonly used for housing projects in countries with rather less-mature markets;
- The lack of informed knowledge by building professionals in terms of the principles, characteristics, and best practices relevant to the use of low-cost green materials at the design stage, has been identified as a common constraint peculiar to their wider-scale use in the housing industry;
- The majority of building professionals still regard cost and environmental factors as conventional project priorities when selecting building materials or components, but rarely consider the implications of social, political, technical, sensorial, legal and cultural factors in their choice of materials; and finally,
- The majority of low-cost green building materials are yet to be certified under the building regulations, standard specifications and codes of practice; and most importantly,
- There are no demonstrable and compelling evidence of technical research on a holistic approach used by design professionals for the evaluation and selection of low cost green building materials and components at the design stage.

The results of the study thus, provided the platform that suggested the need for a system that could aid informed decision-making to improve understanding, and enhance the effectiveness of actions to implement and promote the wider-scale use of low-cost green building materials and components at the core of the construction business process. In light of their feedback and useful suggestions from building experts who partook in the study, the following portions of the DSS model were either readjusted or improved.

- Easy searchable material selection inputs database;
- Ability to add/remove material selection features with ease;
- Ability to make custom reports;
- Ability to easily navigate all components with ease;
- Comprehensive “HELP or USER INSTRUCTIONS” menu;
- Being able to understand the material selection process through the lens of non experts;
- Ability to perform trade-off analysis to compare different material options;
- Clarity on the algorithms used to perform the simulations; and Real-time results;
- Data input forms to ensure easy and consistent data input; and,
- Having a huge amount of customizability in terms of output.

After the improvement, the system was shown to the same participants, and minor adjustments were made to the usability, applicability and interoperability functions on the basis of second feedback presented in appendix A.

In the following sections the selection methodology is discussed, and a conceptual framework for the decision support system based on the methodology is presented. Subsequently, the MSDSS model is applied to a hypothetical but realistic material selection problem to rank order the candidate materials for selecting the most appropriate one…

4. SYSTEM DEVELOPMENT

For this research, AHP was selected for its simplicity and due to the fact that it can be easily implemented using any spreadsheet software application such as the MS Excel, as it possesses a powerful macro language that is essential since a menu driven interface had to be developed. Since the intention of the research was not to develop a commercial software product, Macro-in-Excel VBA (MEVBA) was utilized for the following reasons:

- Macro-in-Excel VBA (MEVBA) has the ability to write scripts that could automatically convert material data from any graphic table format to an appropriate condensed data table (hidden from the user's view) to allow quick and reliable indexing of material data;
- The Macro-in-Excel VBA framework has the code that makes Windows forms work, so any language can use the built-in code in order to create and use standard Windows forms;
- Makes the application easier to maintain; With MEVBA, codes were easily built into the form or report's definition, since the DSS model contained a large number of macros that respond to events on forms and reports; which would have been difficult to maintain using any other application;
- With Macro-in-Excel VBA it was easy to step through a set of records one record at a time and perform an operation on each record;
- Macro-in-Excel VBA helped to supply a standard security mechanism, which was made available to all parts of the MSDSS data application model;
- Enables the developer to create his own functions: The MSDSS contains a series of mathematical model and computational algorithmic procedures that provided a basis for computing the green development index of material alternatives within an integrated decision-support framework or tool(s).
- Ability to mask error messages during the tests run;
- Enables the system to quickly analyze existing data to discover trends so that predictions and forecasts can be made with reasonable accuracy;
- Allows for extensions and expansions: since the components of the framework are modular, meaning that each may be developed independently, and data may be added as it is acquired to supplement the knowledge and databases, macro-in-excel was used to achieve that goal

4.1 MSDSS Database Design

The data warehouse design constitutes the major portion of the MSDSS development and hence will be explained in detail in this section. The data warehouse design essentially consists of four (4) steps as follows:

1. Identifying the key influential factors that will impact on the choice of materials;

2. Designing the material selection methodology framework and identifying the objectives of each step;
3. Designing the various components of the MSDSS model and defining their features and functions;

4. Defining the workflow selection methodology and analytical procedure of the actual prototype MSDSS model

4.1.1 Identifying the key influential factors

To identify the key influential factors needed to be incorporated in the Material Selection Decision Support System (MSDSS), respondents were asked to first rate the validity of the individual group of factors, followed by a range of sub-factors under each category of the parent groups on the frequency with which they are relevant in the selection of low-cost green building materials using a 5- point Likert scale (where "1= least important" to "5 =extremely important"). Respondents were also asked to add and rate the relative importance of any other relevant factors not included in the list.

Considering the individual group/category of factors, the Relative Index (RI) analysis in table 2 indicated that "Economic/Cost (RI=0.918)" and "Technical (RI=0.916)" factors were found to have the strongest influence on material choice(s). These were followed by "Socio-Cultural (RI=0.912)", "Environmental (RI=0.890)", "General/Site (RI=0.838)" and "Sensorial (RI=0.830)". Cronbach's alpha was calculated to test the internal consistency reliability of the generated scale examined. The value for Cronbach's alpha as shown in Table 3 was estimated at 0.781, which was well above Cronbach's specification of 0.7, and thus, provided evidence for composite reliability.

Therefore, the results shown in Tables 2 and 3 proved that all the six parent factors presented adequate reliability scores. This indicated that the six main/parent factors (i.e. GS-Site variables; EH-Environmental; EC-Economic; SC-Socio-Cultural; T-Technical; and SN-Sensorial extracted from the factor analysis could be used as a multidimensional measure for internal and external forces affecting designers' decisions relating to material-selection practices.

Given that the resultant alpha values for each factor category was greater than 0.7, there was strong evidence to show that all reliability coefficients of all the factors were acceptable, and internally consistent.

Table 2. Item statistics

	Relative index (RI)	Rank	Std. deviation	N
F3: Economic or Cost Factors (C)	0.918	1	1.340	250
F5: Technical Factors (T)	0.916	2	1.429	250
F4: Socio-Cultural Factors (SC)	0.912	3	1.385	250
F2: Environmental and Health Factors (EH)	0.890	4	1.331	250
F1: General and Site Factors (GS)	0.838	5	1.518	250
F6: Sensorial Factors (SN)	0.830	6	2.146	250

Table 3. Reliability statistics

Cronbach's Alpha	Cronbach's Alpha Based on Standardized Items	N of Items
0.781	0.789	6

To further identify the relative importance of the sub-categorical factors or variables based on the survey data, ranking analysis was performed. The Relative index analysis was used to rank the sub-factors according to their relative importance as shown in appendix B. Five important levels were transformed from Relative Index values: Highly Significant Level (H) ($0.8 \le RI \le 1$), High–Medium Level (H–M) ($0.6 \le RI < 0.8$), Medium Level (M) ($0.4 \le RI < 0.6$), Medium–Low Level (M–L) ($0.2 \le RI < 0.4$), and Low Level (L) ($0 \le RI < 0.2$).

Kaiser–Meyer–Olkin (KMO) measure and Bartlett's Test of Sphericity were conducted using the Statistical Package for the Social Scientist (SPSS v.20), to examine the sampling adequacy, ensuring that factor analysis was going to be appropriate (see appendix B). Then, the maximum likelihood factor analysis method was also used to derive the minimum number of factors and explain the maximum portion of variance in the original variable. Kline [47] argued that with a sample size of at least 100 participants or above, loadings of 0.30 or higher could be considered significant, or at least salient (see discussion in Kline [47] pp. 52-53). The result of the analysis however, showed that none of the factors fell below 0.30. This meant that variables with factor loadings of 0.30 or higher were considered significant, while variables that loaded near 0 were clearly considered as unimportant.

Given that oblique rotation will easily reproduce an orthogonal solution but not vice versa [48], the oblique rotation was recommend as ideal for this research. The value of KMO arrived at 0.862, which is well above Kaiser's specification of 0.5 (see appendix B). The analysis of the main survey identified 60 key influential factors or variables as important components for the selection of low-cost green building materials. However, the results shown in appendix B proved that fifty-five (55) out of sixty (60) factors were adequate to undertake any material selection process. This means that fifty-five factors fell within the range of 0.5 and higher, well above Kaiser's specification of 0.5.

According to Hutcheson & Sofroniou [60] a KMO value is regarded as ideal if it falls within the range of 0.7 and above. They argued that values closer to 1 indicate that patterns of correlation are relatively compact and therefore, should yield reliable factors that are able to assess low-cost green building materials and components. They recommended that values between 0.5 and 0.7 are mediocre, values between 0.7 and 0.8 are good, values between 0.8 and 0.9 are excellent and values above 0.9 are superb.

From the results of the analysis shown in appendix B, forty (40) factors were identified under the "Highly significant" level for evaluating low-cost green building materials with an RI value ranging from 0.952 to 0.806, with "life expectancy (T15)" topping the list of this group and "Thickness of material" occupying the least position. "Life Expectancy" was ranked as the first priority in the technical category with an RI value of 0.952, and it was also the highest among all factors and was highlighted at "High" importance level. "Resistance to fire" was also rated high in importance among the selection factors. "Maintenance Cost" was ranked third in importance. It was clear from this research that there is a perception of ambiguity surrounding the long-term maintenance of low-cost green building materials. This is not entirely any surprise given that maintenance free buildings are increasingly sought after by clients, anxious to minimise the running costs associated with buildings.

“Life-cycle cost” has been, and will continue to be, major concerns for building designers, as well as important traditional performance measure.

Fifteen factors where grouped under the “High-Medium” level. From appendix A, a total of 15 factors, consisting of 12 site factors, 1 socio-cultural factor, and 2 sensorial factors, were recorded to have “High–Medium” importance levels. Although these 15 variables were in the same importance level category, the “building orientation” factor within the “general/site category” (average RI=0.652) was considered to be the least important variable compared to the factor “Glossiness” under the “sensorial category” (with an average RI=0.774), and “material availability” still under the “general/site category” (with an average RI=0.795).

However, it should be noted that site factor account for 75% in the “High-Medium” importance level. The findings of the result analysis also showed a discrepancy between what architects claim to be convinced about, and knowledgeable in, and their commitment and practices; architects seem to be unable to translate their environmental awareness and knowledge into appropriate design decisions. For example, respondents ranked environment-related measures lowly among other factors. The result is an example of evidence pointing to the trend that environmental and perhaps site issues are no longer considered as the most important factors for material selection in housing projects, especially within the context of the less developed regions.

This finding also corroborates the initial observations of various studies [12,13,44] repeatedly highlighted in the background and literature studies. They suggest that the problems within the developing regions are characterised by mainly social and economic issues, unlike the developed regions where the scale of social issues and lack of access to basic resources are simply not much of a challenge as it is in the developing world.

Some factors in the three categories were ranked relatively higher in the “High– Medium” level. For example, “material availability (GS1)” was rated as first in the general/site subcategory, and ranked as thirty-fifth in the overall ranking with an RI value of 0.795. An interesting observation from the results shown in appendix A is that only five (5) out of the sixty (60) factors/criteria fell under the medium and other lower importance level. This clearly shows how important the fifty-five (55) factors are to building designers in evaluating low-cost green building materials. All fifty-five (55) factors were rated with “High” or “High–Medium” importance levels.

The findings of the analysis asserted that the criteria with low RI does not mean they are not important for selecting materials, but rather created an opportunity to highlight the relative importance of criteria from their vantage point.

For easy evaluation, and to enable users to access information quickly and accurately during crucial stages of the material selection process, 60 factors were further compressed into six categories of assessment variables of –site impacts, environmental/health impact, economic/cost, socio-cultural, technical, and sensorial variables as shown in Fig. 1. The categorisation of the factors is to allow decision makers to have an appropriate balance between the different groups, in a manner that will enable them to easily evaluate building material options by aggregating their performance along various groups of sustainability criteria.

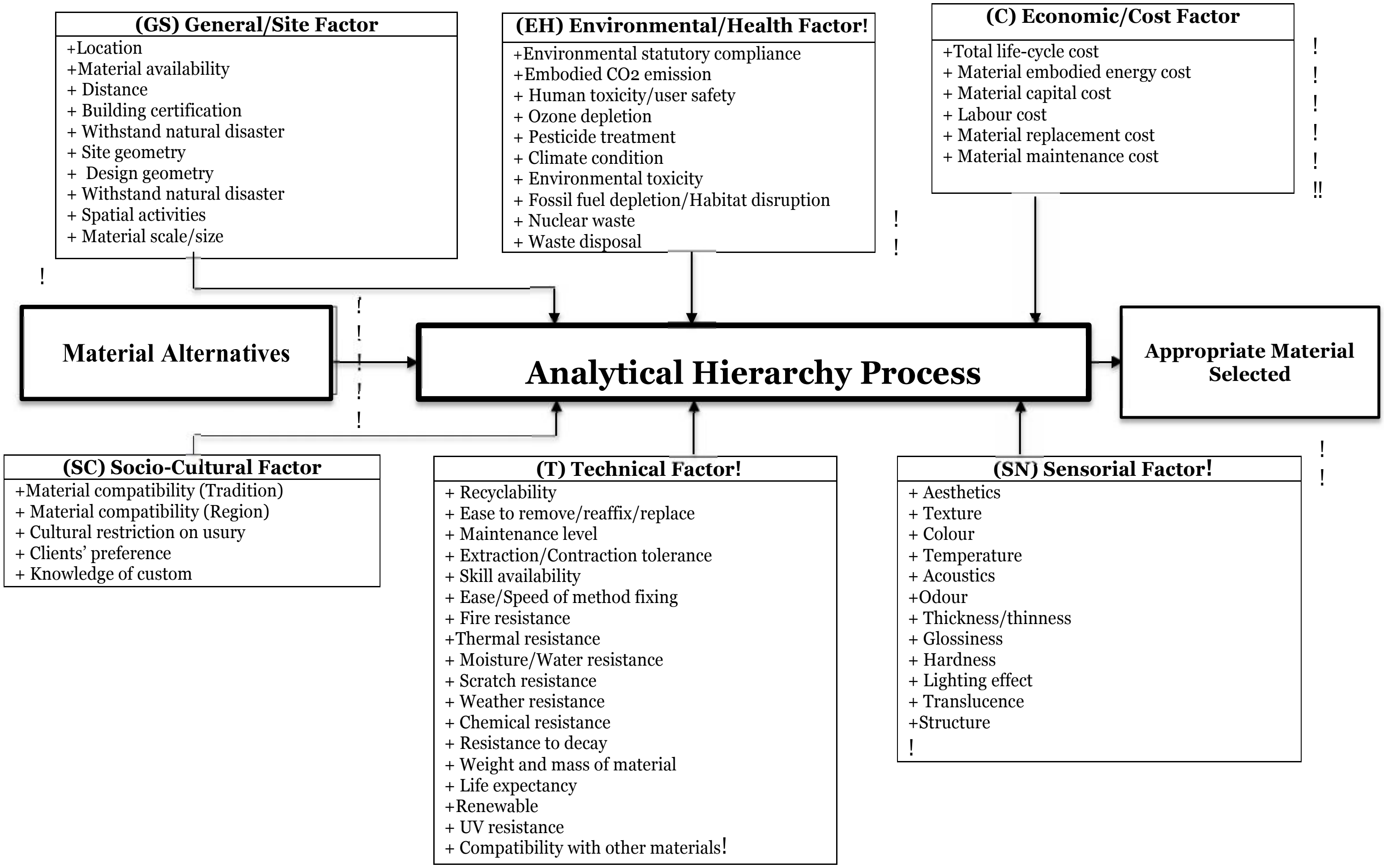


Fig. 1. Key influential factors for measuring the suitability of low-cost green materials

4.1.2 Designing the selection methodology of the MSDSS model

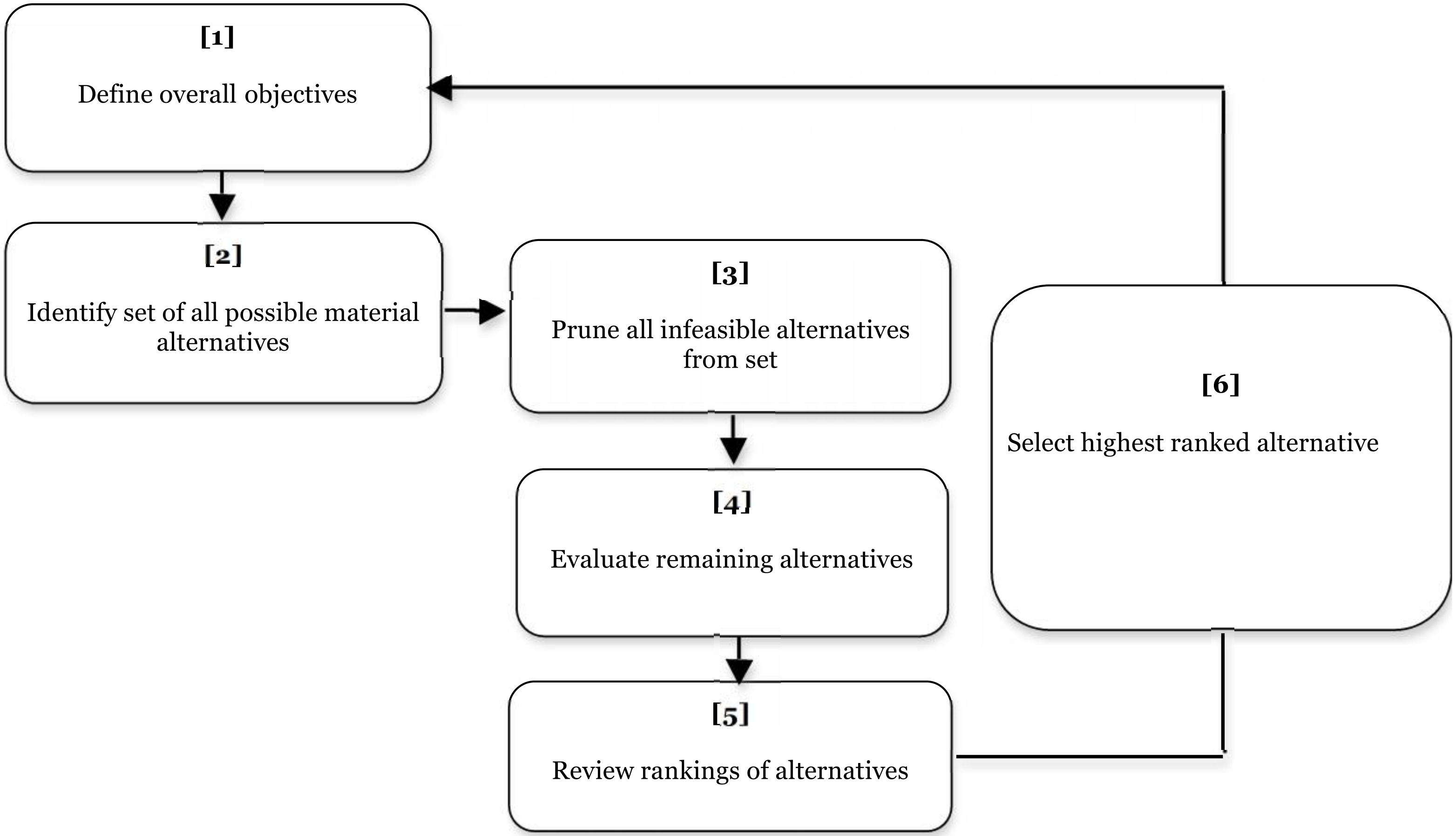


Fig. 2. Materials selection methodology of the MSDSS model

Table 4. Step-by step approaches of the material selection methodology

Objective	Task
1. Define or state overall objective/goal	The first step of the methodology is to define the main goal of the intended task.
2. Identify Set of all Possible Material Alternatives to be Assessed	After defining the main goal of the task, the next step is to generate the set of all possible alternatives that are available for selection based on the decision-making parameters. In the material selection process, this comprehensive set of alternatives includes all construction materials and components currently in the database, and the market in context.
3. Prune all infeasible alternatives from set	The third step is to reduce the complete set of alternatives by eliminating/pruning those alternatives, which are clearly infeasible for the intended application from the database consisting of all materials, based on classifications of materials according to the Construction Standards Institute (CSI) Divisions, and material heuristics. For example, if the element under consideration is a structural beam, materials such as roofing sheet and glass are automatically pruned from the set of possible alternatives under consideration, since none of these materials fall under the CSI structural divisions. This should result in a subset of alternatives, all of which would be feasible choices for the intended application. The "pruning" approach is used rather than allowing the user to select feasible materials from the whole set because users tend to overlook alternatives which might be unfamiliar to them but are nonetheless feasible.
4. Evaluate Remaining Alternatives	The fourth step in the methodology is to evaluate the feasible alternatives using the AHP model such that a ranking can be developed according to the relative importance of the material for the intended application.
• Weight Attributes (Decision Factors)	• First, the decision maker weights each factor or variable according to the relative importance that the decision factor or variable holds for the decision maker. It involves the decision-maker replacing probabilities with user weightings for each factor or variable to supplement, not replace, his judgment.
• Calculate Values for Attributes	• Second, values for each of the factors or variables are determined for each material with regard to the manufacturer's information & details of the material or component contained in the material

	database, and then, a normalized value between zero and one is calculated for each factor value.
- Amalgamate Weighted Attributes	- After weights have been established and values calculated for each attribute against a set of materials or components, the weights and normalized values are multiplied and summed to create an index of preference for that alternative(s).
- Develop Ranking	- Then, a list of alternatives ranked according to the relative importance of the factors or variables is then presented.
5. Review Ranking of Alternatives	When the indices of factors or variables have been calculated for all feasible alternatives, a ranking is developed sorting the alternatives according to each utility value based on the AHP model of decision-making. The alternative with the highest utility value is recommended from the ranked list of potential materials for each design/building element.
6. Select Alternative Based on Ranking	The decision maker may then either elect/decide to select the highest ranked alternative, or choose another alternative from the set based on his professional judgment.
7. Proceed to Next Design Elements	The decision maker satisfied with the selection process, then proceeds to the next design/building element.

The diagram shown in Fig. 2 demonstrates the conceptual framework of the selection methodology for the decision support system. Table 4 describes a step-by-step procedure of the selection methodology for the material selection decision support system. The next section presents various components of the MSDSS model

4.1.3 Designing the various components of the MSDSS model

The next stage of the model development was to design the various databases containing the logic and showing relationships between the data organized in different modules. Each module contains the physical information and contents needed to aid in the material evaluation and selection process. The system consists of a number of interconnected modules/features with reference to feedbacks from participants. A logical model illustrating the developed DSS for material selection is shown in Fig. 3. Table 5 describes the functions of each component of the MSDSS model.

4.1.4 Defining the workflow of the MSDSS model: How the system works

The following steps highlighted in Fig. 4, explain how the prototype MSDSS model works during the material evaluation process.

- The load manager provides the user with a list of design elements from the “Design Elements” module, and then prompts the user to select the design element of his/her choice in accordance with the terms and specifications of the Construction Standards Institute (CSI) Divisions;

- The User then selects the particular design element needed for the intended task from a list of design elements (as broken down by the Construction Standard Institute Division);

- User then enters values for the relevant parameters to answer prompts about areas and dimensions of the selected design element, and then sets the threshold values in the material knowledge base

The system validates the design parameters and threshold details entered by the user, and then generates the set of all feasible material alternatives that are available for selection, (which includes all categories of construction materials contained in the materials database);

- After a set of feasible material alternatives has been generated for the “particular design element”, the system through the “Weighting Score Extractor Module” prompts the user to obtain weightings for the desired parent and sub-factors according to the relative importance that each factor or variable holds over another based on the decision maker’s preference of value;

- After weights have been established and values calculated for each factor for a particular material, the weights and normalized values are multiplied and summed to create an index of subjective utility for each alternative;

- The alternative with the highest utility value or the material with the highest ranking is recommended by the system;

- The user reviews the system’s recommended choice for each element in the “Result” module, and then either selects the highest ranked alternative, or chooses another alternative from the set based on professional judgment and/or the system’s recommendation.

- The user may choose to generate a printout report or graphical representation of the list of selected materials and green utility indices if desired.

- The selection process then proceeds to the next design element.

Appendix C displays various stages of the actual prototype MSDSS model. Each step (as shown in Appendix C), describes the working procedures or tasks undertaken during the material evaluation process.

In the following section, an illustrative example of the AHP concept is explained to demonstrate the selection process of materials by applying the prototype MSDSS model to an on-going real life but hypothetical case study design project.

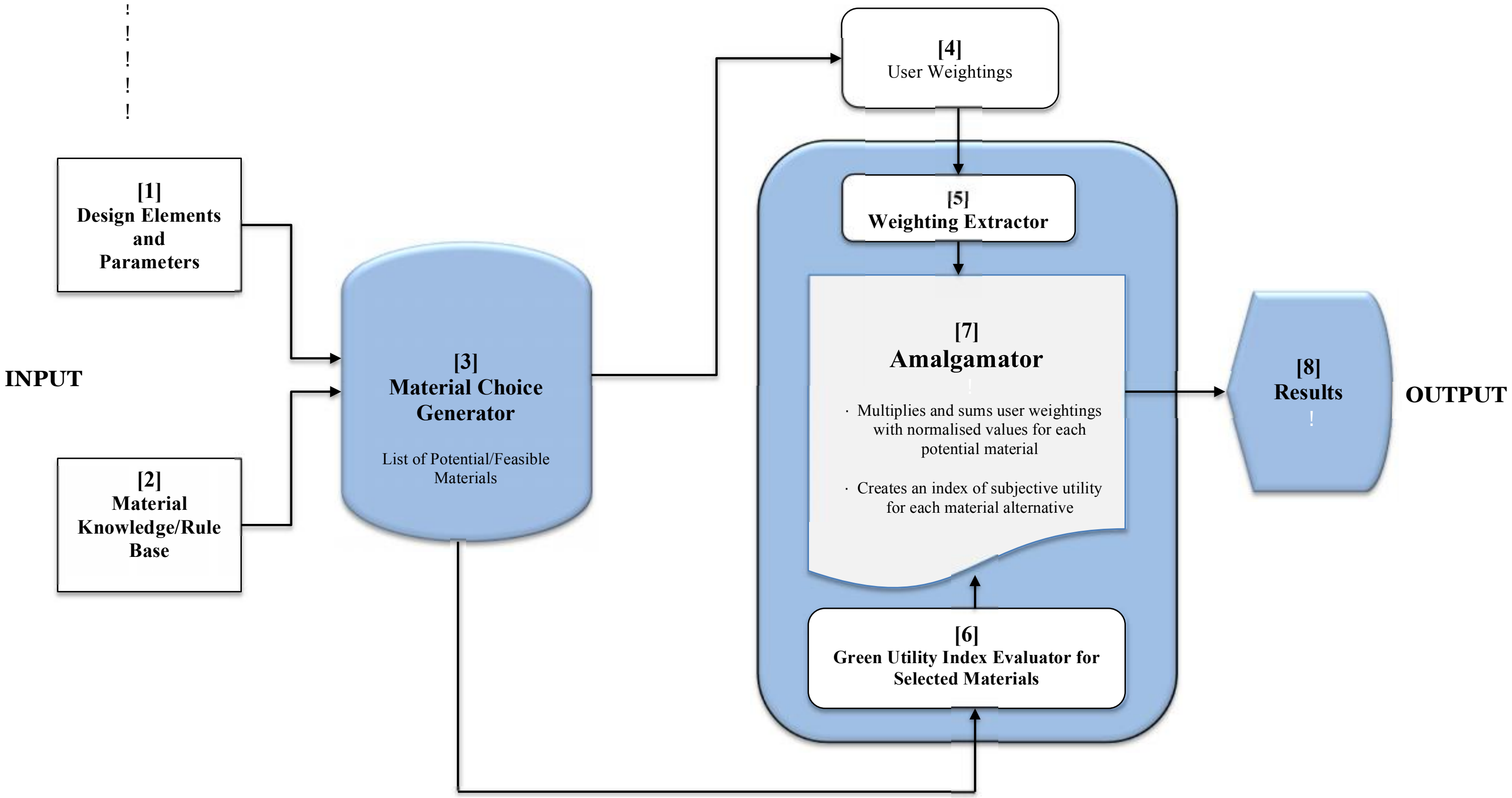


Fig. 3. System architecture/conceptual model of the MSDSS tool

Table 5. Individual functions of the various features/components of the MSDSS model

Features of the MSDSS model	Functions of the various features/components of the decision support model
1. Design elements and parameters	This feature provides users with a range of building design elements and their respective parameters such as the size, thickness, and height of the various design/building elements-which is composed of a set of associated dimension tables, each corresponding to the respective components). The elements include: External Walls ID/description, Internal Wall ID/description, Beam ID/Description, Column ID, Floors & Slab ID, Pavement ID, Skirting ID, Door &Window ID, Stair ID, Ceiling-Dados ID, Roof ID/Description.
2. Material rule base	This feature consists of a collection of set-rules used in current practice(s) for assessing or measuring the project-specific minimum requirements during material selection. This in addition, includes a separate set of contextual considerations that has been developed as heuristics/rules base to facilitate site/context-specific feasibility and appropriateness testing of each material choice. It articulates the listing of individual materials in prescribed sequences, gradually eliminating candidate materials based on their inability to meet stated material selection heuristics/rules.
3. Material choice generator	This feature contains the material/component database, which generates the set of all possible material alternatives that are available for selection. It consists of a list of attributes & other performance requirements specific to all candidate materials or assembled building components.
4. User's weightings	- Sets preferred weighting value for all attributes to compare with.
5. Weighting extractor	Weighting Extractor consists of the various categories of material-selection factors or variables that are scored and used as guidelines to analyse the performance impacts of a range of material alternatives. It queries the user to obtain weightings for the factors, based on the user's preference of value on a scale of 1-9.
6. Material index evaluator	The material index evaluator calculates values of the selected factors or variables for each feasible material choice.
7. Amalgamator	-The feature is responsible for calculating the weights (usually numeric figures given to each material by the user pending on his preference on a scale of 1(least relevant material) to 9 (Most relevant material); and values contained in the value extractor (Which are values assigned to each factor/variable such as cost, aesthetics, durability etcetera). Here the user's weightings are amalgamated with the factor values or weightings for each potential material and sorted by the Amalgamator Module, resulting

	in a relative ranking of the feasible materials for each element. That is the weighting value for the material and the value for the factors are multiplied and summed to create a list of preference for the material alternative(s) selected by the user. -Finally it ranks each material by sorting the alternatives according to the utility value of the calculations for all the materials that were compared.
8. Results	- This component provides the ability to view the processed data, and to generate reports. It allows the MSDSS model User Interface to communicate with the user; and also connects all the reports and queries that are generated in the Monitoring databases to the corresponding project files. -This component generates ranked list of potential materials for specific design elements, which consists of walls, beams, floors and etcetera. A list of alternatives ranked according to the relative importance of the factors or variables is then presented in this section -This section of the system also provides results in form of graphs, quantitative and descriptive reports, showing variance of materials suitability in relation to the relevant variables/factors inputted by the user -Here the User/system has the chance of selecting the alternative with the highest likelihood of resulting in the most desired outcome

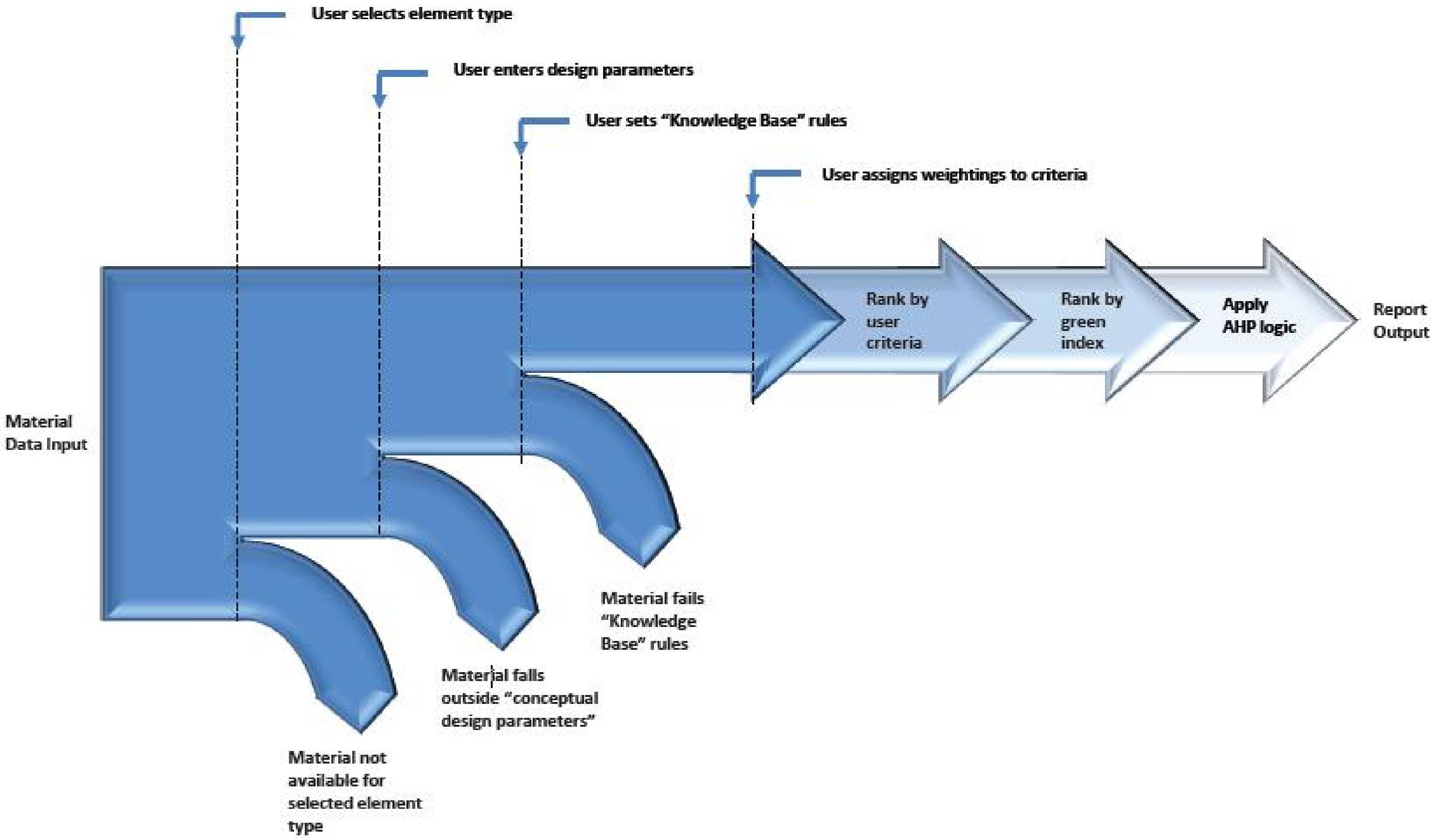


Fig. 4. Schematic representation of the user interface workflow system of the material selection decision support model

5. APPLICATION

The following example illustrates the selection process of floor covering products. It selects the best one among three alternatives. The prototype MSDSS, developed using the AHP technique, was used to select the most appropriate residential building floor material for housing development in the city of London, located in the Sutton County of London. The results demonstrate the capabilities of the MSDSS system in a real-life but hypothetical application scenario. In the following section this process of application is described and discussed.

5.1 A Hypothetical Study Case

The case used intends to provide an indication and practical application of the MSDSS model to material selection problems, following the AHP multi- criteria decision-making technique. The proposed scenario taken as study case is a hypothetical design of a 5-bedroom single-family home located in a sub-urban residential area of Sutton in London, United Kingdom. An architect is selecting a set of low-cost green building materials (in this case floor materials) for a proposed 5-bedroom low-cost residential green building project. The client tells the architect that he wants a building made from materials that are environmentally friendly and cost effective, but does not want the building's functions to be compromised by the architect's choice of materials. To meet the client's requirements, the architect decides to use the MSDSS model that is based on the concept of the Analytical Hierarchy Process (AHP), to help him in deciding which material option is best for the project, and to make the material choices that will best satisfy the client's needs. He has six main criteria to base his decision on namely: site, environmental, economic or cost, socio-cultural, technical and sensorial, as well as a host of sub-factors to consider. He has three material options from which he has to decide. The architect is expected to weigh the selected factors and rank the selected material IDs to decide the best option using the MSDSS model. Table 6 summarizes the details for the three options of flooring materials for the proposed project. From the table, the description of the three options was based on the standard practices and construction details commonly used in the housing construction industry.

Table 6. Summary of flooring options for the proposed residential building project

Description	Material A	Material B	Material C
Design element type	Panelledflooring	Laminated flooring	Concrete flooring
Building type	Residential	Residential	Residential
Material type	Bamboo xl laminated split panelled flooring	Reclaimed/recycled laminated wood flooring and panelling	Fly Ash cement concrete floor slab
Size of materials	230mm x 150mm	50mm x 6000mm	900mm x 900mm

These three (3) floor materials described above will be analysed amongst a host of other material alternatives for the selection of a more sustainable option. In other words, this section will analyse the problem using the MSDSS model, which relies on the use of the AHP mathematical multi-criteria decision-making technique, to identify and decide which material is the most sustainable and suitable flooring material in this case.

To achieve this goal, the MSDSS model was sent to 10 expert evaluators who had the following qualities:

- Considerable amount of knowledge in material analysis based on the AHP concept (Fig. 5),
- Used a wide range of green building assessment tools for material selection, and
- Taken part in the previous survey.

The aim of this exercise was to compare their view of the prototype model with existing models in terms of their usability, flexibility, and interoperability attributes using the concept of the Analytical Hierarchy Process (AHP) as shown below.

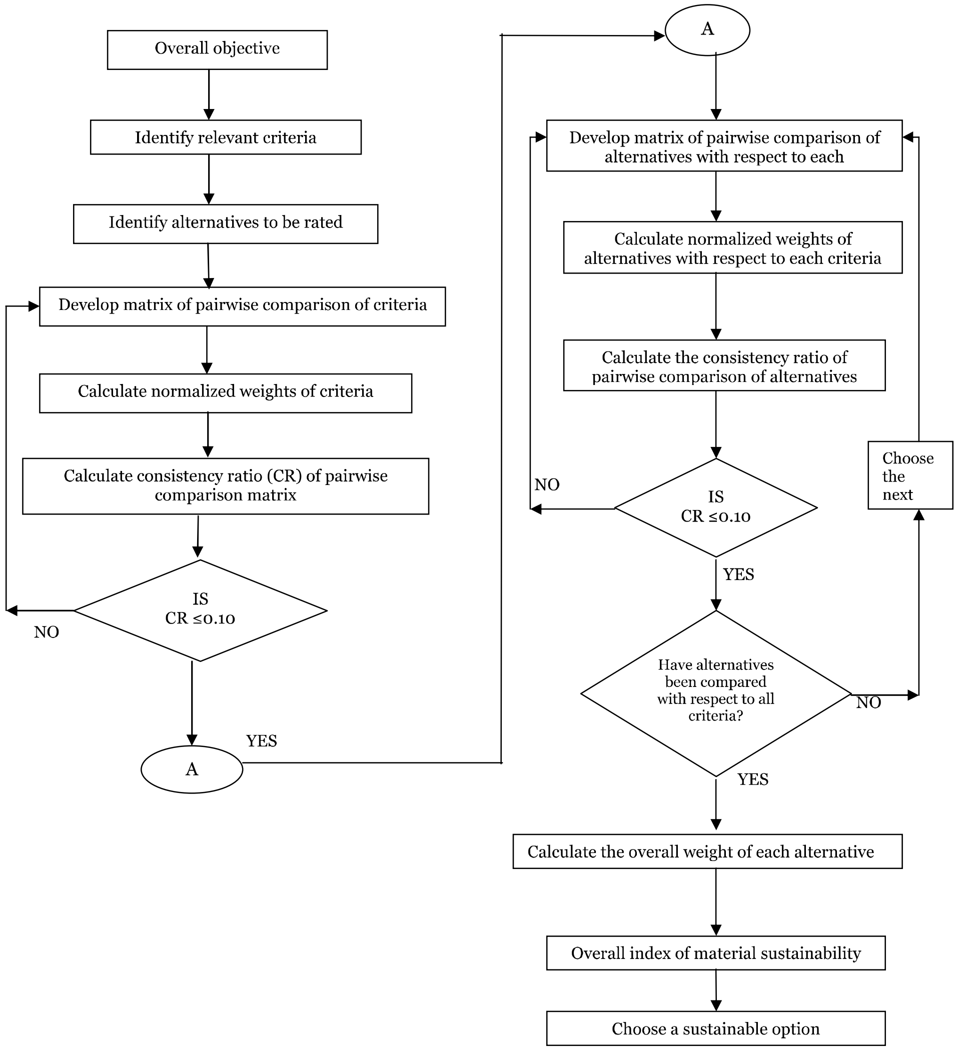


Fig. 5. Flow chart for the selection procedure using the AHP concept of decision-making

Fig. 5 shows the flowchart of the material selection computational analysis technique based on the concept of the Analytical Hierarchy Process model [49]. The following sections present details of the evaluation exercise.

5.2 The Application of the AHP Model to the Problem

To better illustrate the procedure of the AHP technique of decision-making, with reference to the case presented in section 5.1, a complete example of applying AHP to the problem of material selection is provided here based on evaluators' results. However, Reza et al. [50] have noted that AHP is a subjective MCDM method that does not necessarily involve or rely on a large sample for its analysis. Therefore, considering the ambiguity involved in dealing with too many subjects, Ten (10) respondents representing various fields of the housing construction industry, and who had fore knowledge of the AHP procedure were selected to participate in the AHP survey.

By evaluating the consistency level of the collected questionnaires, 5 questionnaires out of the 10 received had acceptable consistency and were entered into the analysis (as demonstrated in sections 5.4 and 5.5). In order, to avoid arbitrary and inconsistent answers in the data, the mean values of five (5) out of the ten (10) respondents were used to fill out the pair-wise comparison matrices for the parent and sub-factors.

The package included the model, evaluation questionnaire and a cover letter stating the purpose of the research, the validation process and what was expected of them. To conduct the exercise, the study adopted Chua's et al. [51] approach based on a number of suggestions as follows

- A document that reminded and explained the overall aim and objectives of the study to the respondents, followed by a step-by-step demonstration of its operation.

- A demo illustrating a practical exercise. This allowed the evaluators the experience of using the system ensued. During the practical assessment session, evaluators were able to see the controls and get a general overview of the MSDSS interface.

- An illustrative example of the objective and methodology of the AHP technique based on the instructions in the demo, to guide and illustrate to every respondent on how to browse and conduct analysis;

- After the introduction, a feedback questionnaire was forwarded to the evaluators;

- After each evaluation, each evaluator highlighted their experience(s) and provided feedback on the feel of the system, with special attention to the problems that they encountered during the evaluation process;

- Finally, a reflective or post-user questionnaire was completed to obtain feedback;

- Evaluators were asked to answer each statement or question relating to the model in the questionnaire based on their personal view(s)

- They were also asked to assess the importance of the system based on their perception. Evaluators were also asked to add general comments on the system, and provide feedback on the applicability of the prototype system in assisting in specific material selection problems during their experience and other ways of improvement.

- Problems uncovered or areas that proved difficult to understand during the evaluation process were immediately modified so that it did not arise in subsequent sessions, as this procedure followed each evaluation.

- The respondents were instructed of the relevance of observing consistency in their answers whilst using the MSDSS model;

- The questions relating to different aspects were presented in different sections. This helped respondents to focus on one aspect at a time. The following sections exemplify the process.

5.3 Step 1: Decomposition of the Decision Problem

The evaluation process or exercise provided users with the opportunity to define the problem. Fig. 6 shows the exemplary hierarchy of the problem. The goal is placed at the top of the hierarchy. The hierarchy descends from the more general or parent factors in the second level to sub- factors in the third level to the alternatives at the bottom or fourth level as shown in Fig. 6). To select a suitable choice among alternatives, the users were instructed to define the decision factors needed for the analysis. In other words, the users determined which alternative could be the best choice to meet the goal considering all the selected decision factors or criteria.

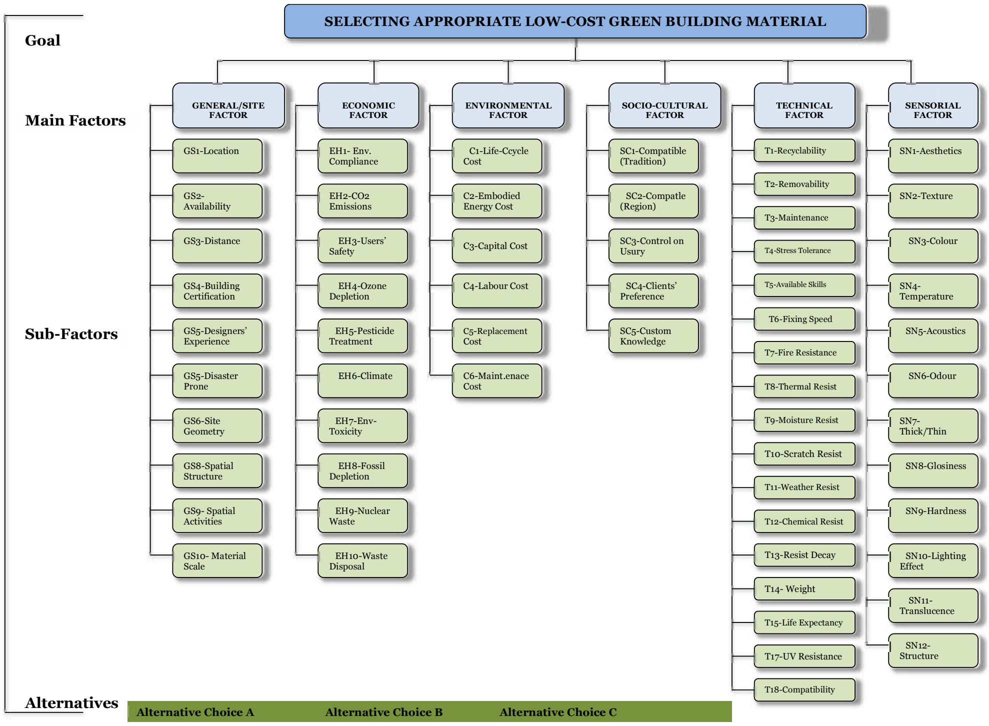
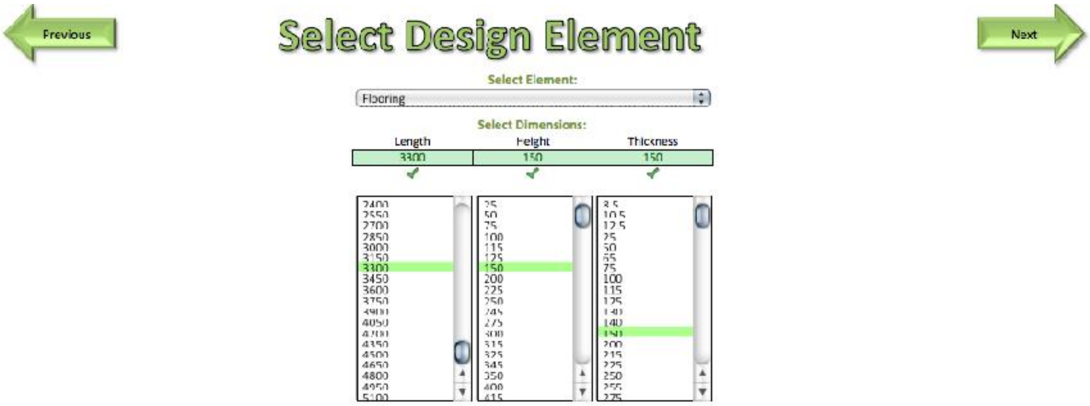


Fig. 6. Hierarchical representation of the floor material selection phases

The first step of the methodology (as illustrated in Fig. 6) was to define the main goal of the intended task, by identifying the design element needed for the analysis, and inputting the relevant dimensional scale for the suggested design element as shown in Fig. 7.



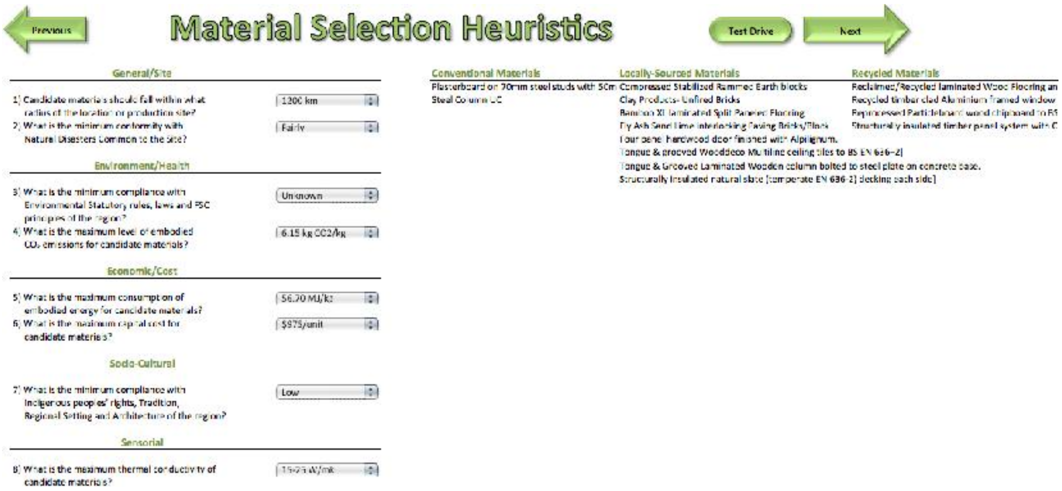
Select Element:
Flooring

Select Dimensions:

Length	Height	Thickness
3300	150	150
✓	✓	✓

Fig. 7. An illustrative example of the dimensional scale for the elected design element

After defining the main goal of the task, the next step was to generate the set of all possible alternatives that were available for selection with reference to the decision-making parameters as shown in Fig. 8. At this stage the users are prompted or alerted by the MSDSS model to identify a set of feasible floor material alternatives based on a range of material selection heuristics/knowledge-based rules. The goal is to choose a suitable floor material among options for the project case described in section 5.1.



General/Site

1) Candidate materials should fall within what radius of the location or production site? — 1200 km
2) What is the minimum conformity with Natural Disasters Common to the Site? — Fairly

Environment/Health

3) What is the minimum compliance with Environmental Statutory rules, laws and FSC principles of the region? — Unknown
4) What is the maximum level of embodied CO₂ emissions for candidate materials? — 6.15 kg CO2/kg

Economic/Cost

5) What is the maximum consumption of embodied energy for candidate materials? — 56.70 MJ/kg
6) What is the maximum capital cost for candidate materials? — $975/unit

Socio-Cultural

7) What is the minimum compliance with Indigenous peoples' rights, Tradition, Regional Setting and Architecture of the region? — Low

Sensorial

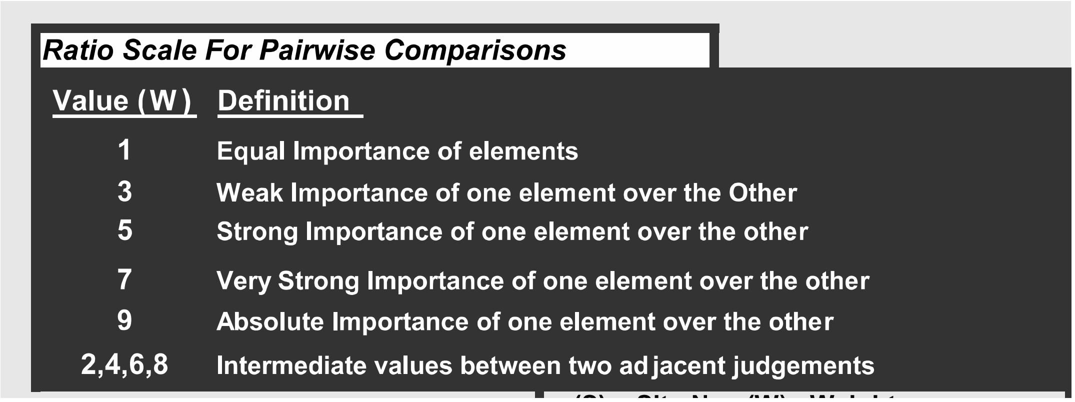
8) What is the maximum thermal conductivity of candidate materials? — 15-25 W/mk

Conventional Materials	Locally-Sourced Materials	Recycled Materials
Plasterboard on 70mm steel studs with 50m	Compressed Stabilized Rammed Earth blocks	Reclaimed/Recycled laminated Wood Flooring an
Steel Column UC	Clay Products- Unfired Bricks	Recycled timber clad Aluminium framed window
	Bamboo XL laminated Split Paneled Flooring	Reprocessed Particleboard wood chipboard to BS
	Fly Ash Sand Lime interlocking Paving Bricks/Block	Structurally insulated timber panel system with C
	Four pane hardwood door finished with Alpilignum.	
	Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636-2]	
	Tongue & Grooved Laminated Wooden column bolted to steel plate on concrete base.	
	Structurally insulated natural slate [temperate EN 636-2] decking each side]	

Fig. 8. An illustrative example of the selection heuristics for the elected design element

5.4 Step 2: Performing Pair-wise Comparisons of Parent Factors

After selecting the design element, and identifying a set of feasible alternatives using the material selection heuristics/knowledge-based rules, the respondents were made to perform pair-wise comparisons following the demo instruction guide of the MSDSS model. This included the analysis of all the combinations of parent factors and sub-factors relationships. The sub-factors were compared according to their relative importance (based on the ratio scale proposed by Saaty [52], with respect to the parent element in the adjacent upper level. After performing all pairwise comparisons by the decision-makers, the individual judgments were aggregated, basing its analysis on the geometric mean technique as Saaty suggested in Saaty [53,54].



Ratio Scale For Pairwise Comparisons

Value (W)	Definition
1	Equal Importance of elements
3	Weak Importance of one element over the Other
5	Strong Importance of one element over the other
7	Very Strong Importance of one element over the other
9	Absolute Importance of one element over the other
2,4,6,8	Intermediate values between two adjacent judgements

Fig. 9. Ratio scale for pair-wise comparisons of factors and alternatives [49]

Table 7. Random index (RI)values for n [49,52,53,54]

Matrix size (n)	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.55	1.57	1.58

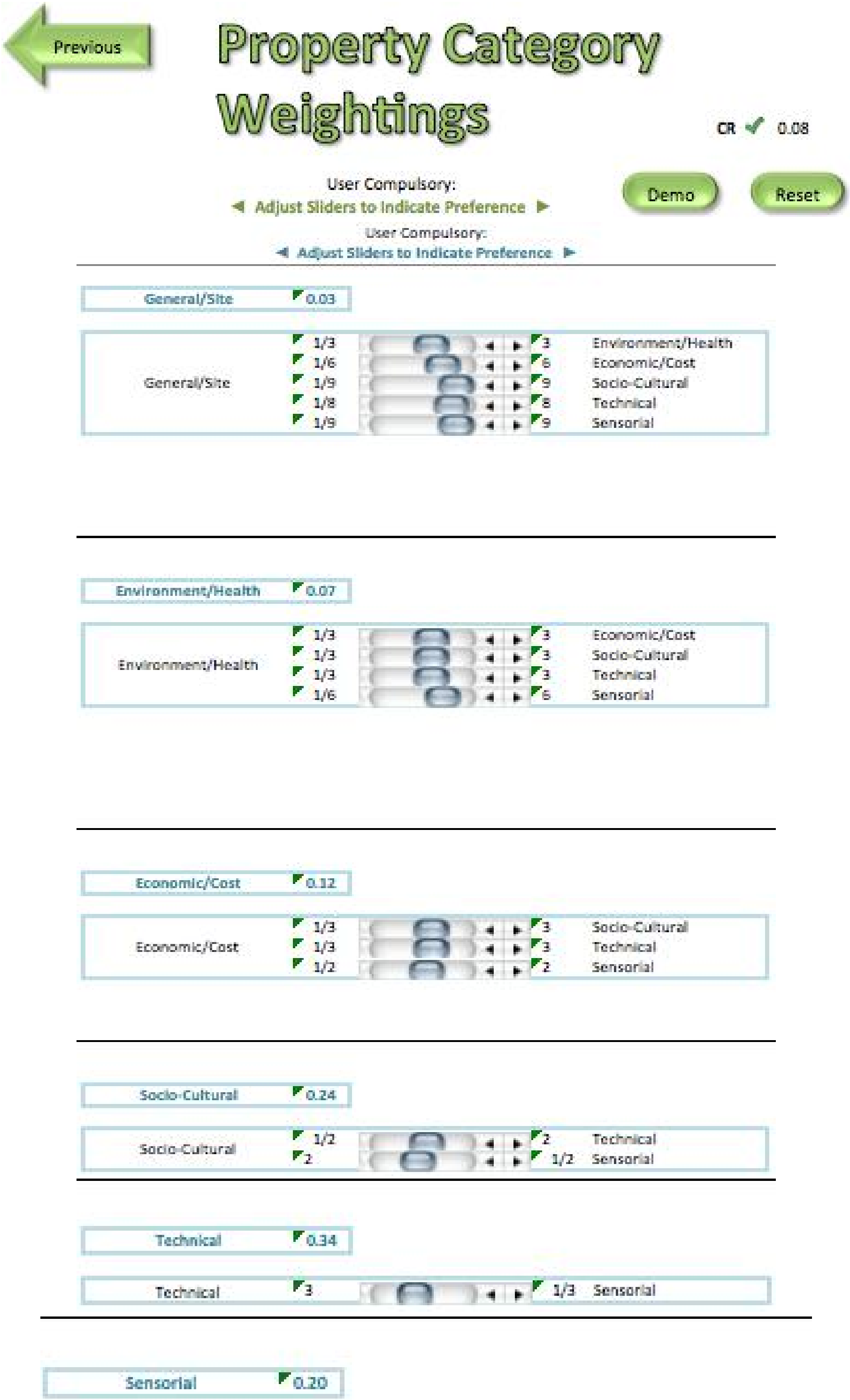
5.4.1 Pair-wise analysis of the main or parent factors

To avoid arbitrary and inconsistent answers in the data obtained from the 10 participants who consented to partaking in the study, the mean values of five (5) out of the ten (10) respondents were used to fill out the pair-wise comparison matrices for both the parent and sub-factors. The pair-wise comparison matrices obtained from 5 respondents were combined using the geometric mean approach at each hierarchy level to obtain the corresponding consensus pair-wise comparison matrices [54,55,56,57].

Using the verbal/ratio scale shown in Fig. 9, respondents obtained weightings for each parent factor, based on their preference of value(s) on a scale of 1-9 and the RI-values in Table 7. The MSDSS model then automatically translated each of the matrixes into the corresponding largest eigenvalue problem and was solved to find the normalised and unique priority weights for each factor (as shown in Fig. 10). Going by Saaty's [49] rule, the judgment of a respondent is accepted if the Consistency Ratio (CR) ≤ 0.10. In cases were the results of the respondents were not consistent, the participants were alerted or prompted by the model to carefully re-evaluate the factors until consistency was achieved.

Fig. 10. **Corresponding consensus pair-wise comparison matrices for main factors**

Fig. 11 represents the principal matrix of comparison, which contains the comparison between main/parent factors in relation to the overall objective of the problem (i.e., the selection of a sustainable low-cost green building floor material). From Fig. 11, it is possible to observe that factor SC is 3 times more important than factor EH. As a logical consequence, factor EH is 3 times less important than factor SC. It is also possible to observe that the elements in the principal diagonal are always equal to 1. In other words, the weight of a criterion in relation to itself, obviously, is always 1.



Property Category Weightings

CR ✓ 0.08

User Compulsory:
◄ Adjust Sliders to Indicate Preference ►

User Compulsory:
◄ Adjust Sliders to Indicate Preference ►

General/Site	0.03

General/Site	1/3	3	Environment/Health
	1/6	6	Economic/Cost
	1/9	9	Socio-Cultural
	1/8	8	Technical
	1/9	9	Sensorial

Environment/Health	0.07

Environment/Health	1/3	3	Economic/Cost
	1/3	3	Socio-Cultural
	1/3	3	Technical
	1/6	6	Sensorial

Economic/Cost	0.12

Economic/Cost	1/3	3	Socio-Cultural
	1/3	3	Technical
	1/2	2	Sensorial

Socio-Cultural	0.24

Socio-Cultural	1/2	2	Technical
	2	1/2	Sensorial

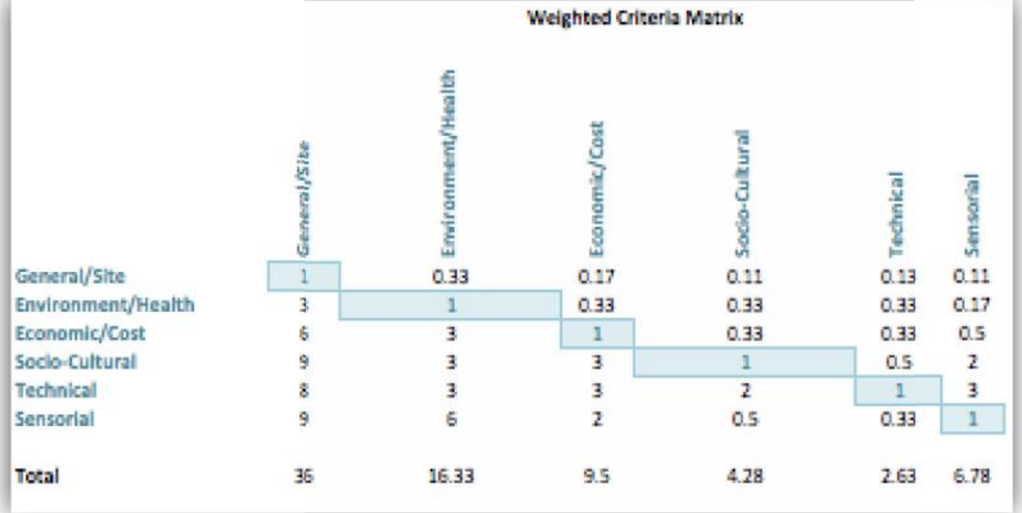
Technical	0.34

Technical	3	1/3	Sensorial

Sensorial	0.20

Fig. 11. Corresponding consensus pair-wise comparison matrices for main factors

At this stage ratio scales are defined for pair-wise comparison of the main or parent factors using a scale of 1 – 9 as shown in Fig. 9. As mentioned earlier, the decision makers obtained values for each parent factor based on their aprioristic knowledge and individual weighting preference.

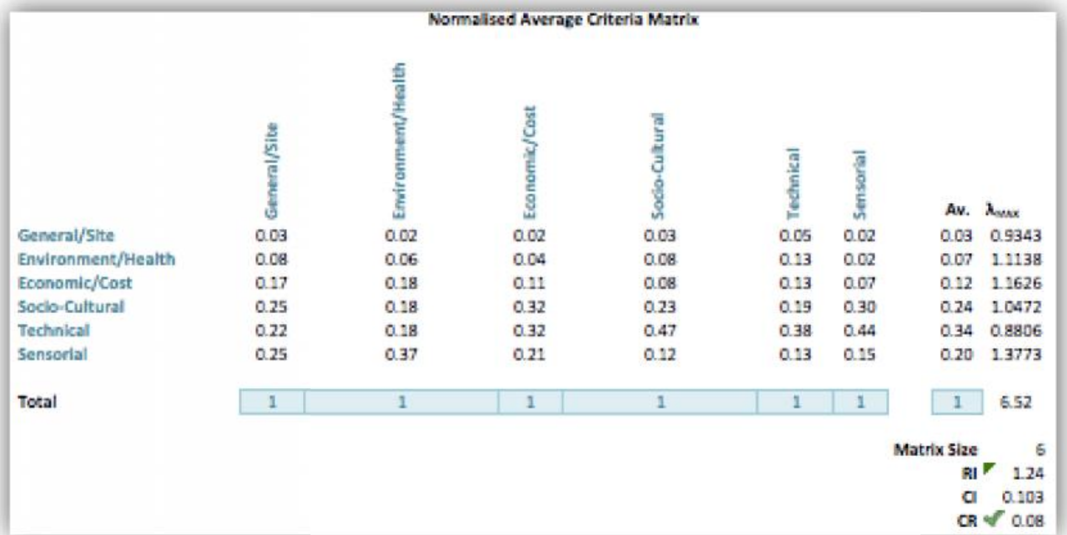


Weighted Criteria Matrix

	General/Site	Environment/Health	Economic/Cost	Socio-Cultural	Technical	Sensorial
General/Site	1	0.33	0.17	0.11	0.13	0.11
Environment/Health	3	1	0.33	0.33	0.33	0.17
Economic/Cost	6	3	1	0.33	0.33	0.5
Socio-Cultural	9	3	3	1	0.5	2
Technical	8	3	3	2	1	3
Sensorial	9	6	2	0.5	0.33	1
Total	36	16.33	9.5	4.28	2.63	6.78

Fig. 12. Corresponding consensus pair-wise comparison matrices for main factors

At this point the AHP main criteria matrix is then automatically developed by comparing the relative importance of one parent factor over the other as shown above in Fig. 12.



Normalised Average Criteria Matrix

	General/Site	Environment/Health	Economic/Cost	Socio-Cultural	Technical	Sensorial	Av.	λ_{MAX}
General/Site	0.03	0.02	0.02	0.03	0.05	0.02	0.03	0.9343
Environment/Health	0.08	0.06	0.04	0.08	0.13	0.02	0.07	1.1138
Economic/Cost	0.17	0.18	0.11	0.08	0.13	0.07	0.12	1.1626
Socio-Cultural	0.25	0.18	0.32	0.23	0.19	0.30	0.24	1.0472
Technical	0.22	0.18	0.32	0.47	0.38	0.44	0.34	0.8806
Sensorial	0.25	0.37	0.21	0.12	0.13	0.15	0.20	1.3773
Total	1	1	1	1	1	1	1	6.52

Matrix Size 6
RI 1.24
CI 0.103
CR ✓ 0.08

Fig. 13. Computing the relative priority scores of parent factors

Next, the parent criteria matrices are normalised (by dividing a cell value by the sum of each column) and then checked for consistency using Eigen values as shown in Fig. 13. A localpriority vector score is then generated for the matrix of judgments by normalizing the vector in each column of the matrix (i.e. dividing each entry of the column by the column total) and then averaging over the rows of the resulting matrix [49]. The normalized eigenvector shown in Fig. 13 represents the relative importance of each parent criteria.

Based on the calculation in Fig. 12, the relative priorities of the parent factors in the final selection of a sustainable floor material were calculated as displayed in Fig. 13. The resulting local priority vectors were given as: (GS=0.030, EH=0.070, C=0.120, SC=0.240, T=0.340, and SN=0.200) as shown in Table 8.

Table 8. Relative priorities of criteria

Factor/Criterion	Relative priority
General/Site	0.030
Environmental/Health	0.070
Economic/Cost	0.120
Socio Cultural	0.240
Technical	0.340
Sensorial	0.200

In order to measure the level of consistency of the matrix of comparison for the parent factors, the consistency index (CI) was then calculated at 0.103 (Fig. 12). The random index (RI) was also taken into consideration and values calculated at this stage of the evaluation exercise. According to Saaty (2008), for matrix of order 6, the RI is 1.24 (Table 5). Given the two values (consisting of both the consistency index (CI=0.103) and the relative index (RI= 1.24), the CR was then calculated as:

CR = CI/RI = 0.103/1.24= 0.083 (Fig. 12).

According to the AHP model, a matrix is considered as being consistent when the CR is less than 10%. With a Consistency Ratio (CR) of 0.083, the matrix was considered consistent since it was less than 0.1.

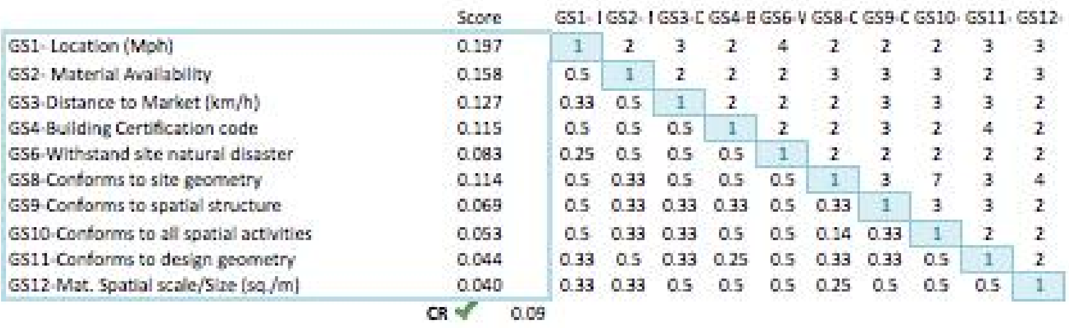
5.5 Step 3: Pair-Wise Analysis of the Sub-Factors

The results of the next pairwise comparison and normalised matrices of the relative sub-factors are shown in Figs. 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24 and 25. The same calculations done for the principal matrices of the parent factors were also done for the matrices of the sub-factors. The local priority vector and the consistency ratio for each sub-criterion matrix were also computed and displayed on each corresponding table as fully displayed below.

Material Property Weightings

ΣCR ✓ 0.02

User Optional:
Please Adjust Scores in any desired ORANGE fields by selecting from the drop-down list



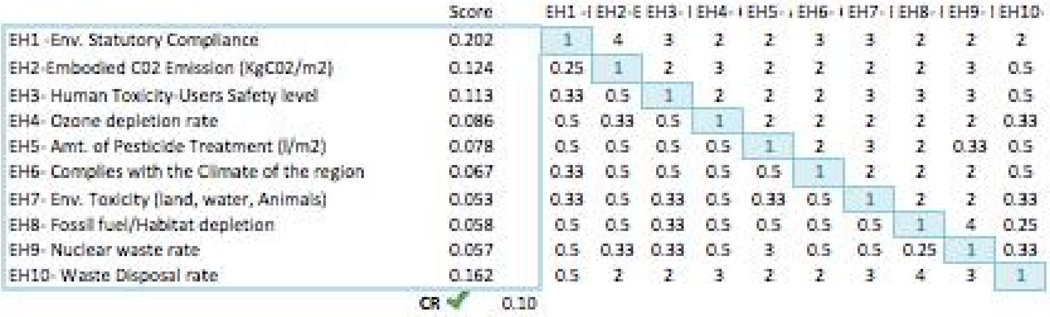
	Score	GS1- I	GS2- I	GS3-C	GS4-B	GS6-V	GS8-C	GS9-C	GS10-	GS11-	GS12-
GS1- Location (Mph)	0.197	1	2	3	2	4	2	2	2	3	3
GS2- Material Availability	0.158	0.5	1	2	2	2	3	3	3	2	3
GS3-Distance to Market (km/h)	0.127	0.33	0.5	1	2	2	2	3	3	3	2
GS4-Building Certification code	0.115	0.5	0.5	0.5	1	2	2	3	2	4	2
GS6-Withstand site natural disaster	0.083	0.25	0.5	0.5	0.5	1	2	2	2	2	2
GS8-Conforms to site geometry	0.114	0.5	0.33	0.5	0.5	0.5	1	3	7	3	4
GS9-Conforms to spatial structure	0.069	0.5	0.33	0.33	0.33	0.5	0.33	1	3	3	2
GS10-Conforms to all spatial activities	0.053	0.5	0.33	0.33	0.5	0.5	0.14	0.33	1	2	2
GS11-Conforms to design geometry	0.044	0.33	0.5	0.33	0.25	0.5	0.33	0.33	0.5	1	2
GS12-Mat. Spatial scale/Size (sq./m)	0.040	0.33	0.33	0.5	0.5	0.5	0.25	0.5	0.5	0.5	1
CR ✓	0.09										

Fig. 14. Pair-wise matrix & priority scores for general/site factors

Normalised Matrix										λ_{MAX}
0.21	0.32	0.33	0.21	0.3	0.15	0.11	0.08	0.13	0.13	0.935
0.11	0.16	0.22	0.21	0.15	0.23	0.17	0.13	0.09	0.13	0.999
0.07	0.08	0.11	0.21	0.15	0.15	0.17	0.13	0.13	0.09	1.147
0.11	0.08	0.06	0.1	0.15	0.15	0.17	0.08	0.17	0.09	1.103
0.05	0.08	0.06	0.05	0.07	0.15	0.11	0.08	0.09	0.09	1.123
0.11	0.05	0.06	0.05	0.04	0.08	0.17	0.29	0.13	0.17	1.486
0.11	0.05	0.04	0.03	0.04	0.03	0.06	0.13	0.13	0.09	1.248
0.11	0.05	0.04	0.05	0.04	0.01	0.02	0.04	0.09	0.09	1.265
0.07	0.08	0.04	0.03	0.04	0.03	0.02	0.02	0.04	0.09	1.042
0.07	0.05	0.06	0.05	0.04	0.02	0.03	0.02	0.02	0.04	0.920

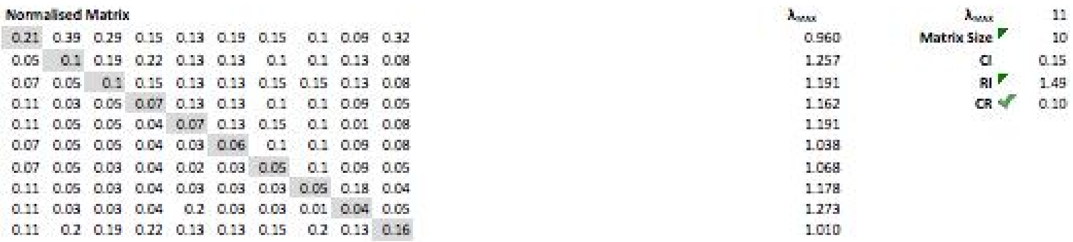
λ_{MAX}	11
Matrix Size	10
CI	0.14
RI	1.49
CR ✓	0.09

Fig. 15. Normalised matrices for general/site factors
C.I. =0.14, R.I. =1.49, C.R. =0.09.



	Score	EH1 -I	EH2-E	EH3- I	EH4- I	EH5- I	EH6- I	EH7- I	EH8- I	EH9- I	EH10-
EH1 -Env. Statutory Compliance	0.202	1	4	3	2	2	3	3	2	2	2
EH2-Embodied C02 Emission (KgC02/m2)	0.124	0.25	1	2	3	2	2	2	2	3	0.5
EH3- Human Toxicity-Users Safety level	0.113	0.33	0.5	1	2	2	2	3	3	3	0.5
EH4- Ozone depletion rate	0.086	0.5	0.33	0.5	1	2	2	2	2	2	0.33
EH5- Amt. of Pesticide Treatment (l/m2)	0.078	0.5	0.5	0.5	0.5	1	2	3	2	0.33	0.5
EH6- Complies with the Climate of the region	0.067	0.33	0.5	0.5	0.5	0.5	1	2	2	2	0.5
EH7- Env. Toxicity (land, water, Animals)	0.053	0.33	0.5	0.33	0.5	0.33	0.5	1	2	2	0.33
EH8- Fossil fuel/Habitat depletion	0.058	0.5	0.5	0.33	0.5	0.5	0.5	0.5	1	4	0.25
EH9- Nuclear waste rate	0.057	0.5	0.33	0.33	0.5	3	0.5	0.5	0.25	1	0.33
EH10- Waste Disposal rate	0.162	0.5	2	2	3	2	2	3	4	3	1
CR ✓	0.10										

Fig. 16. Pair-wise matrix & priority scores for environmental/health factors



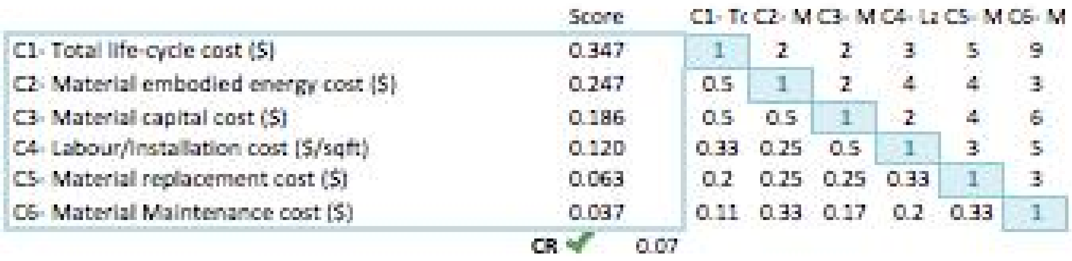
Normalised Matrix

										λ_{max}
0.21	0.39	0.29	0.15	0.13	0.19	0.15	0.1	0.09	0.32	0.960
0.05	0.1	0.19	0.22	0.13	0.13	0.1	0.1	0.13	0.08	1.257
0.07	0.05	0.1	0.15	0.13	0.13	0.15	0.15	0.13	0.08	1.191
0.11	0.03	0.05	0.07	0.13	0.13	0.1	0.1	0.09	0.05	1.162
0.11	0.05	0.05	0.04	0.07	0.13	0.15	0.1	0.01	0.08	1.191
0.07	0.05	0.05	0.04	0.03	0.06	0.1	0.1	0.09	0.08	1.038
0.07	0.05	0.03	0.04	0.02	0.03	0.05	0.1	0.09	0.05	1.068
0.11	0.05	0.03	0.04	0.03	0.03	0.03	0.05	0.18	0.04	1.178
0.11	0.03	0.03	0.04	0.2	0.03	0.03	0.01	0.04	0.05	1.273
0.11	0.2	0.19	0.22	0.13	0.13	0.15	0.2	0.13	0.16	1.010

λ_{max}	11
Matrix Size	10
CI	0.15
RI	1.49
CR ✓	0.10

Fig. 17. Normalised matrices for environmental/health factors

C.I. =0.15, R.I. =1.49, C.R. =0.10.



	Score	C1- Tc	C2- M	C3- M	C4- La	C5- M	C6- M
C1- Total life-cycle cost ($)	0.347	1	2	2	3	5	9
C2- Material embodied energy cost ($)	0.247	0.5	1	2	4	4	3
C3- Material capital cost ($)	0.186	0.5	0.5	1	2	4	6
C4- Labour/installation cost ($/sqft)	0.120	0.33	0.25	0.5	1	3	5
C5- Material replacement cost ($)	0.063	0.2	0.25	0.25	0.33	1	3
C6- Material Maintenance cost ($)	0.037	0.11	0.33	0.17	0.2	0.33	1
CR ✓	0.07						

Fig. 18. Pair-wise matrix & priority scores for economic/cost factors

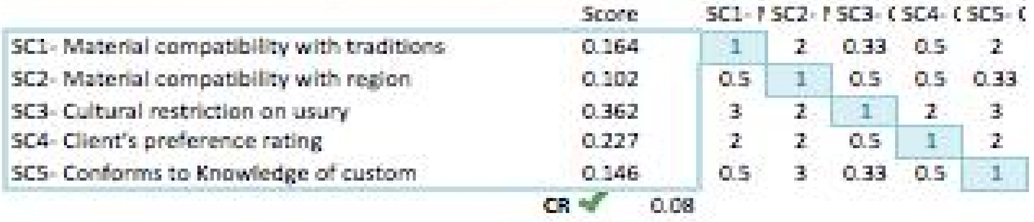
Normalised Matrix

						λ_{max}
0.38	0.46	0.34	0.28	0.29	0.33	0.919
0.19	0.23	0.34	0.38	0.23	0.11	1.069
0.19	0.12	0.17	0.19	0.23	0.22	1.101
0.13	0.06	0.08	0.09	0.17	0.19	1.267
0.08	0.06	0.04	0.03	0.06	0.11	1.086
0.04	0.08	0.03	0.02	0.02	0.04	1.001

λ_{max}	6
Matrix Size	6
CI	0.09
RI	1.24
CR ✓	0.07

Fig. 19. Normalised matrices for economic/cost factors

C.I. =0.09, R.I. =1.24, C.R. =0.07.



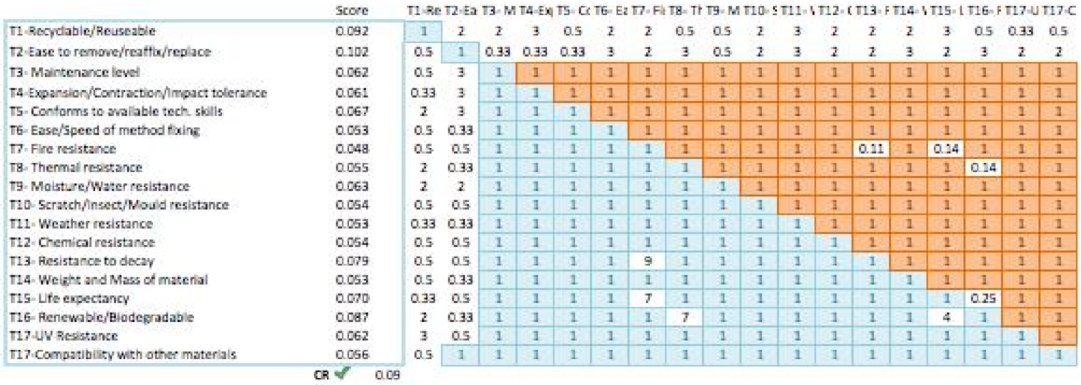
	Score	SC1- F	SC2- F	SC3- C	SC4- C	SC5- C
SC1- Material compatibility with traditions	0.164	1	2	0.33	0.5	2
SC2- Material compatibility with region	0.102	0.5	1	0.5	0.5	0.33
SC3- Cultural restriction on usury	0.362	3	2	1	2	3
SC4- Client's preference rating	0.227	2	2	0.5	1	2
SC5- Conforms to Knowledge of custom	0.146	0.5	3	0.33	0.5	1
CR ✓	0.08					

Fig. 20. Pair-wise matrix & priority scores for socio-cultural factors

Normalised Matrix					λ_{max}	λ_{max}	5
0.14	0.2	0.13	0.11	0.24	1.147	Matrix Size	5
0.07	0.1	0.15	0.11	0.04	1.020	CI	0.09
0.43	0.2	0.38	0.44	0.36	0.964	RI	1.12
0.29	0.2	0.19	0.22	0.24	1.022	CR ✓	0.08
0.07	0.3	0.13	0.11	0.12	1.213		

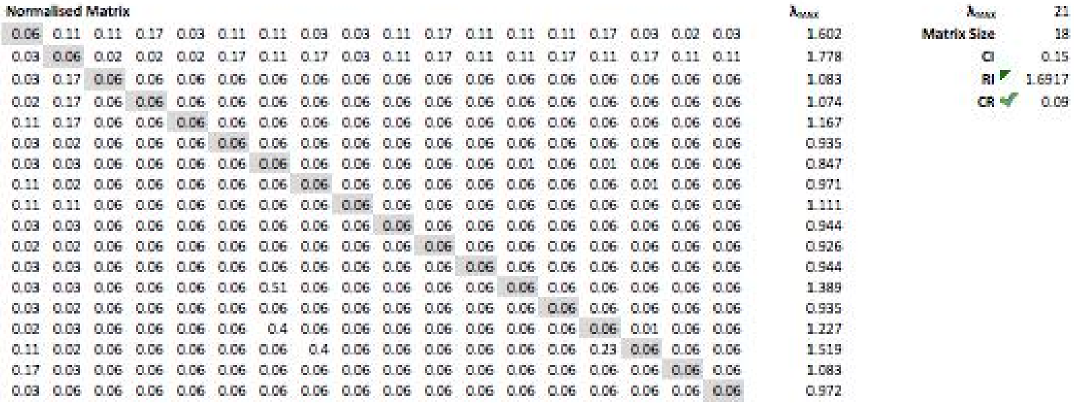
Fig. 21. Normalised matrices for socio-cultural factors

C.I. =0.09, R.I. =1.12, C.R. =0.08.



	Score	T1-Re	T2-Ea	T3- M	T4-Ex	T5- C	T6- E	T7- Fi	T8- Th	T9- M	T10- S	T11-	T12-	T13- R	T14-	T15- L	T16- R	T17-U	T17-C
T1-Recyclable/Reuseable	0.092	1	2	2	3	0.5	2	2	0.5	0.5	2	3	2	2	2	3	0.5	0.33	0.5
T2-Ease to remove/reaffix/replace	0.102	0.5	1	0.33	0.33	0.33	3	2	3	0.5	2	3	2	2	3	2	3	2	2
T3- Maintenance level	0.062	0.5	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T4-Expansion/Contraction/Impact tolerance	0.061	0.33	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T5- Conforms to available tech. skills	0.067	2	3	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T6- Ease/Speed of method fixing	0.053	0.5	0.33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T7- Fire resistance	0.048	0.5	0.5	1	1	1	1	1	1	1	1	1	1	0.11	1	0.14	1	1	1
T8- Thermal resistance	0.055	2	0.33	1	1	1	1	1	1	1	1	1	1	1	1	1	0.14	1	1
T9- Moisture/Water resistance	0.063	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T10- Scratch/Insect/Mould resistance	0.054	0.5	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T11- Weather resistance	0.053	0.33	0.33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T12- Chemical resistance	0.054	0.5	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T13- Resistance to decay	0.079	0.5	0.5	1	1	1	1	9	1	1	1	1	1	1	1	1	1	1	1
T14- Weight and Mass of material	0.053	0.5	0.33	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T15- Life expectancy	0.070	0.33	0.5	1	1	1	1	7	1	1	1	1	1	1	1	1	0.25	1	1
T16- Renewable/Biodegradable	0.087	2	0.33	1	1	1	1	1	7	1	1	1	1	1	1	4	1	1	1
T17-UV Resistance	0.062	3	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
T17-Compatibility with other materials	0.056	0.5	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
CR ✓	0.09																		

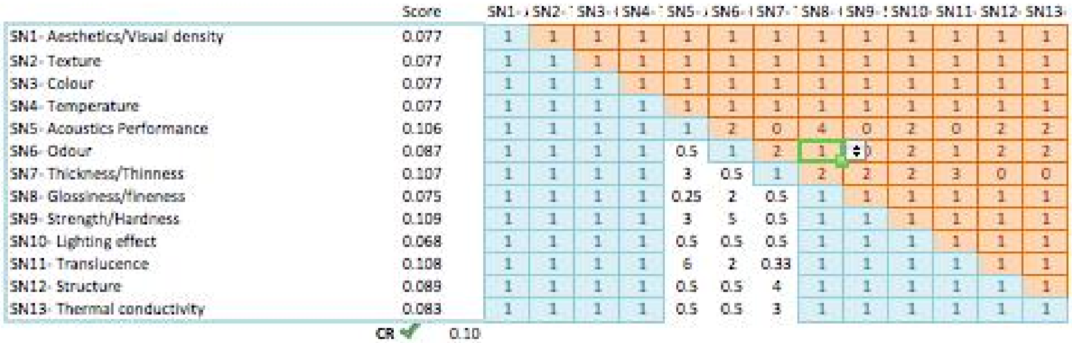
Fig. 22. Pair-wise matrix & priority scores for technical factors



Normalised Matrix																		λ_{max}	λ_{max}	21
0.06	0.11	0.11	0.17	0.03	0.11	0.11	0.03	0.03	0.11	0.17	0.11	0.11	0.11	0.17	0.03	0.02	0.03	1.602	Matrix Size	18
0.03	0.06	0.02	0.02	0.02	0.17	0.11	0.17	0.03	0.11	0.17	0.11	0.11	0.17	0.11	0.17	0.11	0.11	1.778	CI	0.15
0.03	0.17	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	1.083	RI	1.6917
0.02	0.17	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	1.074	CR ✓	0.09
0.11	0.17	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	1.167		
0.03	0.02	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.935		
0.03	0.03	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.01	0.06	0.01	0.06	0.06	0.06	0.847		
0.11	0.02	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.01	0.06	0.06	0.971		
0.11	0.11	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	1.111		
0.03	0.03	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.944		
0.02	0.02	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.926		
0.03	0.03	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.944		
0.03	0.03	0.06	0.06	0.06	0.06	0.51	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	1.389		
0.03	0.02	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.935		
0.02	0.03	0.06	0.06	0.06	0.06	0.4	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.01	0.06	0.06	1.227		
0.11	0.02	0.06	0.06	0.06	0.06	0.06	0.4	0.06	0.06	0.06	0.06	0.06	0.06	0.23	0.06	0.06	0.06	1.519		
0.17	0.03	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	1.083		
0.03	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.972		

Fig. 23. Normalised matrices for technical factors

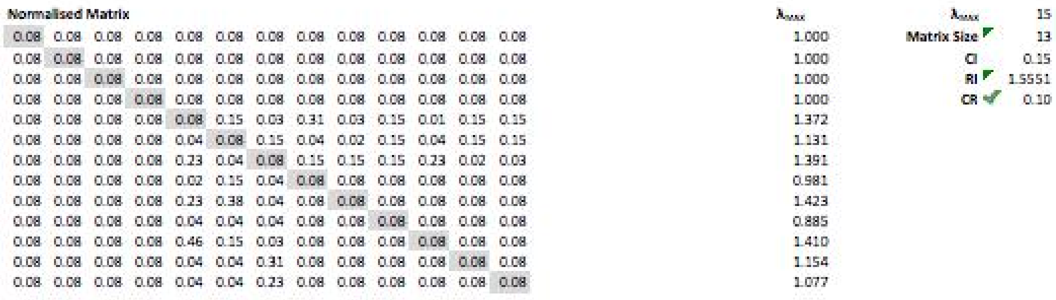
C.I. =0.25, R.I. =1.6917, C.R. =0.10.



	Score	SN1	SN2	SN3	SN4	SN5	SN6	SN7	SN8	SN9	SN10	SN11	SN12	SN13
SN1- Aesthetics/Visual density	0.077	1	1	1	1	1	1	1	1	1	1	1	1	1
SN2- Texture	0.077	1	1	1	1	1	1	1	1	1	1	1	1	1
SN3- Colour	0.077	1	1	1	1	1	1	1	1	1	1	1	1	1
SN4- Temperature	0.077	1	1	1	1	1	1	1	1	1	1	1	1	1
SN5- Acoustics Performance	0.106	1	1	1	1	1	2	0	4	0	2	0	2	2
SN6- Odour	0.087	1	1	1	1	0.5	1	2	1	0	2	1	2	2
SN7- Thickness/Thinness	0.107	1	1	1	1	3	0.5	1	2	2	2	3	0	0
SN8- Glossiness/fineness	0.075	1	1	1	1	0.25	2	0.5	1	1	1	1	1	1
SN9- Strength/Hardness	0.109	1	1	1	1	3	5	0.5	1	1	1	1	1	1
SN10- Lighting effect	0.068	1	1	1	1	0.5	0.5	0.5	1	1	1	1	1	1
SN11- Translucence	0.108	1	1	1	1	6	2	0.33	1	1	1	1	1	1
SN12- Structure	0.089	1	1	1	1	0.5	0.5	4	1	1	1	1	1	1
SN13- Thermal conductivity	0.083	1	1	1	1	0.5	0.5	3	1	1	1	1	1	1

CR ✓ 0.10

Fig. 24. Pair-wise matrix & priority scores for sensorial factors



Normalised Matrix

													λ_{max}
0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	1.000
0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	1.000
0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	1.000
0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.08	1.000
0.08	0.08	0.08	0.08	0.08	0.15	0.03	0.31	0.03	0.15	0.01	0.15	0.15	1.372
0.08	0.08	0.08	0.08	0.04	0.08	0.15	0.04	0.02	0.15	0.04	0.15	0.15	1.131
0.08	0.08	0.08	0.08	0.23	0.04	0.08	0.15	0.15	0.15	0.23	0.02	0.03	1.391
0.08	0.08	0.08	0.08	0.02	0.15	0.04	0.08	0.08	0.08	0.08	0.08	0.08	0.981
0.08	0.08	0.08	0.08	0.23	0.38	0.04	0.08	0.08	0.08	0.08	0.08	0.08	1.423
0.08	0.08	0.08	0.08	0.04	0.04	0.04	0.08	0.08	0.08	0.08	0.08	0.08	0.885
0.08	0.08	0.08	0.08	0.46	0.15	0.03	0.08	0.08	0.08	0.08	0.08	0.08	1.410
0.08	0.08	0.08	0.08	0.04	0.04	0.31	0.08	0.08	0.08	0.08	0.08	0.08	1.154
0.08	0.08	0.08	0.08	0.04	0.04	0.23	0.08	0.08	0.08	0.08	0.08	0.08	1.077

λ_{max}	15
Matrix Size	13
CI	0.15
RI	1.5551
CR ✓	0.10

Fig. 25. Normalised matrices for sensorial factors

C.I. =0.15, R.I. =1.5551, C.R. =0.10.

After comparing each sub-factor according to the user's system of value over other sub-factors, the weightings were obtained to establish each priority weightings in the context of the overall goal: selecting the most sustainable low-cost green floor material. The criteria matrices of each sub-factor were then normalised (by dividing a cell value by the sum of each column) and then checked for consistency as shown all through Figs. 14 to 25.

5.6 Step 4: Determining the Weighting Scores of the Factors

The next stage of the assessment process was to find the final weightings of both the parent and sub-factors that will be used subsequently to evaluate the material attributes for sustainable building material selection. To determine the final weightings of the selected factors, the priority vectors (1) of the parent factors are multiplied by the corresponding relative priority vectors of each sub-criterion weighting vectors (2) to obtain the (final) weighting (3) as shown in Table 9.

The following steps describes the ways by which the various weighting vectors of each criterion are derived

The main/parent factor weighting is derived from users' judgments with respect to a single main criterion. The resultant value of the comparison of each parent factor serves as the priority vector of the main criteria needed for evaluating material attributes. The selected value for each parent factor as shown in Table 9 include: GS=0.026, EH=0.068, C=0.122, SC=0.245, T=0.335 and SN=0.203.

The Sub-~factor weighting is derived from user's judgment with respect to each sub-factor. Some of the selected values that serve as the corresponding relative priority vectors of the general/site variable include: 0.197, 0.158, 0.127, 0.115, 0.083, 0.114, 0.069, 0.053, 0.044, and 0.040 as shown in Table 9.

Final weighting is derived from multiplying the selected value of the main criteria-weighting or priority vector by the selected value of the sub-factor priority vector. This entry is obtained as follows: 0.026 x 0.197= 0.005122 (as highlighted in Table 9). The same process was applied to the other parent factors of the respective categories.

5.7 Step 5: Performing Pair-Wise Comparison of the Selected Material Alternatives against Each Sub-Factor

The final step of the exercise was for the respondents to compare each pair of low-cost green material alternatives with respect to each sub-factor. Here the user evaluates the criteria/factors and material alternatives by comparing them through direct rating, to know which factor is more important; how many times; and which material alternative is better in the context of each factor. The corresponding weightings were based on the importance that the evaluators attached to the dominance of each material alternative relative to all other alternatives under each sub-criterion. These matrices were also normalized and checked for consistency as shown in Figs. 26, 27, 28, 28, 30, 31, 32, 33, 34, 35, 36 and 37.Figs. 26, 27, 28, 28, 30, 31, 32, 33, 34, 35, 36 and 37 present some results of the analyses, which explain the pair-wise matrix priority weightings and normalisation matrices of the various materials with respect to each sub-criterion. Fig. 38 displays the various scores of the Green Utility Index (GUI) resulting from the analysis.

5.8 Step 6: Amalgamating the Results

The next phase, after analysing the pair-wise matrices of the sub-factors against the various low-cost green floor material alternatives was to normalize the priority weights for each pair-wise comparison judgment matrices. Once the normalised matrices of the floor material alternatives and various sub-factors were obtained, the values derived from the analysis were multiplied and summed to obtain the final composite priority weights of all material alternatives, focusing particularly on the three floor materials used in the fourth level of the AHP model of decision-making shown in Fig. 6.

Table 9. Derived final weightings for Site criteria used for the hypothetical case study

Parent factor/Criteria weighting(1)					**Sub-factor/Criteria weighting(2)**				**Final weighting(3)**
Criteria	**User value**	**Default**	**CR <0.1**	**Selected value**	**Sub-criteria**	**User value**	**CR <0.1**	**Selected value**	**Total=1.0000**
General/Site	0.03	0.057	0.08	**0.026**	**GS1- Location (Mph)**	**0.197**	0.09	**0.197**	**0.0051**
					GS2- Material Availability	0.158		0.158	0.0041
					GS3-Distance to Market (km/h)	0.127		0.127	0.0033
					GS4-Building Certification code	0.115		0.115	0.0030
					GS6-Withstand site natural disaster	0.083		0.083	0.0022
					GS8-Conforms to site geometry	0.114		0.114	0.0030
					GS9-Conforms to spatial structure	0.069		0.069	0.0018
					GS10-Conforms to all spatial activities	0.053		0.053	0.0014
					GS11-Conforms to design geometry	0.044		0.044	0.0012
					GS12-Mat. Spatial scale/Size (sq./m)	0.040		0.040	0.0010

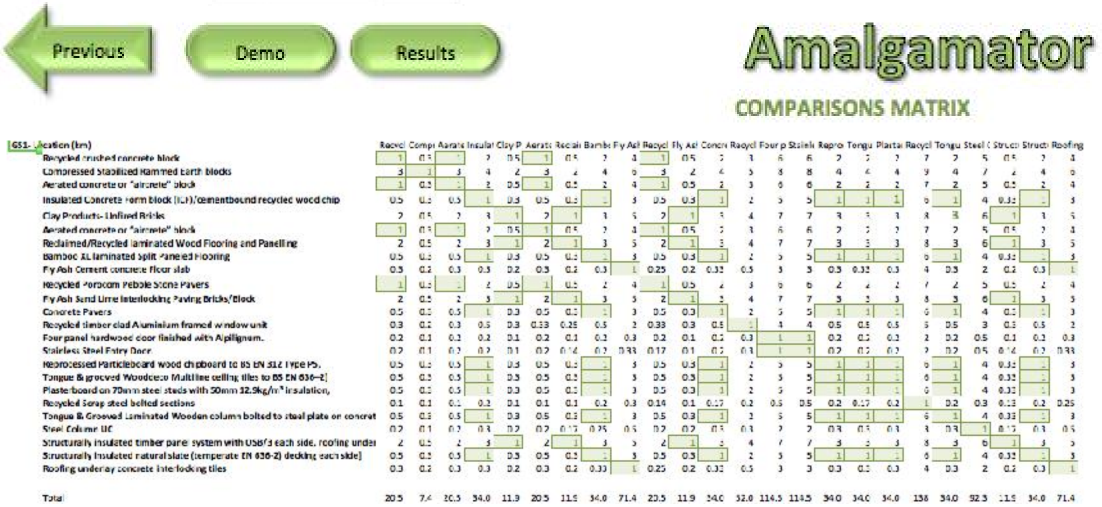
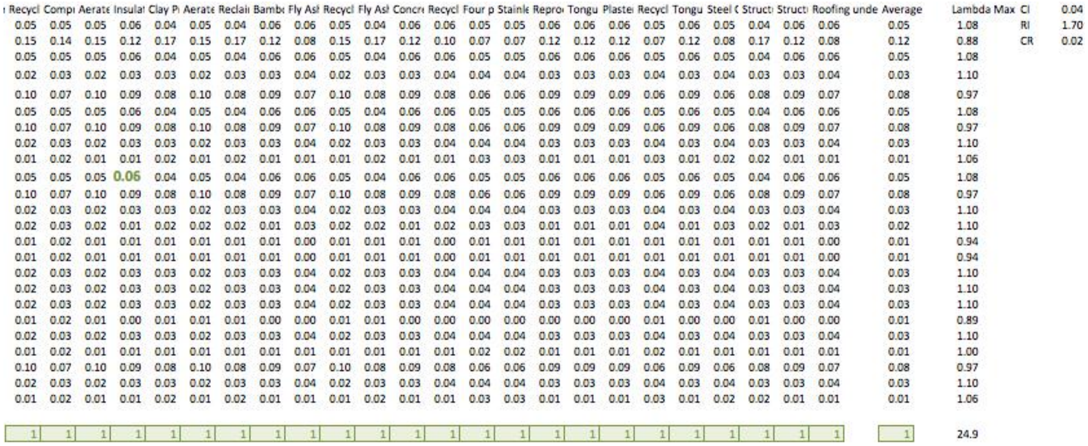


Fig. 26. GS1- Pair-wise matrix & priority scores for location



Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaster	Recycl	Tongu	Steel C	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.04
0.05	0.05	0.05	0.06	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.05	0.04	0.06	0.06	0.05	1.08	RI	1.70
0.15	0.14	0.15	0.12	0.17	0.15	0.17	0.12	0.08	0.15	0.17	0.12	0.10	0.07	0.07	0.12	0.12	0.12	0.07	0.12	0.08	0.17	0.12	0.08	0.12	0.88	CR	0.02
0.05	0.05	0.05	0.06	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.05	0.04	0.06	0.06	0.05	1.08		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.10	0.07	0.10	0.09	0.08	0.10	0.08	0.09	0.07	0.10	0.08	0.09	0.08	0.06	0.06	0.09	0.09	0.09	0.06	0.09	0.06	0.08	0.09	0.07	0.08	0.97		
0.05	0.05	0.05	0.06	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.05	0.04	0.06	0.06	0.05	1.08		
0.10	0.07	0.10	0.09	0.08	0.10	0.08	0.09	0.07	0.10	0.08	0.09	0.08	0.06	0.06	0.09	0.09	0.09	0.06	0.09	0.06	0.08	0.09	0.07	0.08	0.97		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.01	0.03	0.01	0.02	0.02	0.01	0.01	0.01	1.06		
0.05	0.05	0.05	0.06	0.04	0.05	0.04	0.06	0.06	0.05	0.04	0.06	0.06	0.05	0.05	0.06	0.06	0.06	0.05	0.06	0.05	0.04	0.06	0.06	0.05	1.08		
0.10	0.07	0.10	0.09	0.08	0.10	0.08	0.09	0.07	0.10	0.08	0.09	0.08	0.06	0.06	0.09	0.09	0.09	0.06	0.09	0.06	0.08	0.09	0.07	0.08	0.97		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.02	0.03	0.02	0.01	0.02	0.02	0.02	0.01	0.03	0.02	0.02	0.01	0.02	0.03	0.03	0.01	0.01	0.01	0.04	0.01	0.03	0.02	0.01	0.03	0.02	1.10		
0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.94		
0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.94		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.01	0.02	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.89		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	1.00		
0.10	0.07	0.10	0.09	0.08	0.10	0.08	0.09	0.07	0.10	0.08	0.09	0.08	0.06	0.06	0.09	0.09	0.09	0.06	0.09	0.06	0.08	0.09	0.07	0.08	0.97		
0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.04	0.02	0.03	0.03	0.04	0.04	0.04	0.03	0.03	0.03	0.04	0.03	0.04	0.03	0.03	0.04	0.03	1.10		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.01	0.01	0.01	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.01	0.03	0.01	0.02	0.02	0.01	0.01	0.01	1.06		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.9		

Fig. 27. GS1-normilised matrices for location

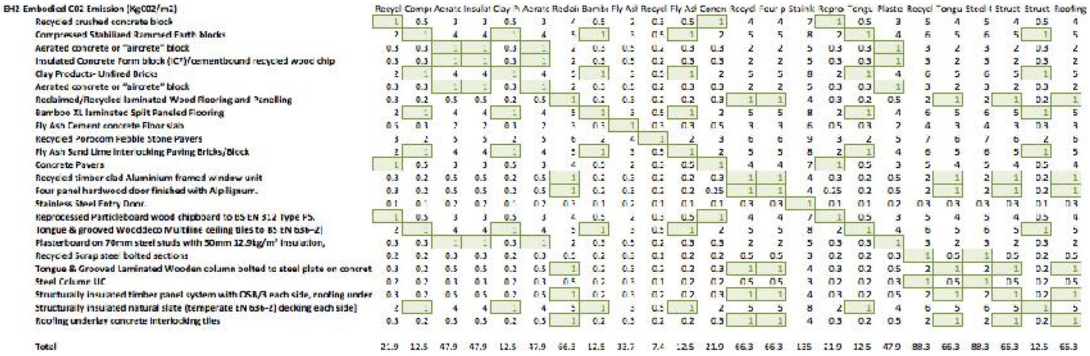
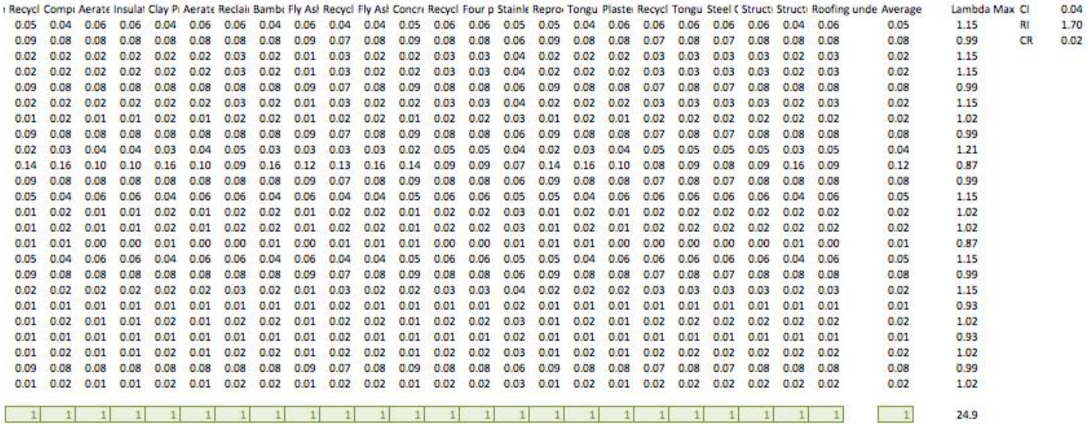
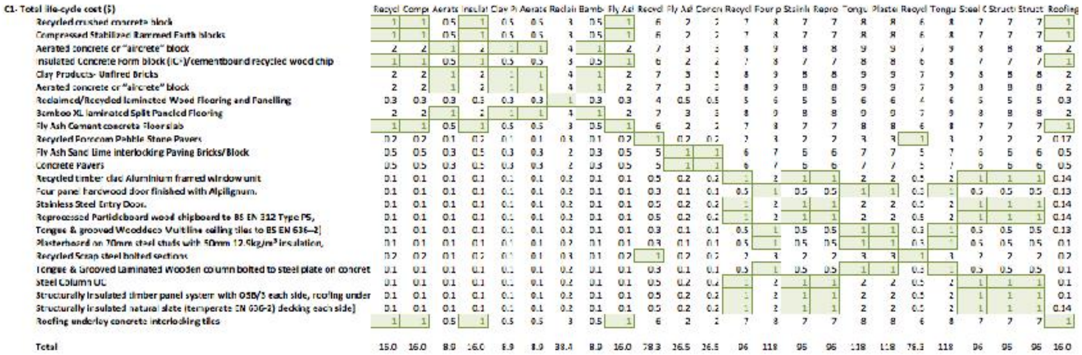


Fig. 28. EH2- Pair-wise matrix & priority scores for embodied carbonemission



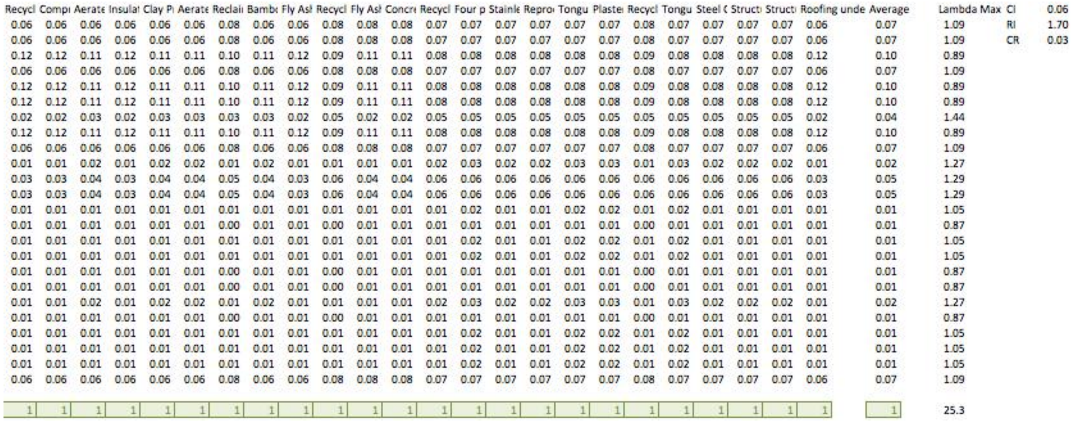
Recycl	Compi	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structu	Structu	Roofing unde	Average	Lambda Max	CI	0.04
0.05	0.04	0.06	0.06	0.04	0.06	0.06	0.04	0.06	0.04	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.06	0.06	0.06	0.06	0.06	0.04	0.06	0.05	1.15	RI	1.70
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99	CR	0.02
0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.02	1.15		
0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.02	1.15		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.02	1.15		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.02	0.03	0.04	0.04	0.03	0.04	0.05	0.03	0.03	0.03	0.03	0.02	0.05	0.05	0.04	0.02	0.03	0.04	0.05	0.05	0.05	0.05	0.03	0.05	0.04	1.21		
0.14	0.16	0.10	0.10	0.16	0.10	0.09	0.16	0.12	0.13	0.16	0.14	0.09	0.09	0.07	0.14	0.16	0.10	0.08	0.09	0.08	0.09	0.16	0.09	0.12	0.87		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.05	0.04	0.06	0.06	0.04	0.06	0.06	0.04	0.06	0.04	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.06	0.06	0.06	0.06	0.06	0.04	0.06	0.05	1.15		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.01	0.01	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.01	0.87		
0.05	0.04	0.06	0.06	0.04	0.06	0.06	0.04	0.06	0.04	0.04	0.05	0.06	0.06	0.05	0.05	0.04	0.06	0.06	0.06	0.06	0.06	0.04	0.06	0.05	1.15		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.02	0.02	0.02	0.02	0.02	0.02	0.03	0.02	0.01	0.03	0.02	0.02	0.03	0.03	0.04	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.02	0.03	0.02	1.15		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.93		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.93		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
0.09	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.07	0.08	0.09	0.08	0.08	0.06	0.09	0.08	0.08	0.07	0.08	0.07	0.08	0.08	0.08	0.08	0.99		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.02	0.02	0.03	0.01	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	1.02		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.9		

Fig. 29. **EH2- Normalised matrices for embodied carbonemission**



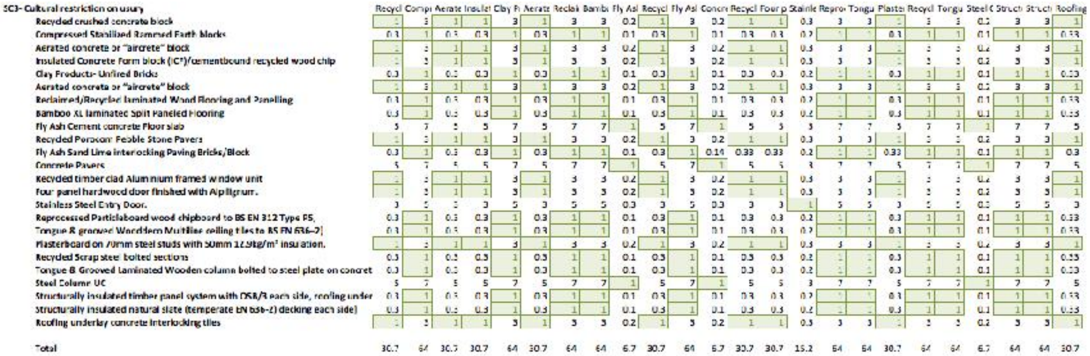
C1- Total life-cycle cost ($)	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structu	Struct	Roofing
Recycled crushed concrete block	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Compressed Stabilized Rammed Earth blocks	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Aerated concrete or "aircrete" block	2	2	1	2	1	1	4	1	2	7	3	3	8	9	8	8	9	9	7	9	8	8	8	2
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Clay Products- Unfired Bricks	2	2	1	2	1	1	4	1	2	7	3	3	8	9	8	8	9	9	7	9	8	8	8	2
Aerated concrete or "aircrete" block	2	2	1	2	1	1	4	1	2	7	3	3	8	9	8	8	9	9	7	9	8	8	8	2
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.3	0.3	0.3	0.3	0.3	0.3	1	0.3	0.3	4	0.5	0.5	5	6	5	5	6	6	4	6	5	5	5	0.3
Bamboo XL laminated Split Panelled Flooring	2	2	1	2	1	1	4	1	2	7	3	3	8	9	8	8	9	9	7	9	8	8	8	2
Fly Ash Cement concrete Floor slab	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Recycled Porcom Pebble Stone Pavers	0.2	0.2	0.1	0.2	0.1	0.1	0.3	0.1	0.2	1	0.2	0.2	2	3	2	2	3	3	1	3	2	2	2	0.17
Fly Ash Sand Lime interlocking Paving Bricks/Block	0.5	0.5	0.3	0.5	0.3	0.3	2	0.3	0.5	5	1	1	6	7	6	6	7	7	5	7	6	6	6	0.5
Concrete Pavers	0.5	0.5	0.3	0.5	0.3	0.3	2	0.3	0.5	5	1	1	6	7	6	6	7	7	5	7	6	6	6	0.5
Recycled timber clad Aluminium framed window unit	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.14
Four panel hardwood door finished with Alpilignum.	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.5	1	0.5	0.5	1	1	0.3	1	0.5	0.5	0.5	0.13
Stainless Steel Entry Door.	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.14
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.14
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636–2]	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.5	1	0.5	0.5	1	1	0.3	1	0.5	0.5	0.5	0.13
Plasterboard on 70mm steel studs with 50mm 12.5kg/m^3 insulation,	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.5	1	0.5	0.5	1	1	0.3	1	0.5	0.5	0.5	0.1
Recycled Scrap steel bolted sections	0.2	0.2	0.1	0.2	0.1	0.1	0.3	0.1	0.2	1	0.2	0.2	2	3	2	2	3	3	1	3	2	2	2	0.2
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.3	0.1	0.1	0.5	1	0.5	0.5	1	1	0.3	1	0.5	0.5	0.5	0.1
Steel Column UC	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.1
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.1
Structurally insulated natural slate (temperate EN 636-2) decking each side]	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.1	0.1	0.5	0.2	0.2	1	2	1	1	2	2	0.5	2	1	1	1	0.14
Roofing underlay concrete interlocking tiles	1	1	0.5	1	0.5	0.5	3	0.5	1	6	2	2	7	8	7	7	8	8	6	8	7	7	7	1
Total	15.0	16.0	8.9	16.0	8.9	8.9	38.4	8.9	16.0	78.3	26.5	26.5	96	118	96	96	118	118	76.3	118	96	96	96	16.0

Fig. 30. **C1- Pair-wise matrix & priority scores for total life-cycle cost**



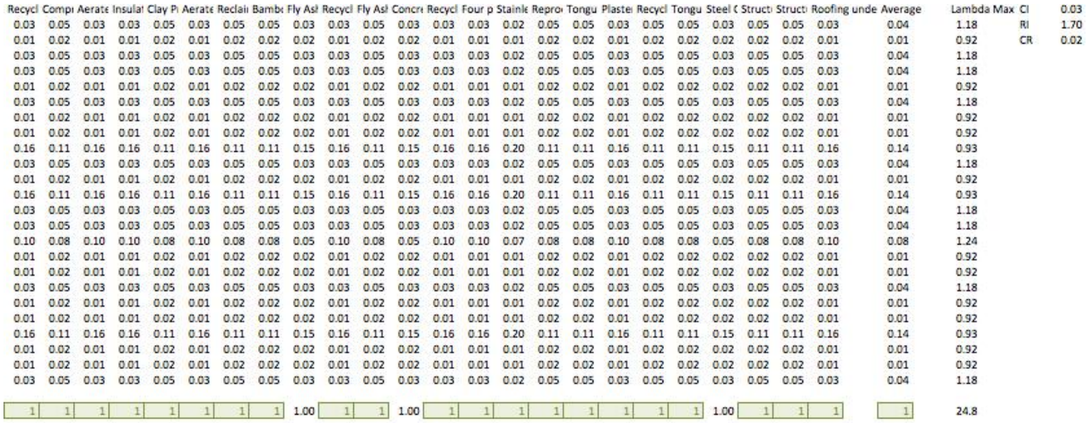
Recycl	Compi	Aerate	Insulat	Clay P	Aerate	Reclai	Bamb	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structu	Structu	Roofing unde	Average	Lambda Max	CI	0.06
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09	RI	1.70
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09	CR	0.03
0.12	0.12	0.11	0.12	0.11	0.11	0.10	0.11	0.12	0.09	0.11	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.12	0.10	0.89		
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09		
0.12	0.12	0.11	0.12	0.11	0.11	0.10	0.11	0.12	0.09	0.11	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.12	0.10	0.89		
0.12	0.12	0.11	0.12	0.11	0.11	0.10	0.11	0.12	0.09	0.11	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.12	0.10	0.89		
0.02	0.02	0.03	0.02	0.03	0.03	0.03	0.03	0.02	0.05	0.02	0.02	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.02	0.04	1.44		
0.12	0.12	0.11	0.12	0.11	0.11	0.10	0.11	0.12	0.09	0.11	0.11	0.08	0.08	0.08	0.08	0.08	0.08	0.09	0.08	0.08	0.08	0.08	0.12	0.10	0.89		
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09		
0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.02	0.03	0.03	0.01	0.03	0.02	0.02	0.02	0.01	0.02	1.27		
0.03	0.03	0.04	0.03	0.04	0.04	0.05	0.04	0.03	0.06	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.05	1.29		
0.03	0.03	0.04	0.03	0.04	0.04	0.05	0.04	0.03	0.06	0.04	0.04	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.06	0.03	0.05	1.29		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.87		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.87		
0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.87		
0.01	0.01	0.02	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.03	0.02	0.02	0.03	0.03	0.01	0.03	0.02	0.02	0.02	0.01	0.02	1.27		
0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.87		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.02	0.01	0.01	0.01	0.01	0.01	1.05		
0.06	0.06	0.06	0.06	0.06	0.06	0.08	0.06	0.06	0.08	0.08	0.08	0.07	0.07	0.07	0.07	0.07	0.07	0.08	0.07	0.07	0.07	0.07	0.06	0.07	1.09		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	25.3		

Fig. 31. **C1- Normalised matrices for total life-cycle cost**



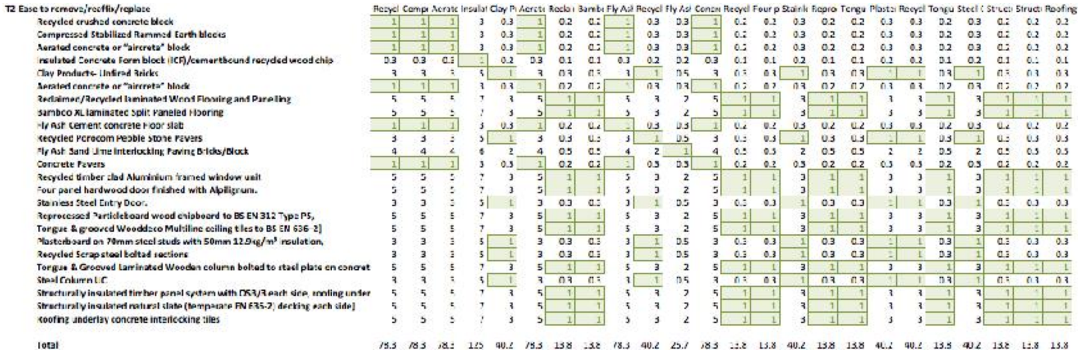
SC3- Cultural restriction on usury	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly As	Recycl	Fly As	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structu	Structu	Roofing
Recycled crushed concrete block	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Compressed Stabilised Rammed Earth blocks	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Aerated concrete or "aircrete" block	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Clay Products- Unfired Bricks	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Aerated concrete or "aircrete" block	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Bamboo XL laminated Split Paneled Flooring	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Fly Ash Cement concrete Floor slab	5	7	5	5	7	5	7	7	1	5	7	1	5	5	3	7	7	5	7	7	1	7	7	5
Recycled Porocom Pebble Stone Pavers	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Fly Ash Sand Lime interlocking Paving Bricks/Block	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.14	0.33	0.33	0.2	1	1	0.33	1	1	0.1	1	1	0.3
Concrete Pavers	5	7	5	5	7	5	7	7	1	5	7	1	5	5	3	7	7	5	7	7	1	7	7	5
Recycled timber clad Aluminium framed window unit	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Four panel hardwood door finished with Alpilignum.	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Stainless Steel Entry Door.	3	5	3	3	5	3	5	5	0.3	3	5	0.3	3	3	1	5	5	3	5	5	0.3	5	5	3
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636-2]	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Plasterboard on 70mm steel studs with 50mm 12.9kg/m² insulation.	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Recycled Scrap steel bolted sections	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Steel Column UC	5	7	5	5	7	5	7	7	1	5	7	1	5	5	3	7	7	5	7	7	1	7	7	5
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Structurally insulated natural slate (temperate EN 636-2) decking each side]	0.3	1	0.3	0.3	1	0.3	1	1	0.1	0.3	1	0.1	0.3	0.3	0.2	1	1	0.3	1	1	0.1	1	1	0.33
Roofing underlay concrete interlocking tiles	1	3	1	1	3	1	3	3	0.2	1	3	0.2	1	1	0.3	3	3	1	3	3	0.2	3	3	1
Total	30.7	64	30.7	30.7	64	30.7	64	64	6.7	30.7	64	6.7	30.7	30.7	15.2	64	64	30.7	64	64	6.7	64	64	30.7

Fig. 32. Pair-wise matrix & priority scores for SC3-Cultural Restriction on Usury



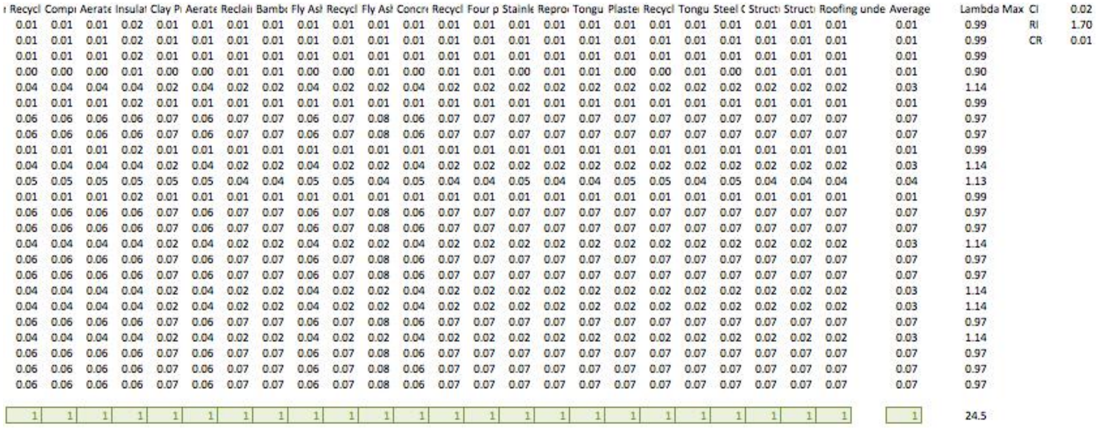
Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly As	Recycl	Fly As	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structu	Structu	Roofing unde	Average	Lambda Max	CI	0.03
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18	RI	1.70
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92	CR	0.02
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.16	0.11	0.16	0.16	0.11	0.16	0.11	0.11	0.15	0.16	0.11	0.15	0.16	0.16	0.20	0.11	0.11	0.16	0.11	0.11	0.15	0.11	0.11	0.16	0.14	0.93		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.16	0.11	0.16	0.16	0.11	0.16	0.11	0.11	0.15	0.16	0.11	0.15	0.16	0.16	0.20	0.11	0.11	0.16	0.11	0.11	0.15	0.11	0.11	0.16	0.14	0.93		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.10	0.08	0.10	0.10	0.08	0.10	0.08	0.08	0.05	0.10	0.08	0.05	0.10	0.10	0.07	0.08	0.08	0.10	0.08	0.08	0.05	0.08	0.08	0.10	0.08	1.24		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.16	0.11	0.16	0.16	0.11	0.16	0.11	0.11	0.15	0.16	0.11	0.15	0.16	0.16	0.20	0.11	0.11	0.16	0.11	0.11	0.15	0.11	0.11	0.16	0.14	0.93		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.01	0.02	0.01	0.01	0.02	0.01	0.02	0.02	0.02	0.01	0.02	0.02	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.92		
0.03	0.05	0.03	0.03	0.05	0.03	0.05	0.05	0.03	0.03	0.05	0.03	0.03	0.03	0.02	0.05	0.05	0.03	0.05	0.05	0.03	0.05	0.05	0.03	0.04	1.18		
1	1	1	1	1	1	1	1	1.00	1	1	1.00	1	1	1	1	1	1	1	1	1.00	1	1	1	1	24.8		

Fig. 33. Normalised matrices for SC3-cultural restriction on usury



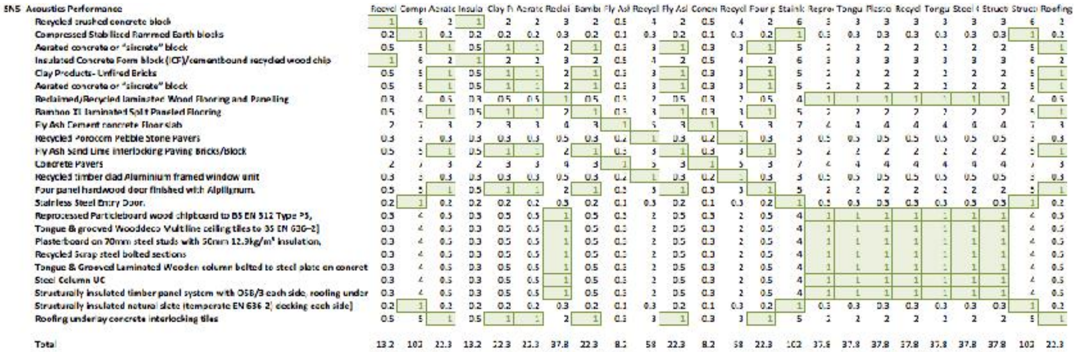
T2 Ease to remove/reaffix/replace	Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly As	Recycl	Fly As	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Structu	Structu	Roofing
Recycled crushed concrete block	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Compressed Stabilized Rammed Earth blocks	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Aerated concrete or "aircrete" block	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	0.3	0.3	0.3	1	0.2	0.3	0.1	0.1	0.3	0.2	0.2	0.3	0.1	0.1	0.2	0.1	0.1	0.2	0.2	0.1	0.2	0.1	0.1	0.1
Clay Products- Unfired Bricks	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Aerated concrete or "aircrete" block	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Reclaimed/Recycled laminated Wood Flooring and Panelling	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Bamboo XL laminated Split Paneled Flooring	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Fly Ash Cement concrete Floor slab	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Recycled Porocom Pebble Stone Pavers	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Fly Ash Sand Lime interlocking Paving Bricks/Block	4	4	4	6	2	4	0.5	0.5	4	2	1	4	0.5	0.5	2	0.5	0.5	2	2	0.5	2	0.5	0.5	0.5
Concrete Pavers	1	1	1	3	0.3	1	0.2	0.2	1	0.3	0.3	1	0.2	0.2	0.3	0.2	0.2	0.3	0.3	0.2	0.3	0.2	0.2	0.2
Recycled timber clad Aluminium framed window unit	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Four panel hardwood door finished with Alpilignum.	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Stainless Steel Entry Door.	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636-2]	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Plasterboard on 70mm steel studs with 50mm 12.9kg/m² insulation,	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Recycled Scrap steel bolted sections	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Steel Column UC	3	3	3	5	1	3	0.3	0.3	3	1	0.5	3	0.3	0.3	1	0.3	0.3	1	1	0.3	1	0.3	0.3	0.3
Structurally insulated timber panel system with OSB/3 each side, roofing under	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Structurally insulated natural slate (temperate EN 636-2) decking each side]	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Roofing underlay concrete interlocking tiles	5	5	5	7	3	5	1	1	5	3	2	5	1	1	3	1	1	3	3	1	3	1	1	1
Total	78.3	78.3	78.3	125	40.2	78.3	13.8	13.8	78.3	40.2	25.7	78.3	13.8	13.8	40.2	13.8	13.8	40.2	40.2	13.8	40.2	13.8	13.8	13.8

Fig. 34.T2- Pair-wise matrix & priority scores for ease to remove/reaffix/replace



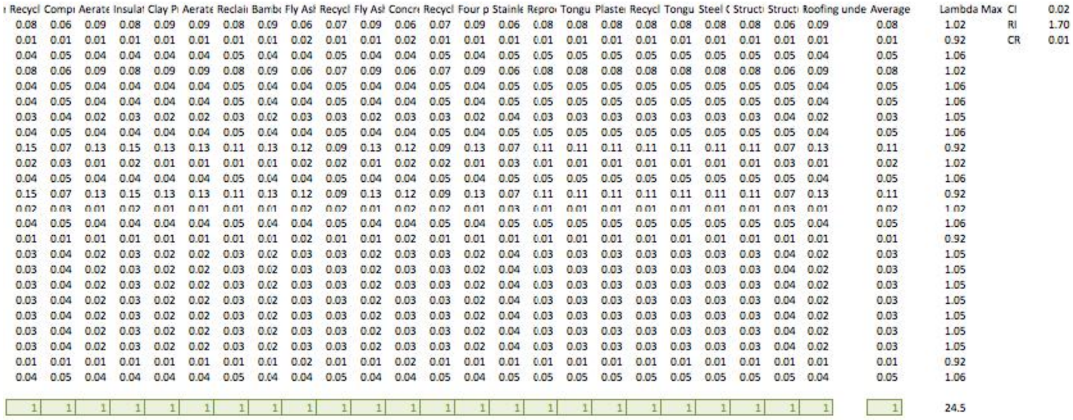
Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly Ash	Recycl	Fly Ash	Concre	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.02
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99	RI	1.70
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99	CR	0.01
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99		
0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.00	0.01	0.01	0.00	0.00	0.01	0.00	0.01	0.01	0.01	0.01	0.90		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.04	0.05	0.05	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.05	0.04	0.05	0.04	0.04	0.04	0.04	1.13		
0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.99		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.04	0.04	0.04	0.04	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.03	1.14		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
0.06	0.06	0.06	0.06	0.07	0.06	0.07	0.07	0.06	0.07	0.08	0.06	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.97		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.5		

Fig. 35.T2- Normalised matrices for ease to remove/reaffix/replace



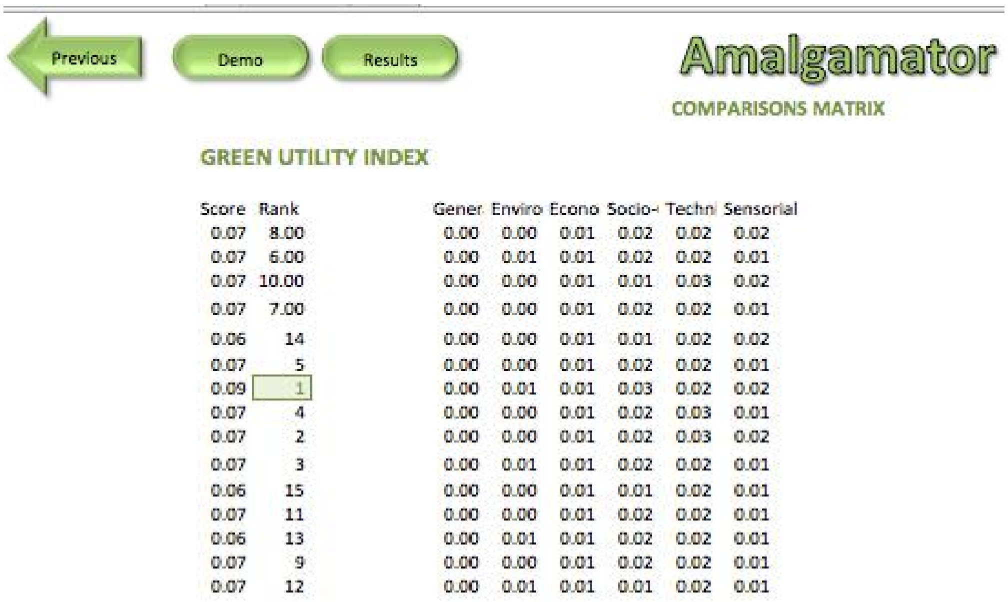
SN5 Acoustics Performance	Recycl	Compr	Aerate	Insula	Clay P	Aerate	Reclai	Bambo	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Struct	Struct	Roofing
Recycled crushed concrete block	1	6	2	1	2	2	3	2	0.5	4	2	0.5	4	2	6	3	3	3	3	3	3	3	6	2
Compressed Stabilised Rammed Earth blocks	0.2	1	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.3	0.2	0.1	0.3	0.2	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1	0.2
Aerated concrete or "sincrete" block	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	1	6	2	1	2	2	3	2	0.5	4	2	0.5	4	2	6	3	3	3	3	3	3	3	6	2
Clay Products- Unfired Bricks	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Aerated concrete or "sincrete" block	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Reclaimed/Recycled laminated Wood Flooring and Panelling	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Bamboo XL laminated Split Panelled Flooring	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Fly Ash Cement concrete Floor slab	2	7	3	2	3	3	4	3	1	5	3	1	5	3	7	4	4	4	4	4	4	4	7	3
Recycled Porocom Pebble Stone Pavers	0.3	3	0.3	0.3	0.3	0.3	0.5	0.3	0.2	1	0.3	0.2	1	0.3	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	3	0.3
Fly Ash Sand Lime Interlocking Paving Bricks/Block	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Concrete Pavers	2	7	3	2	3	3	4	3	1	5	3	1	5	3	7	4	4	4	4	4	4	4	7	3
Recycled timber clad Aluminium framed window unit	0.3	3	0.3	0.3	0.3	0.3	0.5	0.3	0.2	1	0.3	0.2	1	0.3	3	0.5	0.5	0.5	0.5	0.5	0.5	0.5	3	0.3
Four panel hardwood door finished with Alpilignum.	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Stainless Steel Entry Door.	0.2	1	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.3	0.2	0.1	0.3	0.2	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1	0.2
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636-2)	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Recycled Scrap steel bolted sections	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Steel Column UC	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Structurally insulated timber panel system with OSB/3 each side, roofing under	0.3	4	0.5	0.3	0.5	0.5	1	0.5	0.3	2	0.5	0.3	2	0.5	4	1	1	1	1	1	1	1	4	0.5
Structurally insulated natural slate (temperate EN 636 2, decking each side)	0.2	1	0.2	0.2	0.2	0.2	0.3	0.2	0.1	0.3	0.2	0.1	0.3	0.2	1	0.3	0.3	0.3	0.3	0.3	0.3	0.3	1	0.2
Roofing underlay concrete interlocking tiles	0.5	5	1	0.5	1	1	2	1	0.3	3	1	0.3	3	1	5	2	2	2	2	2	2	2	5	1
Total	13.2	102	22.3	13.2	22.3	22.3	37.8	22.3	8.2	58	22.3	8.2	58	22.3	102	37.8	37.8	37.8	37.8	37.8	37.8	37.8	102	22.3

Fig. 36. SN5- Pair-wise matrix & priority scores for acoustics performance



Recycl	Compr	Aerate	Insulat	Clay P	Aerate	Reclai	Bambo	Fly Ash	Recycl	Fly Ash	Concre	Recycl	Four p	Stainle	Repro	Tongu	Plaste	Recycl	Tongu	Steel C	Struct	Struct	Roofing unde	Average	Lambda Max	CI	0.02
0.08	0.06	0.09	0.08	0.09	0.09	0.08	0.09	0.06	0.07	0.09	0.06	0.07	0.09	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.06	0.09	0.08	1.02	RI	1.70
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.92	CR	0.01
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.08	0.06	0.09	0.08	0.09	0.09	0.08	0.09	0.06	0.07	0.09	0.06	0.07	0.09	0.06	0.08	0.08	0.08	0.08	0.08	0.08	0.08	0.06	0.09	0.08	1.02		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.15	0.07	0.13	0.15	0.13	0.13	0.11	0.13	0.12	0.09	0.13	0.12	0.09	0.13	0.07	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.07	0.13	0.11	0.92		
0.02	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.02	1.02		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.15	0.07	0.13	0.15	0.13	0.13	0.11	0.13	0.12	0.09	0.13	0.12	0.09	0.13	0.07	0.11	0.11	0.11	0.11	0.11	0.11	0.11	0.07	0.13	0.11	0.92		
0.02	0.03	0.01	0.02	0.01	0.01	0.01	0.01	0.02	0.02	0.01	0.02	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.02	1.02		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.92		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.03	0.04	0.02	0.03	0.02	0.02	0.03	0.02	0.03	0.03	0.02	0.03	0.03	0.02	0.04	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.02	0.03	1.05		
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.92		
0.04	0.05	0.04	0.04	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.04	0.05	0.04	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.04	0.05	1.06		
1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	24.5		

Fig. 37. SN5- normalised matrices for acoustics performance



Amalgamator

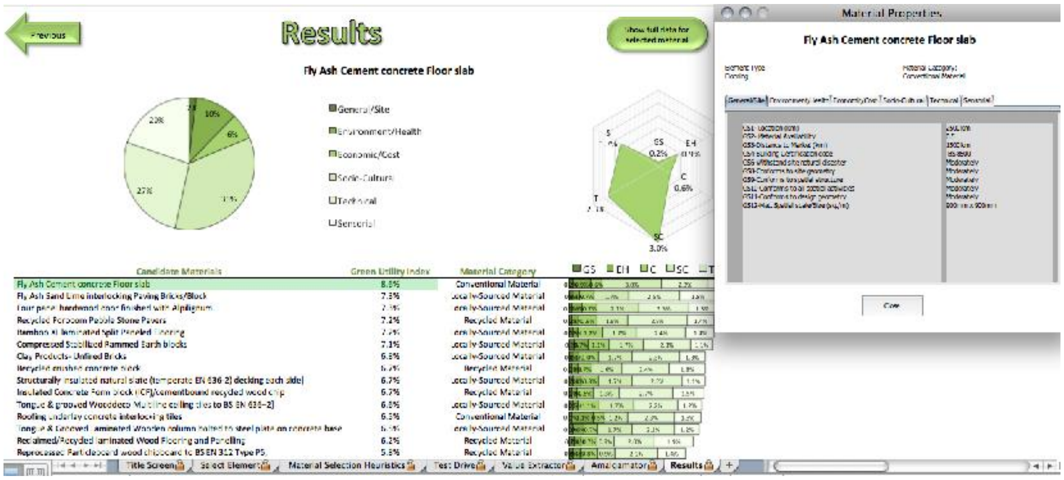
COMPARISONS MATRIX

GREEN UTILITY INDEX

Score	Rank	Gener	Enviro	Econo	Socio-	Techni	Sensorial
0.07	8.00	0.00	0.00	0.01	0.02	0.02	0.02
0.07	6.00	0.00	0.01	0.01	0.02	0.02	0.01
0.07	10.00	0.00	0.00	0.01	0.01	0.03	0.02
0.07	7.00	0.00	0.00	0.01	0.02	0.02	0.01
0.06	14	0.00	0.00	0.01	0.01	0.02	0.02
0.07	5	0.00	0.00	0.01	0.02	0.02	0.01
0.09	1	0.00	0.01	0.01	0.03	0.02	0.02
0.07	4	0.00	0.00	0.01	0.02	0.03	0.01
0.07	2	0.00	0.00	0.01	0.02	0.03	0.02
0.07	3	0.00	0.01	0.01	0.02	0.02	0.01
0.06	15	0.00	0.00	0.01	0.01	0.02	0.01
0.07	11	0.00	0.00	0.01	0.02	0.02	0.01
0.06	13	0.00	0.01	0.01	0.02	0.02	0.01
0.07	9	0.00	0.00	0.01	0.02	0.02	0.01
0.07	12	0.00	0.01	0.01	0.01	0.02	0.01

Fig. 38. **Green utility index scores of all selected material alternatives against the parent factors**

In this case, the final weighting scores (obtained from multiplying the priorities vectors of the parent criteria with that of individual sub-factors), is further multiplied by the priority vector of each material alternative after the pair-wise comparison against each sub-factor. This resulted in a final composite priority/weighting score of each sub-factor for the three floor material alternatives. Using the priorities determined through these matrices, the weighted overall priority of each candidate material was determined. The amalgamation method yielded a single green utility index of alternative worth, which allowed the material options to be ranked according to their overall priorities. The material with the highest score then becomes the selected candidate material as shown in Fig. 39.



Candidate Materials	Green Utility Index	Material Category
Fly Ash Cement concrete Floor slab	8.8%	Conventional Material
Fly Ash Sand Lime interlocking Paving Bricks/Block	7.3%	Locally-Sourced Material
Four pane hardwood floor finished with Alpilignum	7.3%	Locally-Sourced Material
Recycled Porocom Pebble Stone Pavers	7.2%	Recycled Material
Bamboo XL laminated Split Paneled Flooring	7.2%	Locally-Sourced Material
Compressed Stabilized Rammed Earth blocks	7.1%	Locally-Sourced Material
Clay Products- Unfired Bricks	6.9%	Locally-Sourced Material
Recycled crushed concrete block	6.7%	Recycled Material
Structurally insulated natural slate (temperate EN 636-2) decking each side)	6.7%	Locally-Sourced Material
Insulated Concrete Form block (ICF)/cementbound recycled wood chip	6.7%	Recycled Material
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636-2)	6.6%	Locally-Sourced Material
Roofing underlay concrete interlocking tiles	6.3%	Conventional Material
Tongue & Grooved Laminated Wooden column bolted to steel plate on concrete base	6.3%	Locally-Sourced Material
Reclaimed/Recycled laminated Wood Flooring and Panelling	6.2%	Recycled Material
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5	5.8%	Recycled Material

Fig. 39. Corresponding indices of ranked floor material alternatives

Looking at Fig. 39, it is clear from the results of the analysis that Material option (A) turns out to be the most preferred material among the three material options identified in Table4, with an overall priority or index score of 0.086. It is based on the concept of the higher the green utility index value, the better the option. The green utility index as calculated for each of the three material alternatives was M(C) =0.086, M(A)= 0.072 and M(B)= 0.062 for material options C, A and B respectively, making Option C (fly-ash cement concrete floor slab) emerge as the best option amongst the other alternatives as shown in Fig. 39.

The above example has illustrated the application of the MSDSS in a material selection problem for a proposed 5-bedroom low-cost residential green building project in the London Borough of Sutton. From the illustrated example it can be deduced that the MSDSS model is able to provide rankings in low-cost green building material assessment combining site, economic, technical, social-cultural, sensorial and environmental criteria into a composite index system based on the AHP technique. This model is therefore, based on the presumption that decision makers, given full knowledge of all possible consequences of all possible alternatives and factors, will select the material with the highest-ranking score.

6. CONCLUSION

Careful selection of low-cost green construction materials at the early design stage(s) of the building process, has been suggested as a crucial step to improving the quality of the housing stock in Less Developed Countries (LDCs), and reducing CO_2 emissions from the built environment [3,4,46]. The research presented in this paper however, acknowledged the lack of reliable data that decision makers can readily use to aid informed decision-making when selecting such materials for residential housing development. The findings from the reviewed literature and the results of the surveyed questionnaire further underscored the need for improving understanding of relevant data associated with the use of low-cost green building materials and components, with the goal to change and positively influence the current mental models, attitudes and priorities of multiple stakeholders involved in the production of the built environment, so as to encourage their wider-scale use in mainstream housing. Based on the data obtained from selected expert builder/developer companies, a prototype MSDSS model was developed as a means to aid designers in making informed decisions regarding their choice of materials for residential housing development. Since the purpose of this research study was to develop an innovative concept to demonstrate a step-by-step methodology for selecting low-cost green materials with reasonable accuracy and in real time, as opposed to developing a fully-equipped commercial software, macro-in-excel database management technique was used in the back-end of the system to integrate the large volumes of data obtained from multiple sources.

This report has demonstrated how a DSS model can be used to support multi –stakeholder involvement in the selection of low-cost green construction materials in ways that enable building energy performance and life-cycle cost to be considered at the early stage of residential housing design. The study further reinforced the significance in taking a multi-attribute approach to assessing a building product’s sustainable performance. To achieve this goal, the AHP model of decision-making was adopted to deal with the ambiguities involved in the assessment of material alternatives and relative importance weightings of multiple factors, given its ability to solve multi-criteria decision-making (MCDM) between finite alternatives. To prove the validity of the model and the feasibility of the proposed selection methodology, a real-life but hypothetical application scenario was used to further illustrate the application of the MSDSS model in selecting the most appropriate floor material for a single 5-bedroom residential housing project located in the Sutton County of London.

The results demonstrated the capabilities of the system, and exposed the way in which the system transparently demonstrates the implications of each step of the analysis. It also proved the practicality of using the MSDSS model, as it combines multiple factors into a single performance value that is easily interpreted.

The process followed to develop the prototype MSDSS model in this research demonstrates that, depending on the domain and scope of the problem at hand, a DSS can be built fairly quickly and can be used effectively to help designers quantify how they compare materials that are yet to be certified under the standard specifications and codes of practice, and that which are already permitted under existing codes. However further work is required to fully validate the MSDSS and the methodology presented. To do so, this research intends to run further case studies ideally using 'live' building design projects, by comparing the outputs from the algorithms of the MSDSS system to monitored data from the completed case study building, in order to review the potential savings of the new materials or components proposed by the MSDSS model.

6.1 Potential Benefits of the Tool

The following are the usability benefits expected from the application of the MSDSS Model. Moreover, the MSDSS model differs from that of the previous works in the following ways:

- The main point of difference from off-the-shelf assessment tools is that they only trade-off numerical values based on single-attributes. These single- attribute claims ignore the possibility of what other variables could possibly yield. MSDSS supports trade-off with and without tangible variables, such as a client's preference, environmental statutory compliance, and cultural restriction on usury. This feature is important as decision making in reality engages with solid, verbal and subjective elements.

- In terms of cost, the MSDSS tool provides an opportunity for designers to be able to advise their clients as to what the probable financial estimate of the project may be. This helps clients to decide how much they are prepared to spend on different variables of construction.

- A separate set of contextual considerations was included as heuristics base to facilitate site-specific feasibility and appropriateness testing of each material choice. Boundaries of sustainability inform of knowledge base rules as contained in the MSDSS model could help reduce bias that is often associated with the material selection process.

- Available material assessment tools are particularity ill-adapted for the early stages of the design process and are generally labour intensive. Consequently, they are restrictive, since they allow only minor changes to be made. In addition, the details of data input required by many of these tools are inconsistent with the nature of the design information available at the early stage. The MSDSS model consists of a resource for relatively small information input to produce quick and fairly accurate or approximate output of results with little or no training on the part of experienced users. This means that users that may require little training are inexperienced users but not as extensive as obtainable in previous tools.

- There are still significant numbers of smaller firms who cannot afford most material assessment tools because they are extremely expensive. This tool is more or less open source software recommended to provide solution to this challenge.

- Context is a critical consideration for all project decision-making, since even projects located on neighbouring sites will have different end users, and different specific site characteristics. This tool could be applied to other regions with minimal or no changes, and therefore has the ability to adapt to any situation, or change in design according to users' needs or different material alternatives.

- Unlike the previous models, this tool contains tutorials and help-menu as well as video and demo guidance on how to use the software. This provides adequate help to beginners or inexperienced designers.

- For the visual aspect, the MSDSS model has the ability to produce a picture representative of data input rather than abstract. It is able to transfer data from it to other software, applicable to building material selection, and present the properties of each material in a successive window. Although there have been significant progress since the early days, potential still exists for better software to be developed as exiting tools require a significant amount of time, both to learn and to achieve expertise. The MSDSS is a simpler and easier to use tool, with interfaces that are more natural.
- The MSDSS has the ability to produce a high level, or relatively accurate degree of details for the design, no matter how low the input; The model is able to adapt to users'/clients' demand or change in choice of materials or factor with greater degree;

- User weightings have been included in the selection methodology to supplement, and not supplant human judgment in the decision-making process. By incorporating user weightings into the selection process, the methodology gains greater acceptability to the user who supplies the weightings.

- Materials change in their innovation, composition, price and availability and most tools find it challenging to update information relating to products. In this MSDSS model, the materials and the corresponding performance of the selected products is updated through a link to the manufacturers web page on the internet, and the users may access more information regarding the selected material or technology through internet from the supplier's web pages.

6.2 Contribution of the Study to Knowledge and Practice

This paper contributes to growing evidence concerning the sustainable use of low-cost green materials in research and practice, which is part of the overall preparedness to improve the standard of housing for the least-advantaged population. By suggesting an alternative means of integrating the available resources associated with the informed selection of such materials, it is hoped that this MSDSS model will help decision makers to further refine their material selection criteria hence, improve the effectiveness and usefulness of the system according to user requirements.

The capacity of the system to compare materials using multiple factors with user-specified weightings should be able to encourage decision-makers to explicitly consider the effects of their previously-implicit judgments on the outcome of the project, and thus make choices which result in more sustainable residential housing project design and implementation. The ability to quickly quantify and qualify the suitability outcomes of alternative materials may encourage greater industry acceptance of innovative technology for materials that are yet to be certified under the standard specifications and codes of practice.

The material selection factors identified in the prototype model of the MSDSS, provides a unique insight into sustainability and environmental design information requirements for low-cost green housing. The methodology employed to address the research objectives in section 3 represents part of the original contribution to knowledge made by the study. The number of academic publications on the impacts of low-cost green materials is low; hence makes a crucial contribution.

In the short term, the model could be used in the housing sector as a catalogue of materials to support decision-making in low-cost green housing designs. In the longer term, the database is an initial step toward constructing an effective resource for design and building professionals in the public and private housing sectors. As low-cost green building materials and components become well understood by design and building professionals, there is a likelihood of reducing over-dependency on conventional construction materials. These trend can aid top executives within the housing sector to consider low-cost green materials as part of existing regulatory frameworks and building codes of the Construction Standards Institute (CSI) that govern the use of building construction materials. By so doing, such an approach may create a potential market for local manufacturing and processing of such materials, and thus, provide lasting and replicable improvements to the lives of both the urban and rural population of less developed countries.

6.3 Limitations

This research, like any other type of research, will be expected to have a number of strengths and limitations. The strengths of the research have been highlighted in sections 6.1 and 6.2, in form of benefits and contribution to knowledge. The limitations are hereby listed for future consideration.

- The process of developing the selection methodology was faced with critical issues that led to several changes in the research methodology and its objectives so many times, in order to achieve the aim of the research.

- As literature on DSS for low-cost green housing design is still relatively low, the study therefore had to rely on the most current reports, interviews, and observations from the different and various organisations, and building professionals for its information.

- The AHP technique at the pare-wise comparison stage generally tend to be quite cumbersome and often takes a lot of time to maintain the consistency of the response. To eliminate this challenge the MSDSS automatically debugs the system at every stage of the evaluation and selection process.

While the findings of this research focused specifically on a subset of design and building professionals involved with public residential housing sector projects, the overall approach used here could be tested in other contexts to determine its generalizability and applicability. In other words, the system could be extended to select materials for commercial development or for any other purpose. Although not demonstrated in this system but it is also possible that potential researchers can redesign or customize the database to best fit the needs of any particular region.

ACKNOWLEDGMENT

We thank God almighty for his infinite grace, and the Rivers State Sustainable Development Agency for their contributions towards this work.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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APPENDIX

APPENDIX A: FEEDBACK FROM POTENTIAL USERS

The following are feedbacks and suggestions retrieved from users on the MSDS tool:

“The system relates to issues concerned with local knowledge, local materials data, local climate know-how, local experts needed to operate system, which are hardly considered in other systems”. I think it shows great promise and the mechanics are very well-developed and user-friendly,

“Material costs vary from location to location (especially in the USA where material costs vary not just from state to state but also from city to city”. Perhaps when the material selection is sorted by the element choice, this will seem more useful”.

“It depends on what resources you are referring to; if referring to the underlying database, those are considerable. If referring to the resource needs of the organization that would use the model, not too costly to operate”.

“The interface is very well-designed and easy to navigate. However, there is a need for more explanatory material to allow the user to understand what s/he is actually doing, and how to operate some parts of the model appropriately”.

“In terms of its operation, interoperability, flexibility, usability and applicability, per se, it is very clear and straightforward; it's the underlying premise and data that needs little clarification in order for the user to operate the model effectively

APPENDIX B: RANKED DECISION FACTORS FOR LOW-COST GREEN BUILDING MATERIAL SELECTION

Material selection factors/variables	**Valid percentage of score (%)**					**Relative index scores**	**Ranking by category**	**Overall ranking**	**Importance Level**
	1	**2**	**3**	**4**	**5**				
General/site factors									
GS2-Material Availability	1.6	2.9	17.9	50.5	27.0	0.795	1	35	H-M
GS1-Geographic Location of Building Site	2.1	2.6	19.3	51.2	24.3	0.773	2	38	H-M
GS10-Building and Space Usage	0.8	5.5	21.4	52.2	20.1	0.764	3	39	H-M
GS9-Knowledge Base in Construction	1.1	7.4	33.2	42.1	16.3	0.731	4	41	H-M
GS6- Natural Disasters Common to the Site	1.4	11.3	27.7	39.5	20.1	0.726	5	42	H-M
GS7-The Type of Building Material(s)	1.8	8.2	36.3	37.0	16.7	0.712	6	43	H-M
GS4-Building Regulation and Certification for Use	2.7	10.8	33.5	36.1	16.9	0.709	7	44	H-M
GS5-Design Concept	0.8	15.2	35.5	13.1	15.4	0.702	8	45	H-M
GS12-Spatial Scale: Building Size and Mass	4.5	17.8	30.3	28.4	19.0	0.675	9	47	H-M
GS8-Project Site Geometry/Setting/Condition	1.4	17.5	38.1	33.3	9.7	0.663	10	46	H-M
GS3-Distance	5.6	17.9	32.1	31.3	13.1	0.653	11	47	H-M
GS11-Building Orientation	4.6	21.9	29.5	28.4	15.6	0.652	12	48	H-M
Environmental/health factors									
EH3-Safety and Health of End-users	0.5	2.5	3.1	46.2	47.1	0.876	1	17	H
EH6-The Climatic Condition of the Region	0.3	2.0	5.3	49.2	42.6	0.860	2	23	H
EH7-Material Environmental Impact	0.7	2.6	6.0	49.0	41.1	0.850	3	27	H
EH2-Level of Carbon Emissions and Toxicity	0.3	4.9	5.6	49.2	39.5	0.849	4	28	H
EH4-Habitat Disruption: Ozone Depletion Potential	1.6	1.8	9.6	52.0	34.4	0.830	5	30	H
EH1-Environmental Statutory Compliance	2.1	6.3	9.7	42.7	38.7	0.820	6	32	H
EH5-The Amount of Pesticide Treatment Required	3.0	2.9	8.2	52.5	32.9	0.813	7	33	H
Economic/cost factors									
C4-Maintenance or Replacement Cost	0.5	1.8	5.9	20.2	71.6	0.912	1	3	H
C5-Labour or Installation Cost	0.5	2.0	5.2	27.3	64.9	0.898	2	8	H
C1-Life Cycle Cost	4.5	3.0	26.1	66.4	99.6	0.897	3	9	H
C3-Capital Cost (Economic Status of the Client)	0.8	3.6	7.1	22.0	66.5	0.891	4	10	H
C2-Material Embodied Energy Cost	0.5	5.6	4.0	25.4	64.5	0.876	5	17	H
Socio-cultural factors									
SC5-Local Knowledge of the Custom	0.5	3.7	5.5	32.0	57.8	0.884	1	13	H
SC1-Material Compatibility with Cultural Traditions	1.0	4.5	2.7	33.9	57.4	0.879	2	16	H
SC6-Material Compatibility with Cultural Traditions	0.4	2.9	3.7	36.2	56.2	0.876	3	17	H
SC2-Material Compatibility with Regional Settings	0.5	2.5	6.4	32.7	57.4	0.875	4	18	H

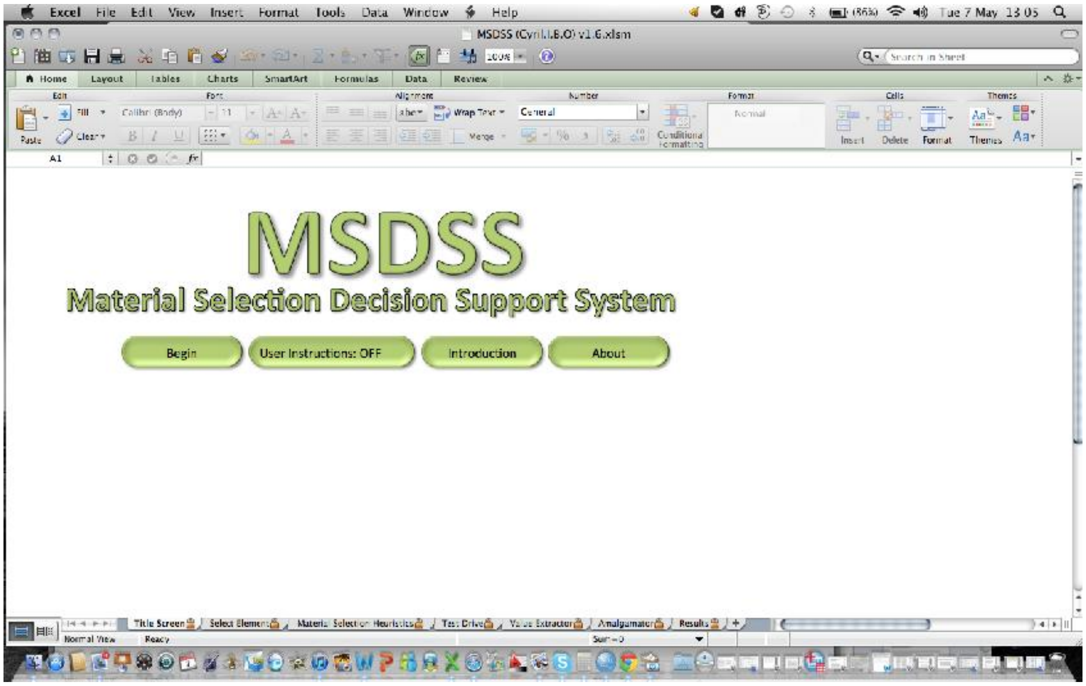
SC3-Cultural Restriction(s) on Usury	1.0	3.3	10.8	31.1	53.3	0.851	5	26	H
SC4-Family Structure: Type & Size of Family Unit	3.0	21.0	15.7	19.8	39.9	0.737	6	40	H-M
Technical factors									
T15-Life Expectancy	1.1	0.3	4.2	26.9	66.8	0.952	1	1	H
T7-Resistance to Fire	0.3	1.2	4.8	28.8	64.9	0.919	2	2	H
T9-Resistance to Moisture	0.5	1.5	3.6	24.7	69.7	0.911	3	4	H
T11-Resistance to Weather	0.3	1.0	4.8	25.0	69.0	0.911	3	4	H
T5-Availability of the Technical Skills	0.5	1.5	4.5	28.4	65.0	0.905	4	5	H
T8-Resistance to Heat	0.3	1.2	4.8	28.8	64.9	0.904	5	6	H
T13-Resistance to Decay	0.3	1.5	5.7	25.7	66.8	0.902	6	7	H
T3-Level of Maintenance Requirement	0.5	1.8	4.2	30.6	62.8	0.897	7	9	H
T6-Ease and Speed of Method fixing	0.5	2.2	7.5	29.4	60.4	0.883	8	14	H
T4-Ability to Tolerate Expansion and Contraction	8.3	2.0	6.7	32.9	50.0	0.882	9	15	H
T1-Recyclability and Reusability	2.2	2.2	5.2	31.4	59.0	0.868	10	20	H
T12-Resistance to Chemicals	0.1	1.9	13.1	27.9	57.0	0.865	11	21	H
T2-Ease to Remove and Reaffix	0.7	2.2	6.8	36.5	53.8	0.864	12	22	H
T14-Weight and Mass of the Material	0.3	2.6	12.4	29.2	55.5	0.856	13	24	H
T10-Resistance to Scratch	1.1	3.1	11.6	27.0	57.1	0.852	14	25	H
Sensorial factors									
SN4-Temperature	0.4	0.4	3.1	44.8	51.0	0.887	1	11	H
SN6-Odour	0.4	1.2	5.6	37.7	54.8	0.886	2	12	H
SN10-Lighting Effect	1.4	8.9	17.5	33.5	37.8	0.886	2	12	H
SN5-Acoustics	0.7	0.5	5.6	42.2	50.7	0.876	3	17	H
SN1-Aesthetics or Visual density	0.3	1.4	6.0	46.0	46.0	0.870	4	19	H
SN2-Texture	3.1	10.0	45.2	41.4	0.3	0.839	5	29	H
SN3-Colour	0.3	3.0	12.2	46.0	38.2	0.823	6	31	H
SN7-Thickness/Thinness	1.5	8.9	13.3	35.5	40.6	0.806	7	34	H
SN9-Hardness	1.5	8.9	18.9	30.6	39.9	0.790	8	36	H-M
SN8-Glossiness/Fineness	2.6	9.2	18.7	33.1	36.2	0.774	9	37	H-M

Source: Analysis of surveyed data, 2013.

Kaiser-Meyer-Olkin and Bartlett's test		
Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0.862
Bartlett's Test of Sphericity	Approx. Chi-Square	42121.213
	df	1485
	Sig.	0.000

APPENDIX C: MSDSS ANALYTICAL SYSTEM: MODEL SET UP AND OPERATIONS

STEP 1: The MSDSS Analytical System main user interface can be opened by double clicking the <MSDSS ICON> menu from the list of MS Excel database file after installation. In the MSDSS main menu the user has options of whether to proceed by clicking the <Begin> button or close the menu by clicking the < Exit> button.

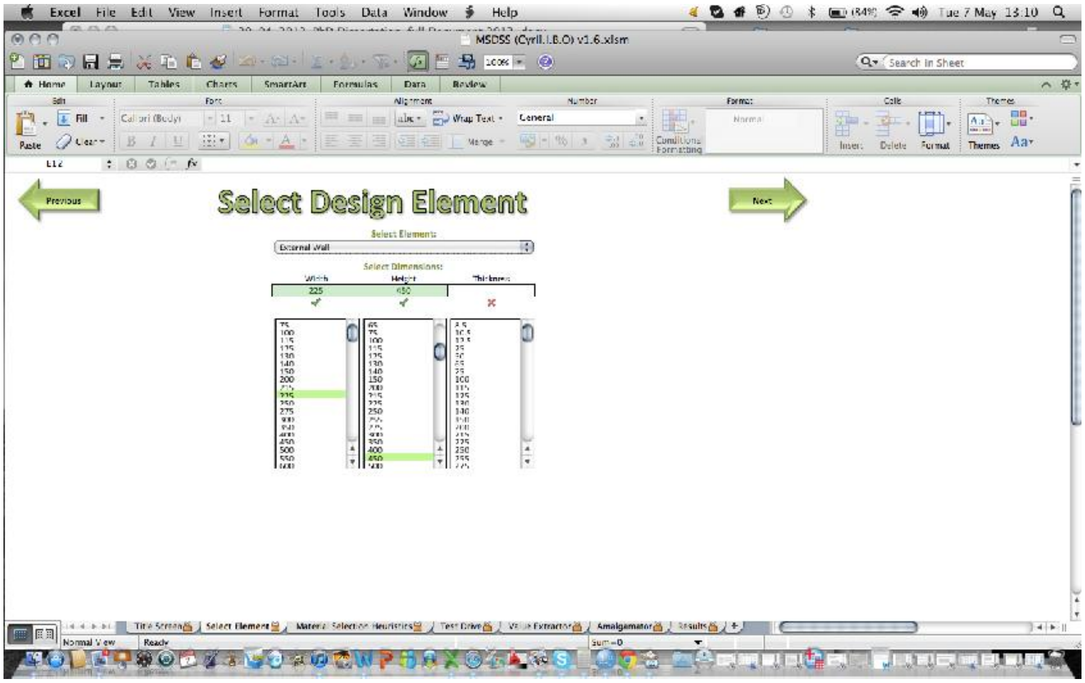


User interface of the prototype MSDSS analytical system main menu

STEP 2: To proceed, the user is to click the <BEGIN) button. This opens in a new window with various input parameters for the available <DESIGN ELEMENTS> provided by the system.

Clicking on the dropdown list of the <SELECT MATERIAL> tab in the <SELECT DESIGN ELEMENT> user interface/window, the user is able to select any desired building element of his choice. This option also leads to the opening of the <SELECT DIMENSION> tab, which displays various dimensions of the selected <DESIGN ELEMENTS> in the system.

By clicking on the <SELECT DIMENSIONS> from each of the three dimension columns, the desired parameters/dimensions are then highlighted in the upper boxes as shown above. The users then Click on the <NEXT> button to quickly view the next task of the evaluation process. This opens in a new window with various knowledge bases for each factor category.



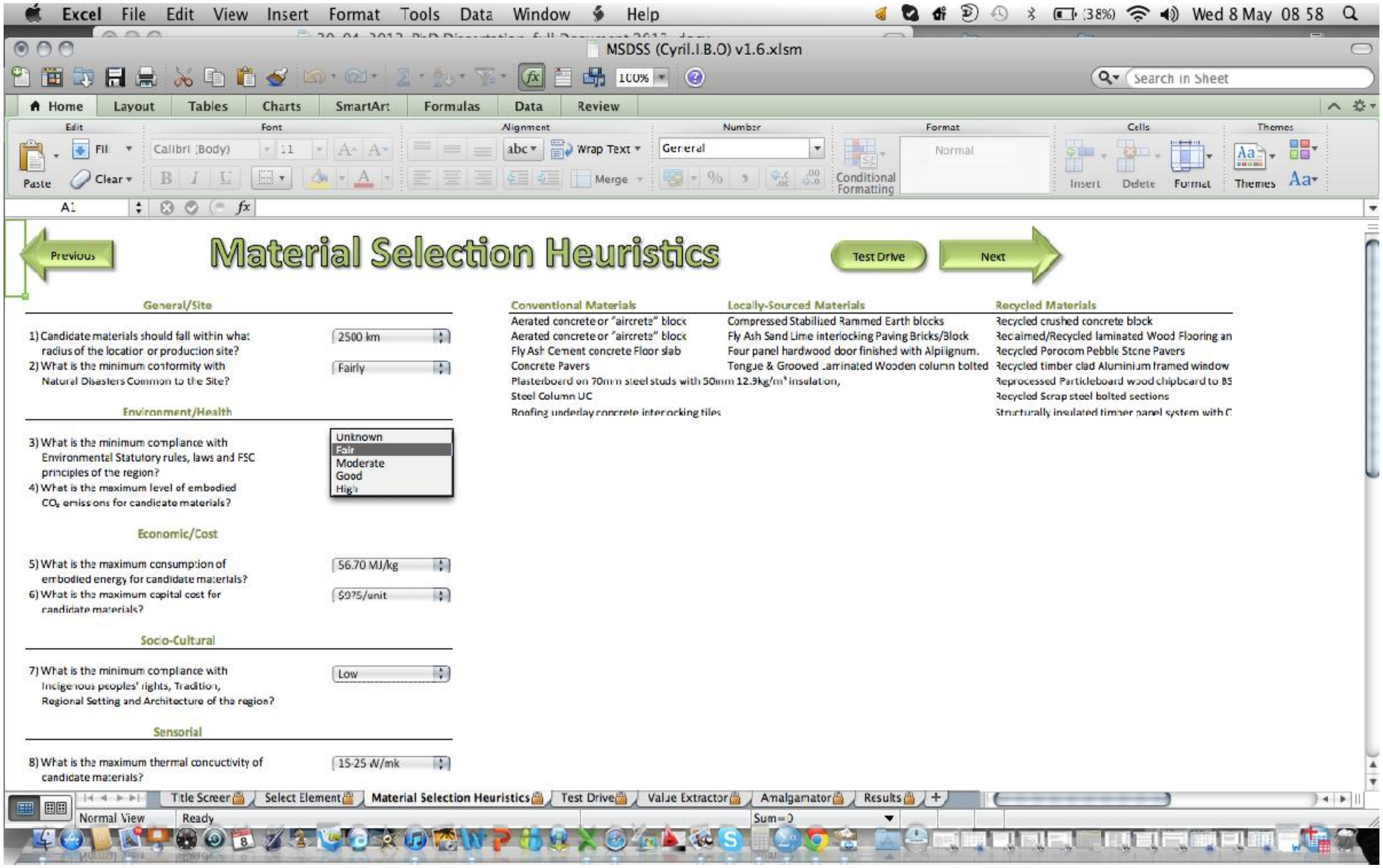
Select Element: External Wall

Select Dimensions:

Width	Height	Thickness
225	450	
✓	✓	✗

Sample of the design element user interface menu

STEP 3: Proceeding to the <MATERIAL HEURISTICS/KNOWLEDGE BASE> main menu is achieved by clicking the <NEXT> menu button. Clicking on the scroll down tabs for each property category in the <MATERIAL HEURISTICS> menu, selects the desired property threshold for material selection heuristics from the drop down list, and the right hand column highlights updated information to user on the available materials that meet the selected criteria as shown below.



Material Selection Heuristics

General/Site

1) Candidate materials should fall within what radius of the location or production site? 2500 km

2) What is the minimum conformity with Natural Disasters Common to the Site? Fairly

Environment/Health

3) What is the minimum compliance with Environmental Statutory rules, laws and FSC principles of the region?

- Unknown
- Fair
- Moderate
- Good
- High

4) What is the maximum level of embodied CO_2 emissions for candidate materials?

Economic/Cost

5) What is the maximum consumption of embodied energy for candidate materials? 56.70 MJ/kg

6) What is the maximum capital cost for candidate materials? $975/unit

Socio-Cultural

7) What is the minimum compliance with Indigenous peoples' rights, Tradition, Regional Setting and Architecture of the region? Low

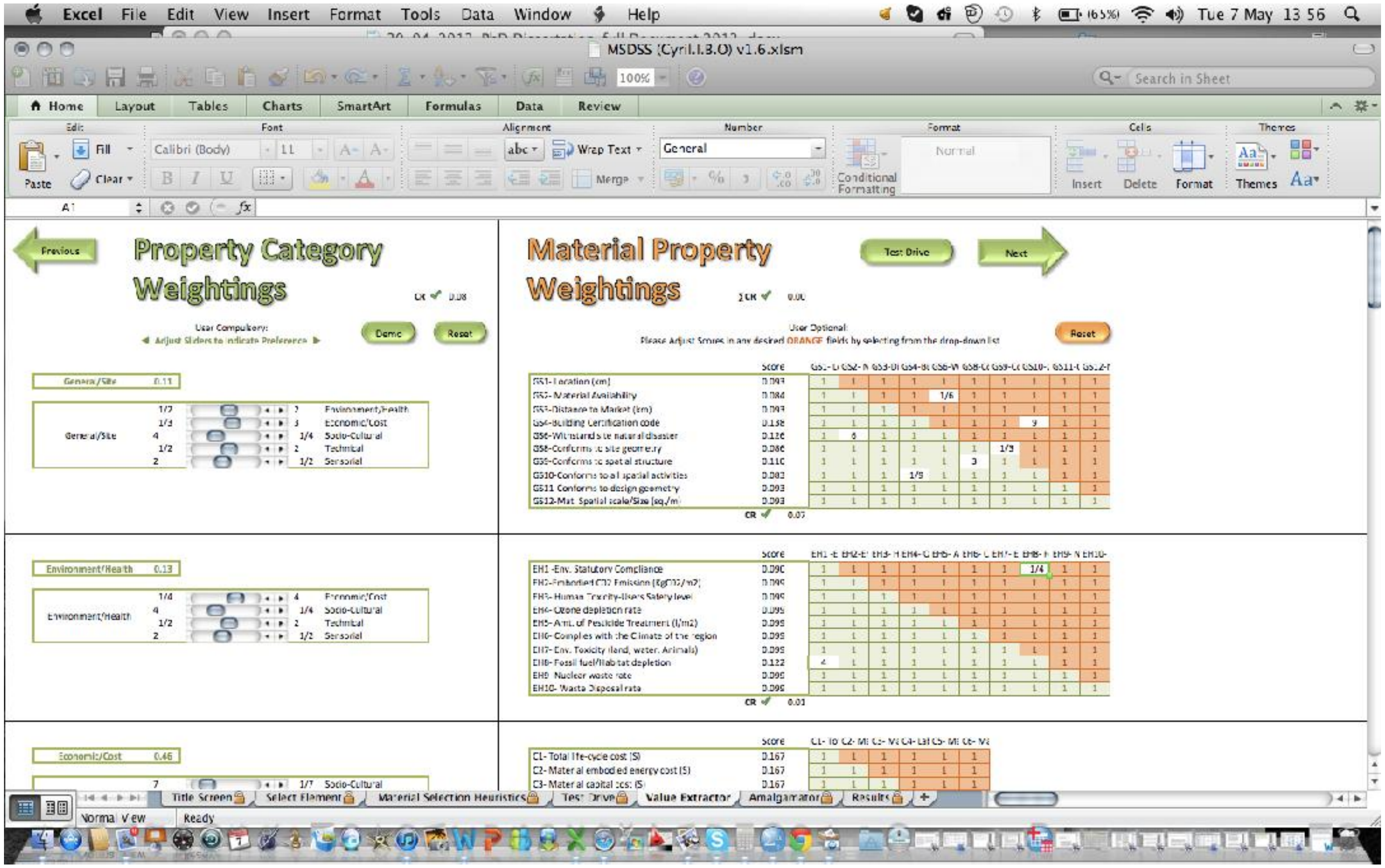
Sensorial

8) What is the maximum thermal conductivity of candidate materials? 15-25 W/mk

Conventional Materials	Locally-Sourced Materials	Recycled Materials
Aerated concrete or "aircrete" block	Compressed Stabilized Rammed Earth blocks	Recycled crushed concrete block
Aerated concrete or "aircrete" block	Fly Ash Sand Lime interlocking Paving Bricks/Block	Reclaimed/Recycled laminated Wood Flooring an
Fly Ash Cement concrete Floor slab	Four panel hardwood door finished with Alpilignum.	Recycled Porocom Pebble Stone Pavers
Concrete Pavers	Tongue & Grooved Laminated Wooden column bolted	Recycled timber clad Aluminium framed window
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,		Reprocessed Particleboard wood chipboard to BS
Steel Column UC		Recycled Scrap steel bolted sections
Roofing underlay concrete interlocking tiles		Structurally insulated timber panel system with C

Shows the menu from which data of the knowledge base and available materials are generated

STEP 4: Clicking on <DEMO> button in the <VALUE EXTRACTOR> window gives the user an idea on how to operate and adjust the factor/property values for each category. This option also enables the user to access the dynamic weighting values from 1-9 based on Saaty's [56] AHP system. The purpose of this option is to allow users to apply their subjective judgment for choosing the most suitable material based on Saaty's (1980) ratio scale of 1-9.



Property Category Weightings

CR ✓ 0.08

User Compulsory:
◀ Adjust Sliders to indicate Preference ▶

General/Site 0.11

General/Site	1/2	2	Environment/Health
	1/3	3	Economic/Cost
	4	1/4	Socio-Cultural
	1/2	2	Technical
	2	1/2	Sensorial

Environment/Health 0.13

Environment/Health	1/4	4	Economic/Cost
	4	1/4	Socio-Cultural
	1/2	2	Technical
	2	1/2	Sensorial

Economic/Cost 0.46

	7	1/7	Socio-Cultural

Material Property Weightings

ΣCR ✓ 0.00

User Optional:
Please Adjust Scores in any desired ORANGE fields by selecting from the drop-down list

	Score	GS1- L	GS2- N	GS3-Di	GS4-Bt	GS6-W	GS8-Cc	GS9-Cc	GS10-	GS11-C	GS12-I
GS1- Location (km)	0.093	1	1	1	1	1	1	1	1	1	1
GS2- Material Availability	0.084	1	1	1	1	1/6	1	1	1	1	1
GS3-Distance to Market (km)	0.093	1	1	1	1	1	1	1	1	1	1
GS4-Building Certification code	0.158	1	1	1	1	1	1	1	9	1	1
GS6-Withstand site natural disaster	0.126	1	6	1	1	1	1	1	1	1	1
GS8-Conforms to site geometry	0.086	1	1	1	1	1	1	1/3	1	1	1
GS9-Conforms to spatial structure	0.110	1	1	1	1	1	3	1	1	1	1
GS10-Conforms to all spatial activities	0.083	1	1	1	1/5	1	1	1	1	1	1
GS11 Conforms to design geometry	0.093	1	1	1	1	1	1	1	1	1	1
GS12-Mat. Spatial scale/Size (sq./m)	0.093	1	1	1	1	1	1	1	1	1	1

CR ✓ 0.07

	Score	EH1 -E	EH2-E	EH3- H	EH4- O	EH5- A	EH6- C	EH7- E	EH8- F	EH9- N	EH10-
EH1 -Env. Statutory Compliance	0.090	1	1	1	1	1	1	1	1/4	1	1
EH2-Embodied CO2 Emission (KgCO2/m2)	0.095	1	1	1	1	1	1	1	1	1	1
EH3- Human Toxicity-Users Safety level	0.095	1	1	1	1	1	1	1	1	1	1
EH4- Ozone depletion rate	0.095	1	1	1	1	1	1	1	1	1	1
EH5- Amt. of Pesticide Treatment (l/m2)	0.095	1	1	1	1	1	1	1	1	1	1
EH6- Complies with the Climate of the region	0.095	1	1	1	1	1	1	1	1	1	1
EH7- Env. Toxicity (land, water, Animals)	0.095	1	1	1	1	1	1	1	1	1	1
EH8- Fossil fuel/Habitat depletion	0.122	4	1	1	1	1	1	1	1	1	1
EH9 Nuclear waste rate	0.095	1	1	1	1	1	1	1	1	1	1
EH10- Waste Disposal rate	0.095	1	1	1	1	1	1	1	1	1	1

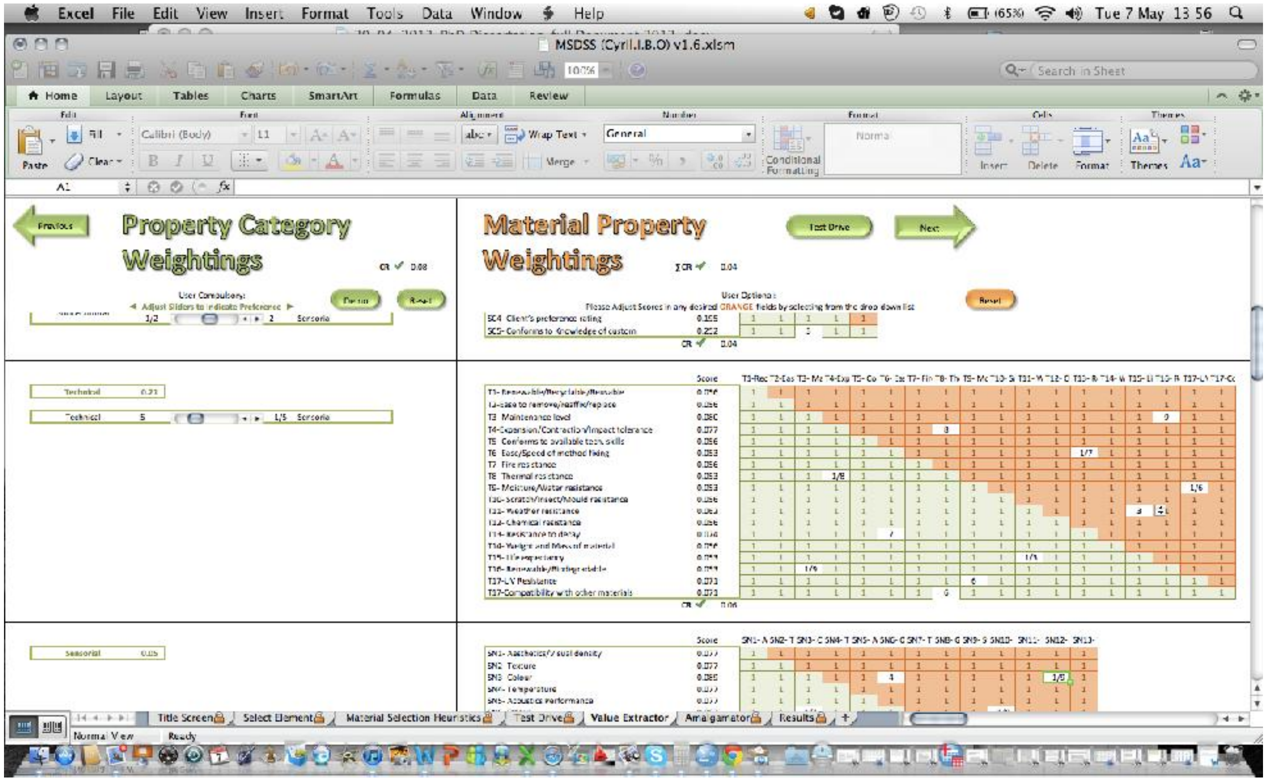
CR ✓ 0.01

	Score	C1- To	C2- Mi	C3- Ma	C4- Lal	C5- Mi	C6- Ma
C1- Total life-cycle cost ($)	0.167	1	1	1	1	1	1
C2- Material embodied energy cost ($)	0.167	1	1	1	1	1	1
C3- Material capital cost ($)	0.167	1	1	1	1	1	1

Sample of the value extractor user interface menu for the property category weightings

Clicking on the < SCROLL BARS > buttons of the PRINCIPAL PROPERTY/FACTOR CATEGORY WEIGHTINGS on the left column enables user to adjust values from 1-9 in each category against every other category such that Consistency Ratio (CR) is less than 0.10.

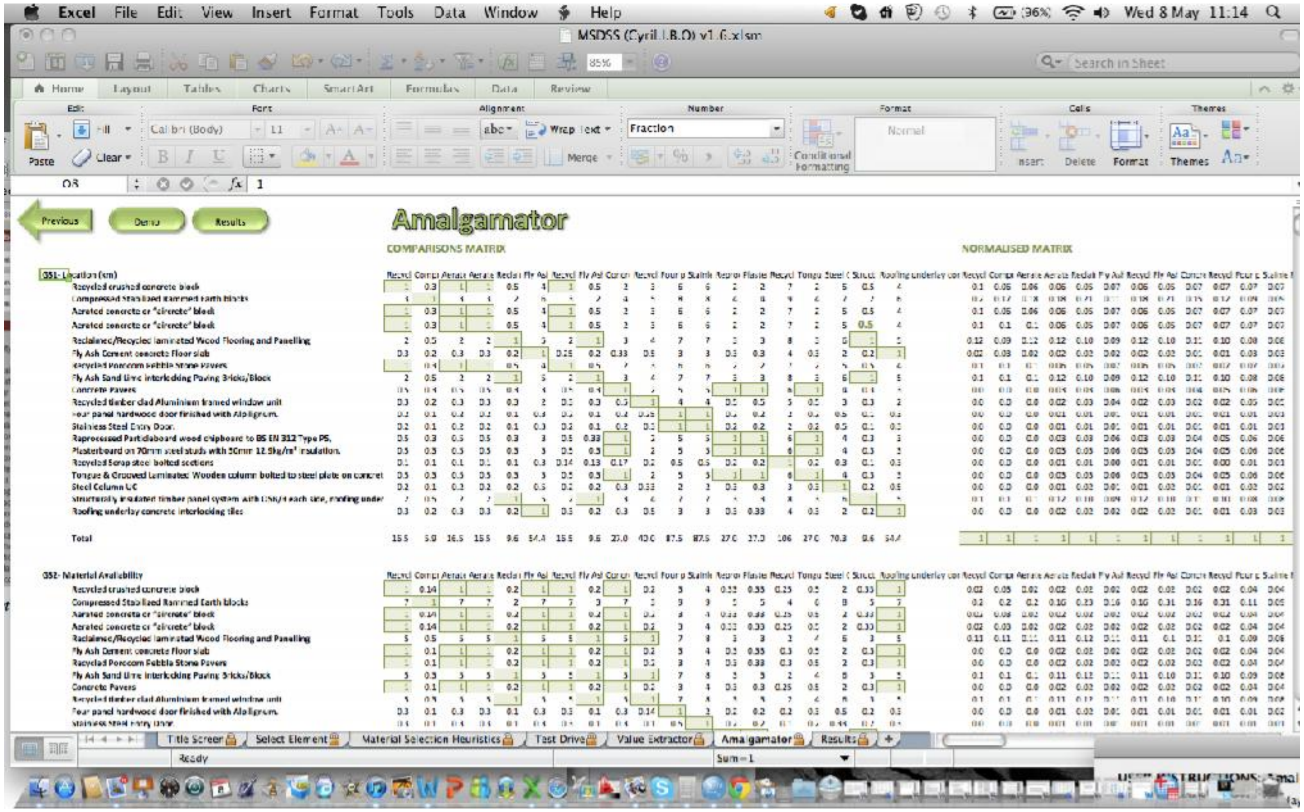
STEP 5: Clicking on the <SCROLL BARS> buttons of the subsets of a range of SUB-MATERIAL PROPERTY/FACTOR WEIGHTINGS in the ORANGE fields of the right column enables user to adjust values from 1-9 of each sub-categorical material selection factors against every other such that Consistency Ratio (CR) is less than 0.10



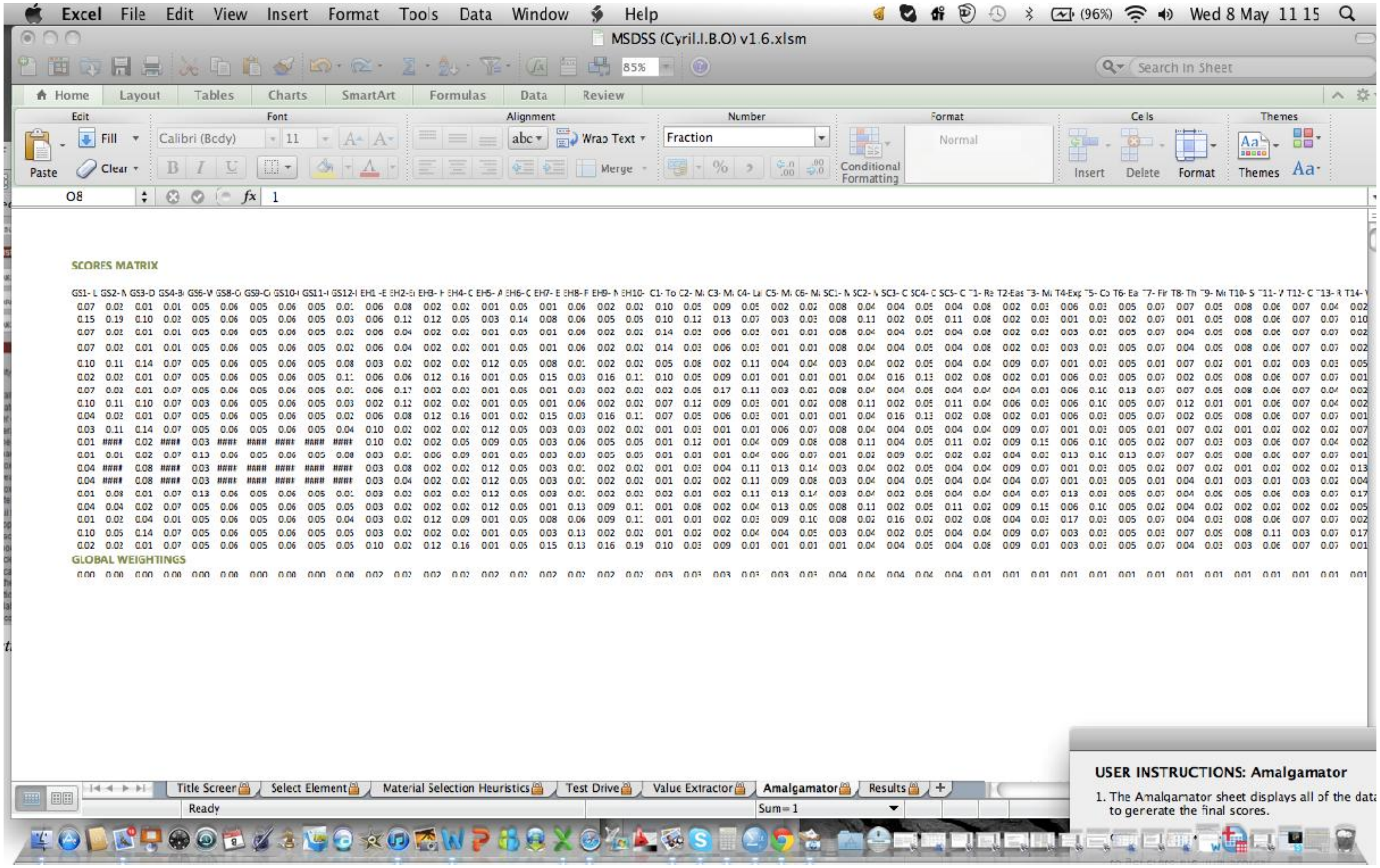
Sample of the value extractor user interface menu for the sub-material property weightings

Click on the <TEST DRIVE> button to quickly compare a few of the candidate materials if desired OR Click on the <NEXT > button to proceed to the next drive. Click on the <NEXT > button leads to the opening of the <Amalgamator> window below, which illustrates various preloaded weighting queries conducted in the system.

STEP 6: Clicking on the <NEXT> button the system displays the AMALGAMATOR sheet that automatically processes all the data from the previous drives to generate overall global weighting scores.



Amalgamator generating matrix results from the calculations performed in the value extractor



MSDSS (Cyril.I.B.O) v1.6.xlsm

Number format: Fraction

O8 fx 1

Sum=1

SCORES MATRIX

GS1- L	GS2- N	GS3-D	GS4-B	GS6-V	GS8-G	GS9-G	GS10-	GS11-	GS12-	EH1 -E	EH2-E	EH3- F	EH4- C	EH5- A
0.07	0.02	0.01	0.01	0.05	0.06	0.05	0.06	0.05	0.01	0.06	0.08	0.02	0.02	0.01
0.15	0.19	0.10	0.02	0.05	0.06	0.05	0.06	0.05	0.03	0.06	0.12	0.12	0.05	0.03
0.07	0.02	0.01	0.01	0.05	0.06	0.05	0.06	0.05	0.02	0.06	0.04	0.02	0.02	0.01
0.07	0.02	0.01	0.01	0.05	0.06	0.05	0.06	0.05	0.02	0.06	0.04	0.02	0.02	0.01
0.10	0.11	0.14	0.07	0.05	0.06	0.05	0.06	0.05	0.08	0.03	0.02	0.02	0.02	0.12
0.02	0.02	0.01	0.07	0.05	0.06	0.05	0.06	0.05	0.11	0.06	0.06	0.12	0.16	0.01
0.07	0.02	0.01	0.07	0.05	0.06	0.05	0.06	0.05	0.01	0.06	0.17	0.02	0.02	0.01
0.10	0.11	0.10	0.07	0.03	0.06	0.05	0.06	0.05	0.03	0.02	0.12	0.02	0.02	0.01
0.04	0.02	0.01	0.07	0.05	0.06	0.05	0.06	0.05	0.02	0.06	0.08	0.12	0.16	0.01
0.03	0.11	0.14	0.07	0.05	0.06	0.05	0.06	0.05	0.04	0.10	0.02	0.02	0.02	0.12
0.01	####	0.02	####	0.03	####	####	####	####	####	0.10	0.02	0.02	0.05	0.09
0.01	0.01	0.02	0.07	0.13	0.06	0.05	0.06	0.05	0.08	0.03	0.01	0.06	0.09	0.01
0.04	####	0.08	####	0.03	####	####	####	####	####	0.03	0.08	0.02	0.02	0.12
0.04	####	0.08	####	0.03	####	####	####	####	####	0.03	0.04	0.02	0.02	0.12
0.01	0.08	0.01	0.07	0.13	0.06	0.05	0.06	0.05	0.01	0.03	0.02	0.02	0.02	0.12
0.04	0.04	0.02	0.07	0.05	0.06	0.05	0.06	0.05	0.05	0.03	0.02	0.02	0.02	0.12
0.01	0.02	0.04	0.01	0.05	0.06	0.05	0.06	0.05	0.04	0.03	0.02	0.12	0.09	0.01
0.10	0.05	0.14	0.07	0.05	0.06	0.05	0.06	0.05	0.05	0.03	0.02	0.02	0.02	0.01
0.02	0.02	0.01	0.07	0.05	0.06	0.05	0.06	0.05	0.05	0.10	0.02	0.12	0.16	0.01

EH6- C	EH7- E	EH8- F	EH9- N	EH10-	C1- To	C2- M	C3- M	C4- La	C5- M	C6- M	SC1- N	SC2- V	SC3- C	SC4- C
0.05	0.01	0.06	0.02	0.02	0.10	0.05	0.09	0.05	0.02	0.02	0.08	0.04	0.04	0.05
0.14	0.08	0.06	0.05	0.05	0.10	0.12	0.13	0.07	0.03	0.03	0.08	0.11	0.02	0.05
0.05	0.01	0.06	0.02	0.02	0.14	0.03	0.06	0.03	0.01	0.01	0.08	0.04	0.04	0.05
0.05	0.01	0.06	0.02	0.02	0.14	0.03	0.06	0.03	0.01	0.01	0.08	0.04	0.04	0.05
0.05	0.08	0.01	0.02	0.02	0.05	0.08	0.02	0.11	0.04	0.04	0.03	0.04	0.02	0.05
0.05	0.15	0.03	0.16	0.11	0.10	0.05	0.09	0.01	0.01	0.01	0.01	0.04	0.16	0.13
0.05	0.01	0.03	0.02	0.02	0.02	0.05	0.17	0.11	0.03	0.03	0.08	0.04	0.04	0.05
0.05	0.01	0.06	0.02	0.02	0.07	0.12	0.09	0.03	0.01	0.02	0.08	0.11	0.02	0.05
0.02	0.15	0.03	0.16	0.11	0.07	0.05	0.06	0.03	0.01	0.01	0.01	0.04	0.16	0.13
0.05	0.03	0.03	0.02	0.02	0.01	0.03	0.01	0.01	0.06	0.07	0.08	0.04	0.04	0.05
0.05	0.03	0.06	0.05	0.05	0.01	0.12	0.01	0.04	0.09	0.08	0.08	0.11	0.04	0.05
0.05	0.03	0.03	0.05	0.05	0.01	0.01	0.01	0.04	0.06	0.07	0.01	0.02	0.09	0.05
0.05	0.03	0.01	0.02	0.02	0.01	0.03	0.04	0.11	0.13	0.14	0.03	0.04	0.02	0.05
0.05	0.03	0.01	0.02	0.02	0.01	0.02	0.02	0.11	0.09	0.08	0.03	0.04	0.04	0.05
0.05	0.03	0.01	0.02	0.02	0.02	0.01	0.02	0.11	0.13	0.14	0.03	0.04	0.02	0.05
0.05	0.01	0.13	0.09	0.11	0.01	0.08	0.02	0.04	0.13	0.09	0.08	0.11	0.02	0.05
0.05	0.08	0.06	0.09	0.11	0.01	0.01	0.02	0.03	0.09	0.10	0.08	0.02	0.16	0.02
0.05	0.03	0.13	0.02	0.02	0.01	0.02	0.02	0.04	0.04	0.05	0.03	0.04	0.02	0.05
0.05	0.15	0.13	0.16	0.19	0.10	0.03	0.09	0.01	0.01	0.01	0.01	0.04	0.04	0.05

SC5- C	T1- Re	T2-Eas	T3- M	T4-Exp	T5- Co	T6- Ea	T7- Fir	T8- Th	T9- Mo	T10- S	T11- V	T12- C	T13- R	T14- V
0.04	0.08	0.02	0.03	0.06	0.03	0.05	0.07	0.07	0.05	0.08	0.06	0.07	0.04	0.02
0.11	0.08	0.02	0.03	0.01	0.03	0.02	0.07	0.01	0.05	0.08	0.06	0.07	0.07	0.10
0.04	0.08	0.02	0.03	0.03	0.03	0.05	0.07	0.04	0.05	0.08	0.06	0.07	0.07	0.02
0.04	0.08	0.02	0.03	0.03	0.03	0.05	0.07	0.04	0.05	0.08	0.06	0.07	0.07	0.02
0.04	0.04	0.09	0.07	0.01	0.03	0.05	0.01	0.07	0.02	0.01	0.02	0.03	0.03	0.05
0.02	0.08	0.02	0.01	0.06	0.03	0.05	0.07	0.02	0.05	0.08	0.06	0.07	0.07	0.01
0.04	0.04	0.04	0.01	0.06	0.10	0.13	0.07	0.07	0.05	0.08	0.06	0.07	0.04	0.02
0.11	0.04	0.06	0.03	0.06	0.10	0.05	0.07	0.12	0.01	0.01	0.06	0.07	0.04	0.02
0.02	0.08	0.02	0.01	0.06	0.03	0.05	0.07	0.02	0.05	0.08	0.06	0.07	0.07	0.01
0.04	0.04	0.09	0.07	0.01	0.03	0.05	0.01	0.07	0.02	0.01	0.02	0.02	0.02	0.07
0.11	0.02	0.09	0.15	0.06	0.10	0.05	0.02	0.07	0.03	0.03	0.06	0.07	0.04	0.02
0.02	0.02	0.04	0.03	0.13	0.10	0.13	0.07	0.07	0.05	0.08	0.06	0.07	0.07	0.01
0.04	0.04	0.09	0.07	0.01	0.03	0.05	0.02	0.07	0.02	0.01	0.02	0.02	0.02	0.13
0.04	0.04	0.04	0.07	0.01	0.03	0.05	0.01	0.04	0.01	0.03	0.01	0.03	0.02	0.04
0.04	0.04	0.04	0.07	0.13	0.03	0.05	0.07	0.04	0.06	0.05	0.06	0.03	0.07	0.17
0.11	0.02	0.09	0.15	0.06	0.10	0.05	0.02	0.04	0.02	0.02	0.02	0.02	0.02	0.05
0.02	0.08	0.04	0.03	0.17	0.03	0.05	0.07	0.04	0.03	0.08	0.06	0.07	0.07	0.02
0.04	0.04	0.09	0.07	0.03	0.03	0.05	0.03	0.07	0.09	0.08	0.11	0.03	0.07	0.17
0.04	0.08	0.09	0.01	0.03	0.03	0.05	0.07	0.04	0.03	0.03	0.06	0.07	0.07	0.01

GLOBAL WEIGHTINGS

GS1- L	GS2- N	GS3-D	GS4-B	GS6-V	GS8-G	GS9-G	GS10-	GS11-	GS12-	EH1 -E	EH2-E	EH3- F	EH4- C	EH5- A
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.02	0.02	0.02	0.02

EH6- C	EH7- E	EH8- F	EH9- N	EH10-	C1- To	C2- M	C3- M	C4- La	C5- M	C6- M	SC1- N	SC2- V	SC3- C	SC4- C
0.02	0.02	0.02	0.02	0.02	0.03	0.03	0.03	0.03	0.03	0.03	0.04	0.04	0.04	0.04

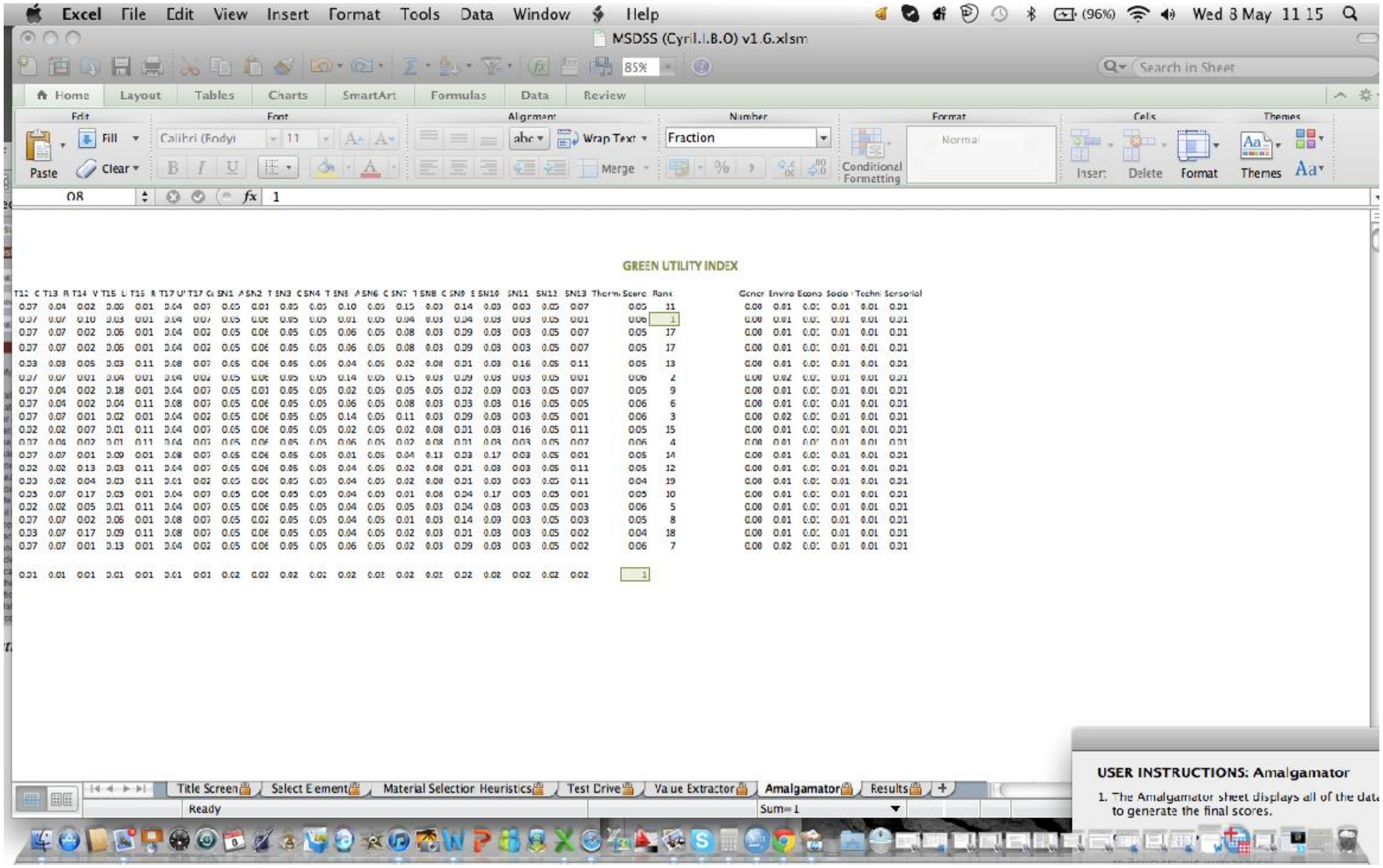
SC5- C	T1- Re	T2-Eas	T3- M	T4-Exp	T5- Co	T6- Ea	T7- Fir	T8- Th	T9- Mo	T10- S	T11- V	T12- C	T13- R	T14- V
0.04	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

USER INSTRUCTIONS: Amalgamator

1. The Amalgamator sheet displays all of the data
to gererate the final scores.

System showing logic trading-off the values of each factor category against others

STEP 7: Next logic trades-off the values of each criteria category against the others as shown in the figure below. Afterwards, the system performs the pair-wise comparison for each material property to create the scores of the comparison matrix as shown below



GREEN UTILITY INDEX

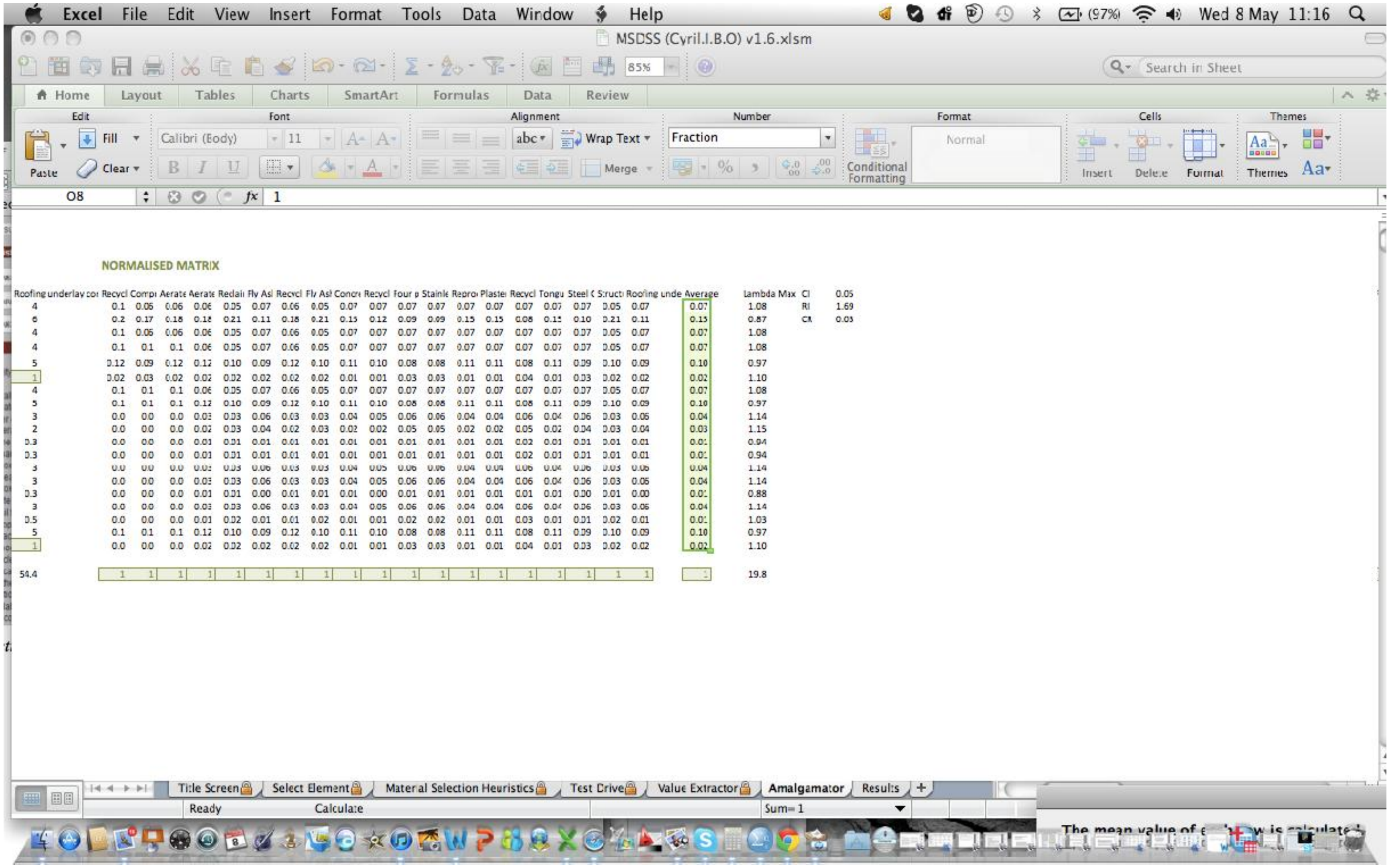
T12 C	T13 R	T14 V	T15 L	T16 R	T17 U'	T17 C(	SN1 A	SN2 T	SN3 C	SN4 T	SN5 A	SN6 C	SN7 T	SN8 C	SN9 S	SN10	SN11	SN12	SN13	Therm	Score	Rank	Gener	Enviro	Econo	Socio	Techni	Sensorial
0.07	0.04	0.02	0.06	0.01	0.04	0.07	0.05	0.01	0.05	0.05	0.10	0.05	0.15	0.03	0.14	0.03	0.03	0.05	0.07		0.05	11	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.07	0.10	0.03	0.01	0.04	0.07	0.05	0.06	0.05	0.05	0.01	0.05	0.04	0.03	0.04	0.03	0.03	0.05	0.01		0.06	1	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.07	0.02	0.06	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.06	0.05	0.08	0.03	0.09	0.03	0.03	0.05	0.07		0.05	17	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.07	0.02	0.06	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.06	0.05	0.08	0.03	0.09	0.03	0.03	0.05	0.07		0.05	17	0.00	0.01	0.0:	0.01	0.01	0.01
0.03	0.03	0.05	0.03	0.11	0.08	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.02	0.08	0.01	0.03	0.16	0.05	0.11		0.05	13	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.07	0.01	0.04	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.14	0.05	0.15	0.03	0.09	0.03	0.03	0.05	0.01		0.06	2	0.00	0.02	0.0:	0.01	0.01	0.01
0.07	0.04	0.02	0.18	0.01	0.04	0.07	0.05	0.01	0.05	0.05	0.02	0.05	0.05	0.05	0.02	0.09	0.03	0.05	0.07		0.05	9	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.04	0.02	0.04	0.11	0.08	0.07	0.05	0.06	0.05	0.05	0.06	0.05	0.08	0.03	0.03	0.03	0.16	0.05	0.05		0.06	6	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.07	0.01	0.02	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.14	0.05	0.11	0.03	0.09	0.03	0.03	0.05	0.01		0.06	3	0.00	0.02	0.0:	0.01	0.01	0.01
0.02	0.02	0.07	0.01	0.11	0.04	0.07	0.05	0.06	0.05	0.05	0.02	0.05	0.02	0.08	0.01	0.03	0.16	0.05	0.11		0.05	15	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.04	0.02	0.01	0.11	0.04	0.02	0.05	0.06	0.05	0.05	0.06	0.05	0.02	0.08	0.01	0.03	0.03	0.05	0.07		0.06	4	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.07	0.01	0.09	0.01	0.08	0.07	0.05	0.06	0.05	0.05	0.01	0.05	0.04	0.13	0.03	0.17	0.03	0.05	0.01		0.05	14	0.00	0.01	0.0:	0.01	0.01	0.01
0.02	0.02	0.13	0.03	0.11	0.04	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.02	0.08	0.01	0.03	0.03	0.05	0.11		0.05	12	0.00	0.01	0.0:	0.01	0.01	0.01
0.03	0.02	0.04	0.03	0.11	0.01	0.02	0.05	0.06	0.05	0.05	0.04	0.05	0.02	0.08	0.01	0.03	0.03	0.05	0.11		0.04	19	0.00	0.01	0.0:	0.01	0.01	0.01
0.03	0.07	0.17	0.03	0.01	0.04	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.01	0.06	0.04	0.17	0.03	0.05	0.01		0.05	10	0.00	0.01	0.0:	0.01	0.01	0.01
0.02	0.02	0.05	0.01	0.11	0.04	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.05	0.03	0.04	0.03	0.03	0.05	0.03		0.06	5	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.07	0.02	0.06	0.01	0.08	0.07	0.05	0.02	0.05	0.05	0.04	0.05	0.01	0.03	0.14	0.09	0.03	0.05	0.03		0.05	8	0.00	0.01	0.0:	0.01	0.01	0.01
0.03	0.07	0.17	0.09	0.11	0.08	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.02	0.03	0.01	0.03	0.03	0.05	0.02		0.04	18	0.00	0.01	0.0:	0.01	0.01	0.01
0.07	0.07	0.01	0.13	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.06	0.05	0.02	0.03	0.09	0.03	0.03	0.05	0.02		0.06	7	0.00	0.02	0.0:	0.01	0.01	0.01
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02		1							

USER INSTRUCTIONS: Amalgamator

1. The Amalgamator sheet displays all of the data to generate the final scores.

System showing scores of the comparison matrices

The COMPARISON MATRIX is normalised so that all columns total 1 as shown above.

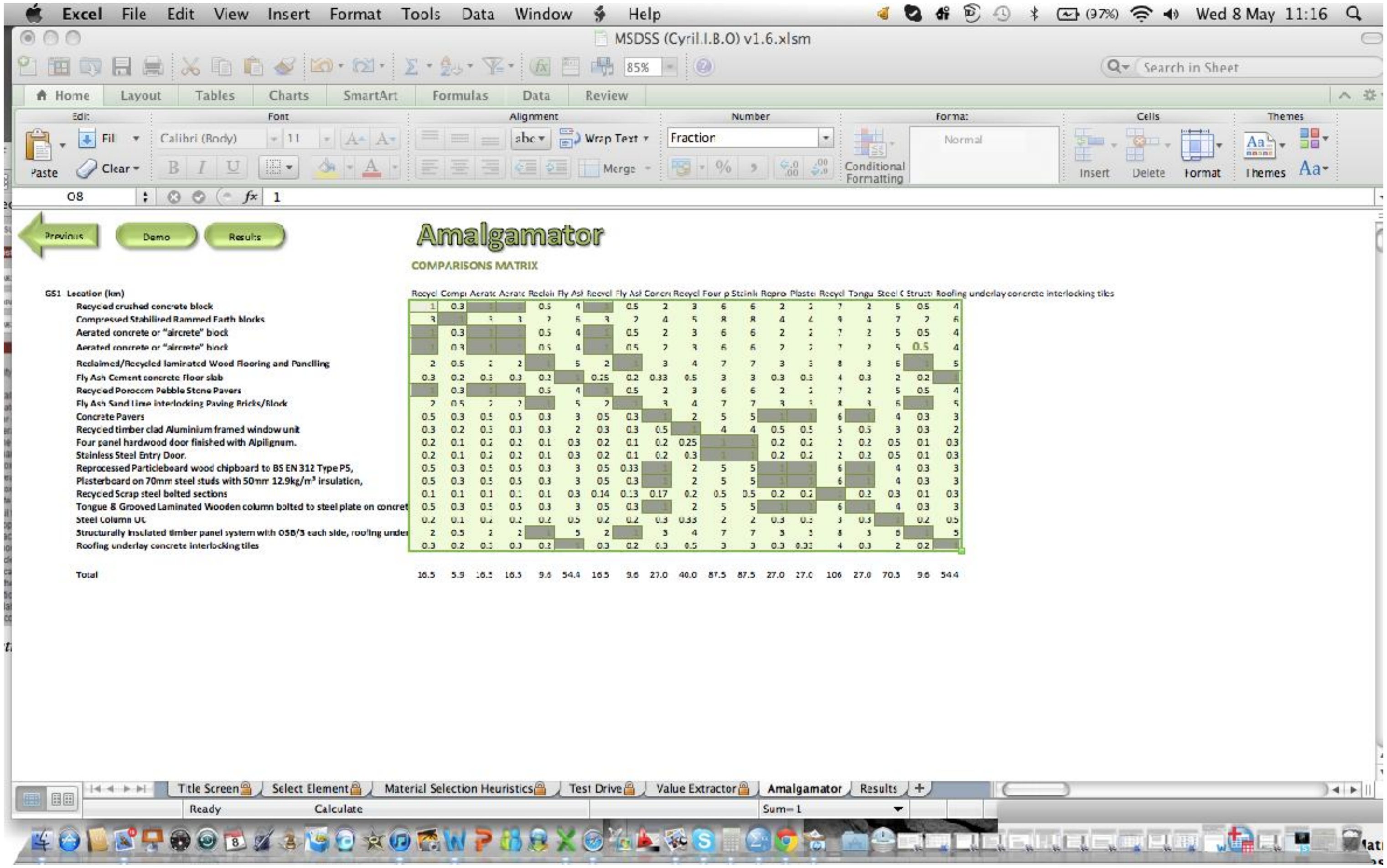


NORMALISED MATRIX

Roofing underlay cor	Recycl	Compr	Aerate	Aerate	Reclai	Fly Asl	Recycl	Fly Asl	Concr	Recycl	Four p	Stainle	Repro	Plaster	Recycl	Tongu	Steel C	Structi	Roofing unde	Average	Lambda Max	CI	0.05
4	0.1	0.06	0.06	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08	RI	1.69
6	0.2	0.17	0.18	0.18	0.21	0.11	0.18	0.21	0.15	0.12	0.09	0.09	0.15	0.15	0.08	0.15	0.10	0.21	0.11	0.15	0.87	CR	0.03
4	0.1	0.06	0.06	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08		
4	0.1	0.1	0.1	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08		
5	0.12	0.09	0.12	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08	0.11	0.11	0.08	0.11	0.09	0.10	0.09	0.10	0.97		
1	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.04	0.01	0.03	0.02	0.02	0.02	1.10		
4	0.1	0.1	0.1	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08		
5	0.1	0.1	0.1	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08	0.11	0.11	0.08	0.11	0.09	0.10	0.09	0.10	0.97		
3	0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
2	0.0	0.0	0.0	0.02	0.03	0.04	0.02	0.03	0.02	0.02	0.05	0.05	0.02	0.02	0.05	0.02	0.04	0.03	0.04	0.03	1.15		
0.3	0.0	0.0	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.94		
0.3	0.0	0.0	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.94		
3	0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
3	0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
0.3	0.0	0.0	0.0	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.88		
3	0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
0.5	0.0	0.0	0.0	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.03	0.01	0.01	0.02	0.01	0.01	1.03		
5	0.1	0.1	0.1	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08	0.11	0.11	0.08	0.11	0.09	0.10	0.09	0.10	0.97		
1	0.0	0.0	0.0	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.04	0.01	0.03	0.02	0.02	0.02	1.10		
54.4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8		

System displaying the normalised scores of the comparison matrices

STEP 8: The system performs pair-wise comparison for the selected materials as shown below



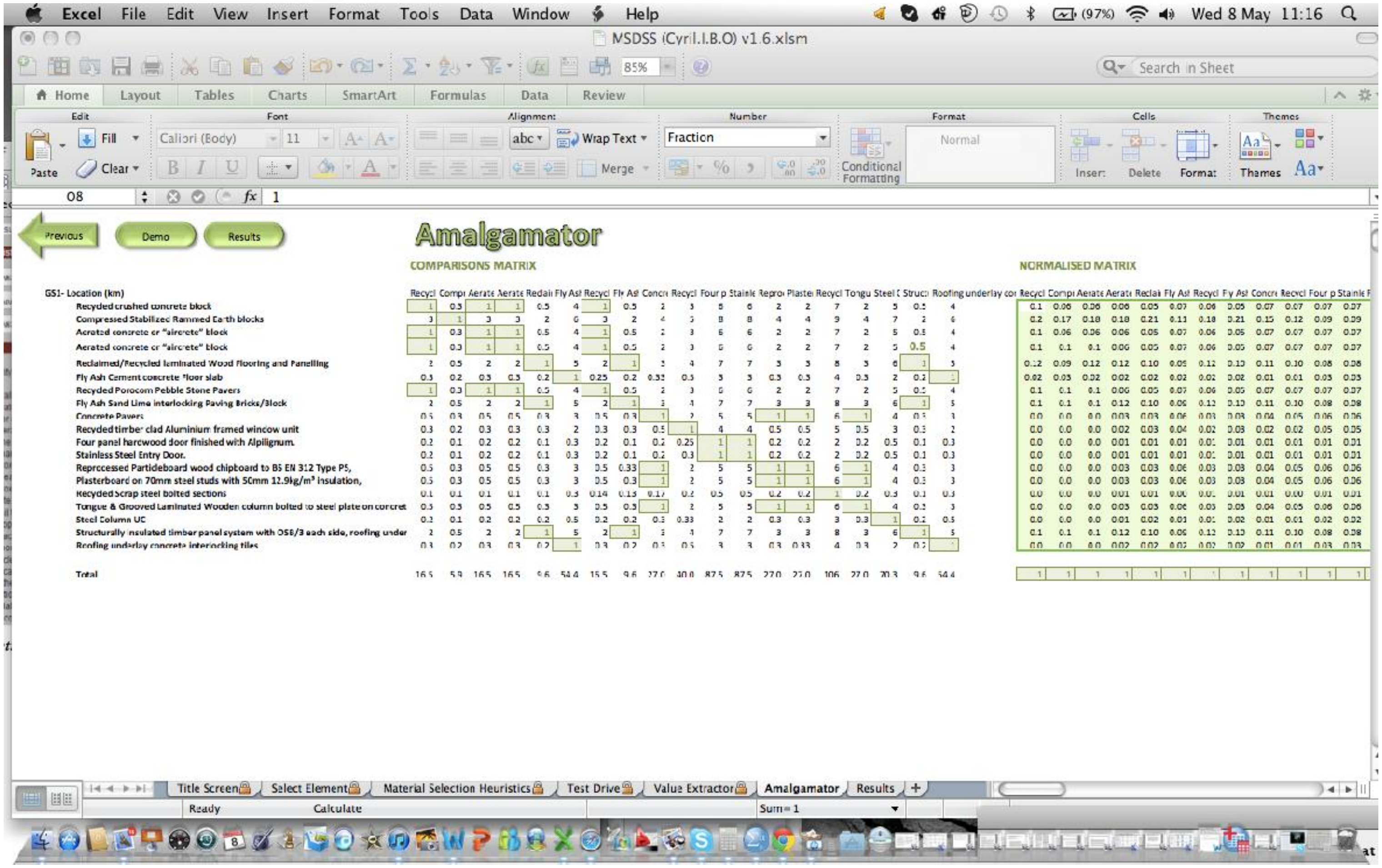
Amalgamator

COMPARISONS MATRIX

GS1 Location (km)	Recycl	Compr	Aeratc	Aeratc	Reclai	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainl	Repro	Plaste	Recycl	Tongu	Steel C	Structi	Roofing underlay concrete interlocking tiles
Recycled crushed concrete block	1	0.3	1	1	0.5	4	1	0.5	2	3	6	6	2	2	7	2	5	0.5	4
Compressed Stabilized Rammed Earth blocks	3	1	3	3	2	6	3	2	4	5	8	8	4	4	9	4	7	2	6
Aerated concrete or "aircrete" block	1	0.3	1	1	0.5	4	1	0.5	2	3	6	6	2	2	7	2	5	0.5	4
Aerated concrete or "aircrete" block	1	0.3	1	1	0.5	4	1	0.5	2	3	6	6	2	2	7	2	5	0.5	4
Reclaimed/Recycled laminated Wood Flooring and Panelling	2	0.5	2	2	1	5	2	1	3	4	7	7	3	3	8	3	6	1	5
Fly Ash Cement concrete floor slab	0.3	0.2	0.3	0.3	0.2	1	0.25	0.2	0.33	0.5	3	3	0.3	0.3	4	0.3	2	0.2	1
Recycled Porocem Pebble Stone Pavers	1	0.3	1	1	0.5	4	1	0.5	2	3	6	6	2	2	7	2	5	0.5	4
Fly Ash Sand Lime interlocking Paving Bricks/Block	2	0.5	2	2	1	5	2	1	3	4	7	7	3	3	8	3	6	1	5
Concrete Pavers	0.5	0.3	0.5	0.5	0.3	3	0.5	0.3	1	2	5	5	1	1	6	1	4	0.3	3
Recycled timber clad Aluminium framed window unit	0.3	0.2	0.3	0.3	0.3	2	0.3	0.3	0.5	1	4	4	0.5	0.5	5	0.5	3	0.3	2
Four panel hardwood door finished with Alpilignum.	0.2	0.1	0.2	0.2	0.1	0.3	0.2	0.1	0.2	0.25	1	1	0.2	0.2	2	0.2	0.5	0.1	0.3
Stainless Steel Entry Door.	0.2	0.1	0.2	0.2	0.1	0.3	0.2	0.1	0.2	0.3	1	1	0.2	0.2	2	0.2	0.5	0.1	0.3
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	0.5	0.3	0.5	0.5	0.3	3	0.5	0.33	1	2	5	5	1	1	6	1	4	0.3	3
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.5	0.3	0.5	0.5	0.3	3	0.5	0.3	1	2	5	5	1	1	6	1	4	0.3	3
Recycled Scrap steel bolted sections	0.1	0.1	0.1	0.1	0.1	0.3	0.14	0.13	0.17	0.2	0.5	0.5	0.2	0.2	1	0.2	0.3	0.1	0.3
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.5	0.3	0.5	0.5	0.3	3	0.5	0.3	1	2	5	5	1	1	6	1	4	0.3	3
Steel Column UC	0.2	0.1	0.2	0.2	0.2	0.5	0.2	0.2	0.3	0.33	2	2	0.3	0.3	3	0.3	1	0.2	0.5
Structurally insulated timber panel system with OSB/3 each side, roofing under	2	0.5	2	2	1	5	2	1	3	4	7	7	3	3	8	3	6	1	5
Roofing underlay concrete interlocking tiles	0.3	0.2	0.3	0.3	0.2	1	0.3	0.2	0.3	0.5	3	3	0.3	0.33	4	0.3	2	0.2	1
Total	16.5	5.9	16.5	16.5	9.6	54.4	16.5	9.6	27.0	40.0	87.5	87.5	27.0	27.0	106	27.0	70.5	9.6	54.4

System displaying the pairwise comparison scores for the selected materials

The system generates the normalised scores of the pair-wise comparison for the selected materials



Amalgamator

COMPARISONS MATRIX

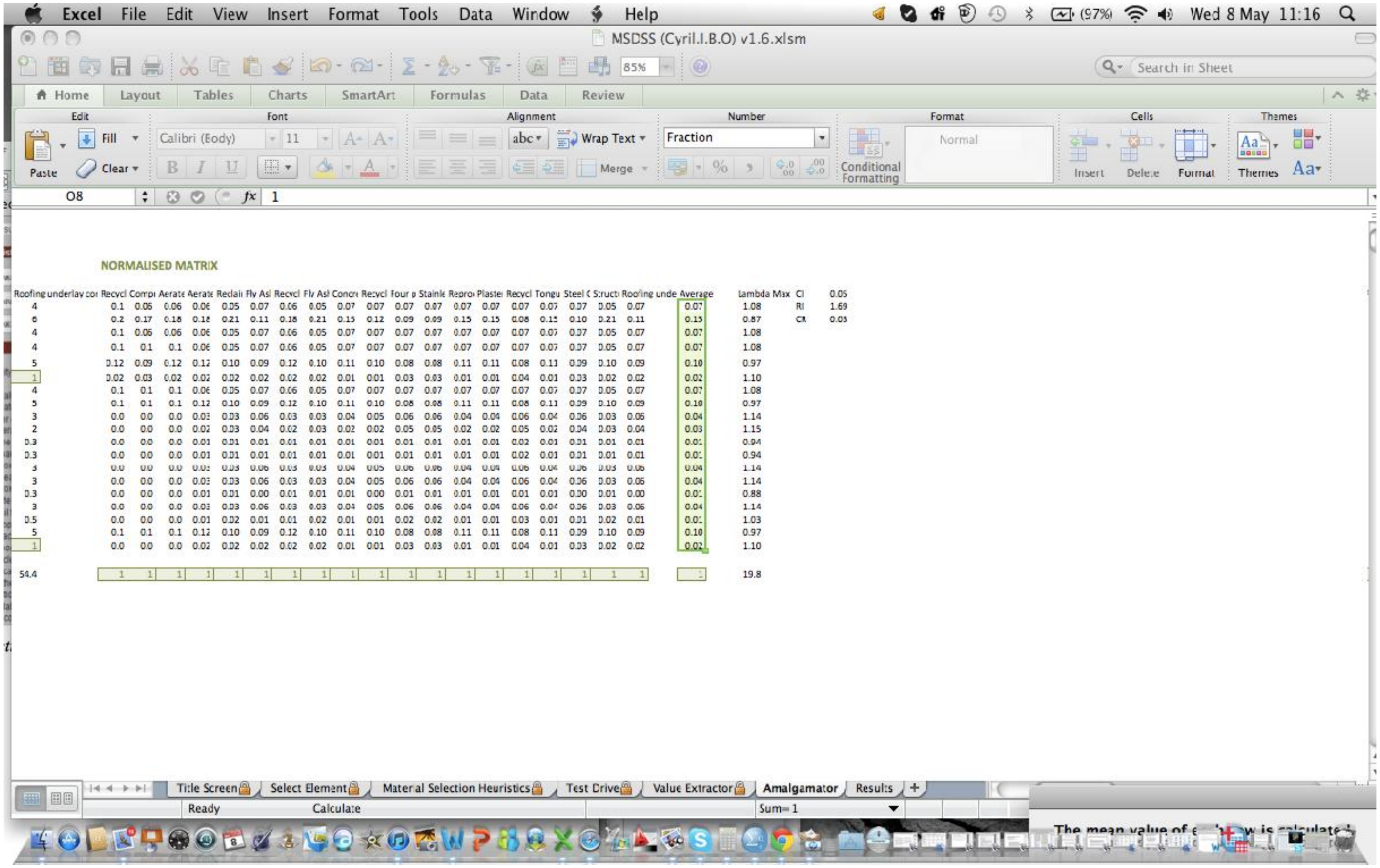
GS1- Location (km)	Recycl	Compr	Aerate	Aerate	Reclai	Fly Ast	Recycl	Fly Ast	Concr	Recycl	Four p	Stainle	Reproc	Plaste	Recycl	Tongu	Steel C	Struct	Roofing underlay cor
Recycled crushed concrete block	1	0.3	1	1	0.5	4	1	0.5	2	3	6	6	2	2	7	2	5	0.5	4
Compressed Stabilized Rammed Earth blocks	3	1	3	3	2	6	3	2	4	5	8	8	4	4	9	4	7	2	6
Aerated concrete or "aircrete" block	1	0.3	1	1	0.5	4	1	0.5	2	3	6	6	2	2	7	2	5	0.5	4
Aerated concrete or "aircrete" block	1	0.3	1	1	0.5	4	1	0.5	2	3	6	6	2	2	7	2	5	0.5	4
Reclaimed/Recycled laminated Wood Flooring and Panelling	2	0.5	2	2	1	5	2	1	3	4	7	7	3	3	8	3	6	1	5
Fly Ash Cement concrete floor slab	0.3	0.2	0.3	0.3	0.2	1	0.25	0.2	0.33	0.5	3	3	0.3	0.3	4	0.3	2	0.2	1
Recycled Porocom Pebble Stone Pavers	1	0.3	1	1	0.5	4	1	0.5	2	3	6	6	2	2	7	2	5	0.5	4
Fly Ash Sand Lime interlocking Paving Bricks/Block	2	0.5	2	2	1	5	2	1	3	4	7	7	3	3	8	3	6	1	5
Concrete Pavers	0.5	0.3	0.5	0.5	0.3	3	0.5	0.3	1	2	5	5	1	1	6	1	4	0.3	3
Recycled timber clad Aluminium framed window unit	0.3	0.2	0.3	0.3	0.3	2	0.3	0.3	0.5	1	4	4	0.5	0.5	5	0.5	3	0.3	2
Four panel hardwood door finished with Alpilignum.	0.2	0.1	0.2	0.2	0.1	0.3	0.2	0.1	0.2	0.25	1	1	0.2	0.2	2	0.2	0.5	0.1	0.3
Stainless Steel Entry Door.	0.2	0.1	0.2	0.2	0.1	0.3	0.2	0.1	0.2	0.3	1	1	0.2	0.2	2	0.2	0.5	0.1	0.3
Reprocessed Partideboard wood chipboard to BS EN 312 Type P5,	0.5	0.3	0.5	0.5	0.3	3	0.5	0.33	1	2	5	5	1	1	6	1	4	0.3	3
Plasterboard on 70mm steel studs with 50mm 12.9kg/m³ insulation,	0.5	0.3	0.5	0.5	0.3	3	0.5	0.3	1	2	5	5	1	1	6	1	4	0.3	3
Recycled Scrap steel bolted sections	0.1	0.1	0.1	0.1	0.1	0.3	0.14	0.13	0.17	0.2	0.5	0.5	0.2	0.2	1	0.2	0.3	0.1	0.3
Tongue & Grooved Laminated Wooden column bolted to steel plate on concret	0.5	0.3	0.5	0.5	0.3	3	0.5	0.3	1	2	5	5	1	1	6	1	4	0.3	3
Steel Column UC	0.2	0.1	0.2	0.2	0.2	0.5	0.2	0.2	0.3	0.33	2	2	0.3	0.3	3	0.3	1	0.2	0.5
Structurally insulated timber panel system with OSB/3 each side, roofing under	2	0.5	2	2	1	5	2	1	3	4	7	7	3	3	8	3	6	1	5
Roofing underlay concrete interlocking tiles	0.3	0.2	0.3	0.3	0.2	1	0.3	0.2	0.3	0.5	3	3	0.3	0.33	4	0.3	2	0.2	1
Total	16.5	5.9	16.5	16.5	9.6	54.4	15.5	9.6	27.0	40.0	87.5	87.5	27.0	27.0	106	27.0	20.3	9.6	54.4

NORMALISED MATRIX

Recycl	Compr	Aerate	Aerate	Reclai	Fly Ast	Recycl	Fly Ast	Concr	Recycl	Four p	Stainle
0.1	0.06	0.06	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07
0.2	0.17	0.18	0.18	0.21	0.11	0.18	0.21	0.15	0.12	0.09	0.09
0.1	0.06	0.06	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07
0.1	0.1	0.1	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07
0.12	0.09	0.12	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08
0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.03	0.03
0.1	0.1	0.1	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07
0.1	0.1	0.1	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08
0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06
0.0	0.0	0.0	0.02	0.03	0.04	0.02	0.03	0.02	0.02	0.05	0.05
0.0	0.0	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.0	0.0	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01
0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06
0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06
0.0	0.0	0.0	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01
0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06
0.0	0.0	0.0	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.02
0.1	0.1	0.1	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08
0.0	0.0	0.0	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.03	0.03
1	1	1	1	1	1	1	1	1	1	1	1

System showing the normalised score of the comparison matrices for the selected materials

STEP 9: The MEAN VALUE of each row is calculated as highlighted below

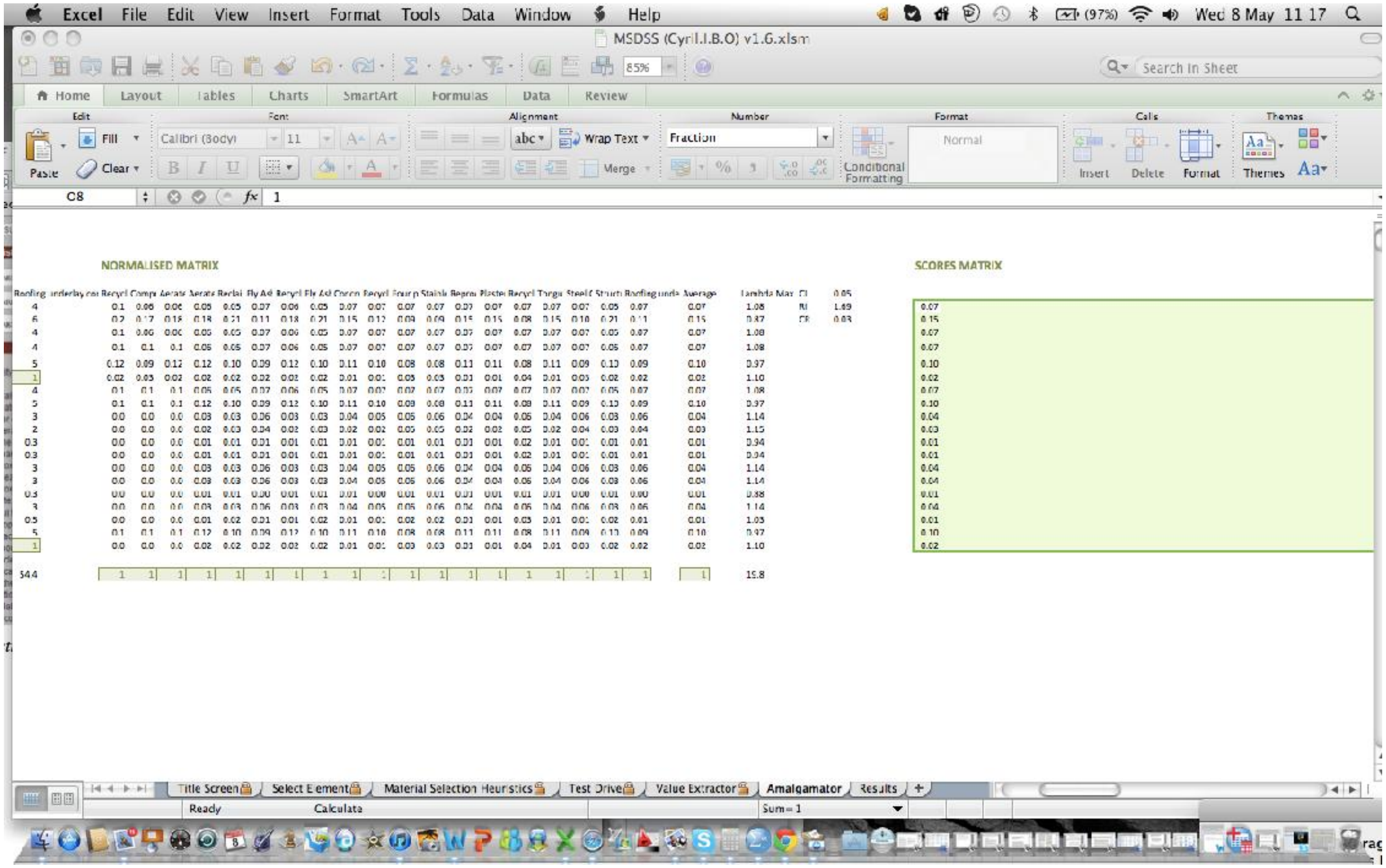


NORMALISED MATRIX

Roofing underlay cor	Recycl	Compr	Aerate	Aerate	Reclai	Fly As	Recycl	Fly As	Concr	Recycl	Four p	Stainle	Repro	Plaste	Recycl	Tongu	Steel C	Structi	Roofing unde	Average	Lambda Max	CI	0.05
4	0.1	0.06	0.06	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08	RI	1.69
6	0.2	0.17	0.18	0.18	0.21	0.11	0.18	0.21	0.15	0.12	0.09	0.09	0.15	0.15	0.08	0.15	0.10	0.21	0.11	0.15	0.87	CR	0.03
4	0.1	0.06	0.06	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08		
4	0.1	0.1	0.1	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08		
5	0.12	0.09	0.12	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08	0.11	0.11	0.08	0.11	0.09	0.10	0.09	0.10	0.97		
1	0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.04	0.01	0.03	0.02	0.02	0.02	1.10		
4	0.1	0.1	0.1	0.06	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08		
5	0.1	0.1	0.1	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08	0.11	0.11	0.08	0.11	0.09	0.10	0.09	0.10	0.97		
3	0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
2	0.0	0.0	0.0	0.02	0.03	0.04	0.02	0.03	0.02	0.02	0.05	0.05	0.02	0.02	0.05	0.02	0.04	0.03	0.04	0.03	1.15		
0.3	0.0	0.0	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.94		
0.3	0.0	0.0	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.94		
3	0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
3	0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
0.3	0.0	0.0	0.0	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.88		
3	0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.06	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
0.5	0.0	0.0	0.0	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.03	0.01	0.01	0.02	0.01	0.01	1.03		
5	0.1	0.1	0.1	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08	0.11	0.11	0.08	0.11	0.09	0.10	0.09	0.10	0.97		
1	0.0	0.0	0.0	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.04	0.01	0.03	0.02	0.02	0.02	1.10		
54.4	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	19.8		

System displaying the calculated mean value of each row

The column of AVERAGES is brought over to form the first column in the SCORES MATRIX as highlighted, and then automatically displays the score data associated with the material database. This process is repeated for all material properties.



C8 fx 1

NORMALISED MATRIX

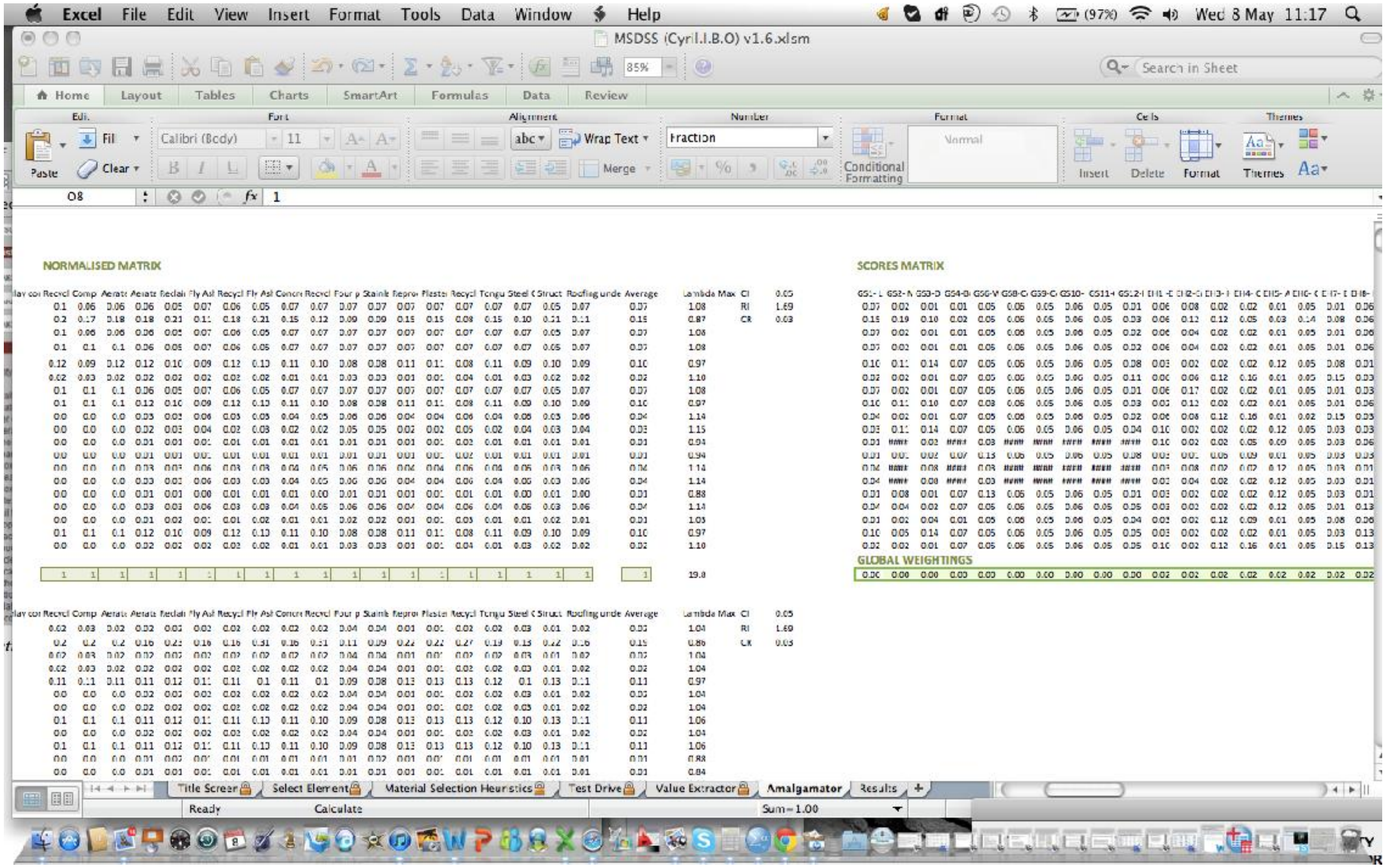
Roofing	underlay co	Recycl	Compr	Aerat	Aerat	Reclai	Fly Ash	Recycl	Fly Ash	Concr	Recycl	Four p	Stainl	Repro	Plaste	Recycl	Tergu	Steel	Struct	Roofing unde	Average	Lambda Max	CI	0.05
4		0.1	0.06	0.06	0.05	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08	RI	1.49
6		0.2	0.17	0.18	0.18	0.21	0.11	0.18	0.21	0.15	0.12	0.09	0.09	0.15	0.15	0.08	0.15	0.10	0.21	0.11	0.15	0.87	CR	0.03
4		0.1	0.06	0.06	0.05	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08		
4		0.1	0.1	0.1	0.05	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08		
5		0.12	0.09	0.12	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08	0.11	0.11	0.08	0.11	0.09	0.13	0.09	0.10	0.97		
1		0.02	0.03	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.04	0.01	0.03	0.02	0.02	0.02	1.10		
4		0.1	0.1	0.1	0.05	0.05	0.07	0.06	0.05	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.05	0.07	0.07	1.08		
5		0.1	0.1	0.1	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.09	0.08	0.11	0.11	0.08	0.11	0.09	0.13	0.09	0.10	0.97		
3		0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.05	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
2		0.0	0.0	0.0	0.02	0.03	0.04	0.02	0.03	0.02	0.02	0.05	0.05	0.02	0.02	0.05	0.02	0.04	0.03	0.04	0.03	1.15		
0.3		0.0	0.0	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.94		
0.3		0.0	0.0	0.0	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.94		
3		0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.05	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
3		0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.05	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
0.3		0.0	0.0	0.0	0.01	0.01	0.00	0.01	0.01	0.01	0.00	0.01	0.01	0.01	0.01	0.01	0.01	0.00	0.01	0.00	0.01	0.88		
3		0.0	0.0	0.0	0.03	0.03	0.06	0.03	0.03	0.04	0.05	0.05	0.06	0.04	0.04	0.06	0.04	0.06	0.03	0.06	0.04	1.14		
0.5		0.0	0.0	0.0	0.01	0.02	0.01	0.01	0.02	0.01	0.01	0.02	0.02	0.01	0.01	0.03	0.01	0.01	0.02	0.01	0.01	1.03		
5		0.1	0.1	0.1	0.12	0.10	0.09	0.12	0.10	0.11	0.10	0.08	0.08	0.11	0.11	0.08	0.11	0.09	0.13	0.09	0.10	0.97		
1		0.0	0.0	0.0	0.02	0.02	0.02	0.02	0.02	0.01	0.01	0.03	0.03	0.01	0.01	0.04	0.01	0.03	0.02	0.02	0.02	1.10		
54.4		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	15.8		

SCORES MATRIX

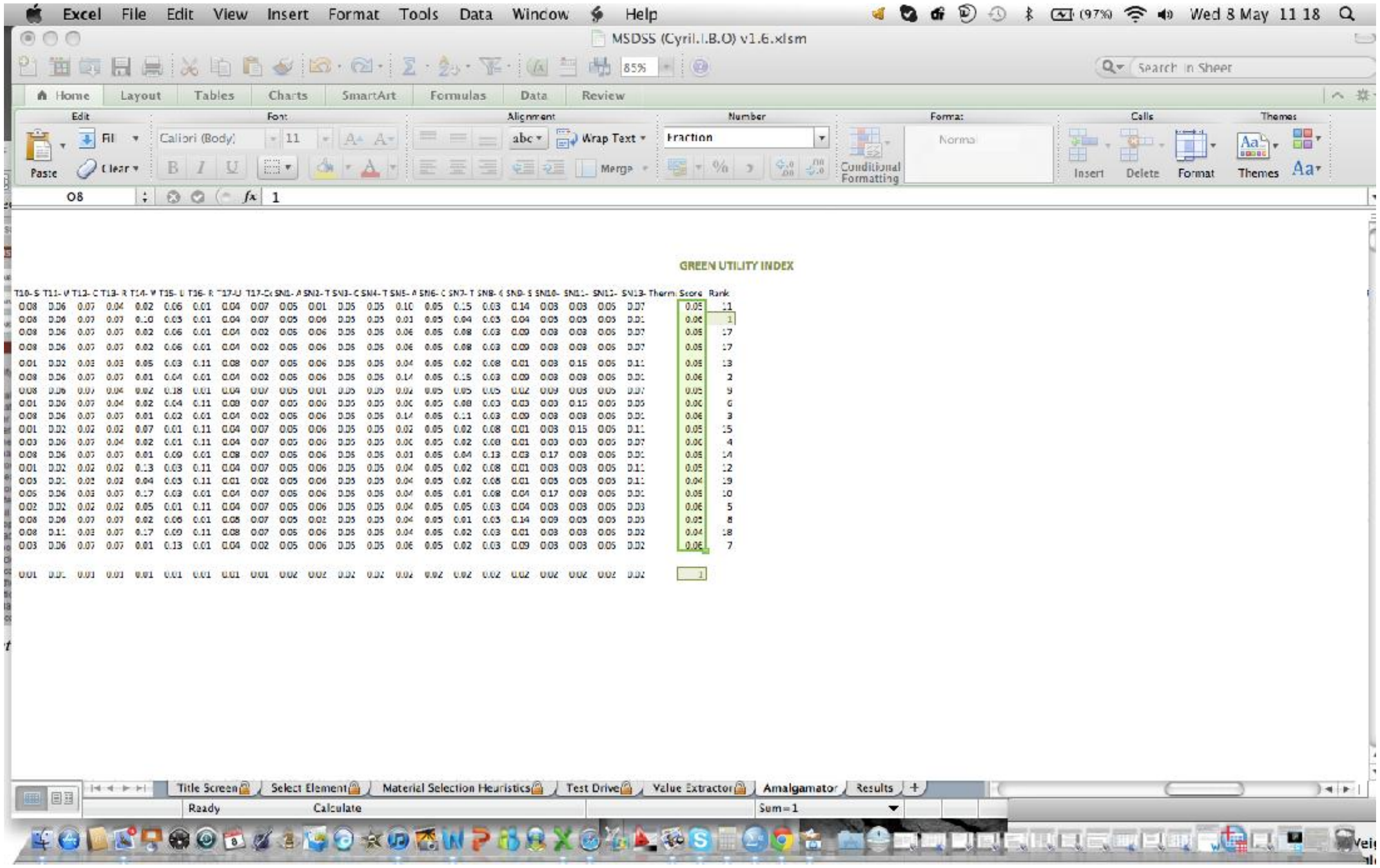
0.07
0.15
0.07
0.07
0.10
0.02
0.07
0.10
0.04
0.03
0.01
0.01
0.04
0.04
0.01
0.04
0.01
0.10
0.02

System displaying the calculated mean value of each row

STEP 10: The GLOBAL WEIGHTINGS as highlighted below is derived automatically by the system from the product of the PROPERTY/FACTOR CATEGORY WEIGHTINGS and the SUB-MATERIAL PROPERTY CATEGORY WEIGHTINGS, brought over from the VALUE EXTRACTOR menu



System showing the calculated global weightings resulting from the product of the factors



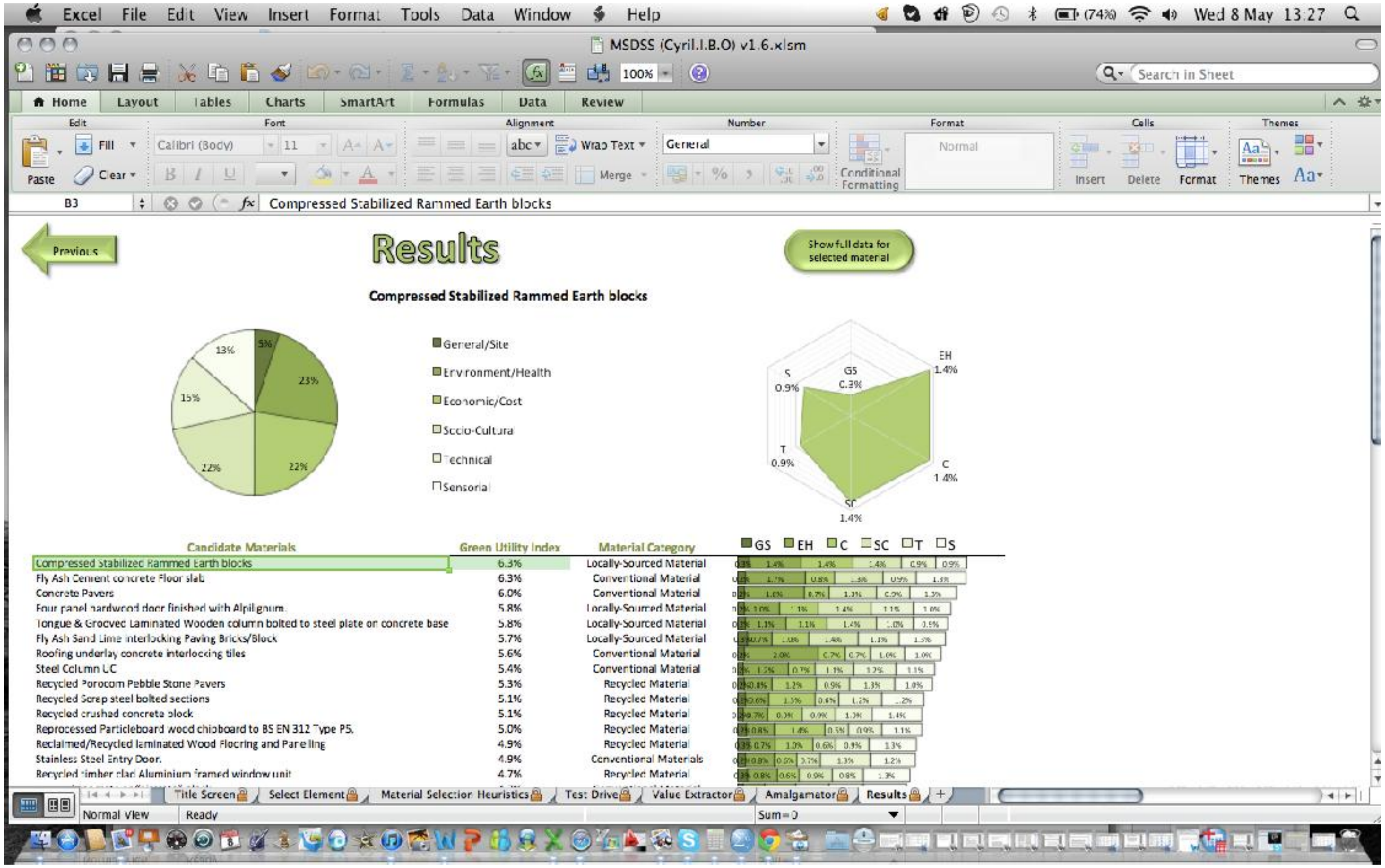
GREEN UTILITY INDEX

T10- S	T11- V	T12- C	T13- R	T14- W	T15- U	T16- R	T17-U	T17-C	SN1- A	SN2- T	SN3- C	SN4- T	SN5- A	SN6- C	SN7- T	SN8- C	SN9- S	SN10-	SN11-	SN12-	SN13-	Therm	Score	Rank
0.08	0.06	0.07	0.04	0.02	0.06	0.01	0.04	0.07	0.05	0.01	0.05	0.05	0.10	0.05	0.15	0.03	0.14	0.03	0.03	0.05	0.07		0.05	11
0.08	0.06	0.07	0.07	0.10	0.03	0.01	0.04	0.07	0.05	0.06	0.05	0.05	0.01	0.05	0.04	0.03	0.04	0.05	0.05	0.05	0.01		0.06	1
0.08	0.06	0.07	0.07	0.02	0.06	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.06	0.05	0.08	0.03	0.09	0.03	0.03	0.05	0.07		0.05	17
0.08	0.06	0.07	0.07	0.02	0.06	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.06	0.05	0.08	0.03	0.09	0.03	0.03	0.05	0.07		0.05	17
0.01	0.02	0.03	0.03	0.05	0.03	0.11	0.08	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.02	0.08	0.01	0.03	0.15	0.05	0.11		0.05	13
0.08	0.06	0.07	0.07	0.01	0.04	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.14	0.05	0.15	0.03	0.09	0.03	0.03	0.05	0.01		0.06	2
0.08	0.06	0.07	0.04	0.02	0.18	0.01	0.04	0.07	0.05	0.01	0.05	0.05	0.02	0.05	0.05	0.05	0.02	0.09	0.03	0.05	0.07		0.05	9
0.01	0.06	0.07	0.04	0.02	0.04	0.11	0.08	0.07	0.05	0.06	0.05	0.05	0.06	0.05	0.08	0.03	0.03	0.03	0.15	0.05	0.05		0.06	6
0.08	0.06	0.07	0.07	0.01	0.02	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.14	0.05	0.11	0.03	0.09	0.03	0.03	0.05	0.01		0.06	3
0.01	0.02	0.02	0.02	0.07	0.01	0.11	0.04	0.07	0.05	0.06	0.05	0.05	0.02	0.05	0.02	0.08	0.01	0.03	0.15	0.05	0.11		0.05	15
0.03	0.06	0.07	0.04	0.02	0.01	0.11	0.04	0.07	0.05	0.06	0.05	0.05	0.06	0.05	0.02	0.08	0.01	0.03	0.03	0.05	0.07		0.06	4
0.08	0.06	0.07	0.07	0.01	0.09	0.01	0.08	0.07	0.05	0.06	0.05	0.05	0.03	0.05	0.04	0.13	0.03	0.17	0.03	0.05	0.01		0.05	14
0.01	0.02	0.02	0.02	0.13	0.03	0.11	0.04	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.02	0.08	0.01	0.03	0.03	0.05	0.11		0.05	12
0.03	0.01	0.02	0.02	0.04	0.03	0.11	0.01	0.02	0.05	0.06	0.05	0.05	0.04	0.05	0.02	0.08	0.01	0.03	0.03	0.05	0.11		0.04	19
0.05	0.06	0.03	0.07	0.17	0.03	0.01	0.04	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.01	0.08	0.04	0.17	0.03	0.05	0.01		0.05	10
0.02	0.02	0.02	0.02	0.05	0.01	0.11	0.04	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.05	0.03	0.04	0.03	0.03	0.05	0.03		0.06	5
0.08	0.06	0.07	0.07	0.02	0.06	0.01	0.08	0.07	0.05	0.02	0.05	0.05	0.04	0.05	0.01	0.03	0.14	0.09	0.05	0.05	0.05		0.05	8
0.08	0.11	0.03	0.07	0.17	0.09	0.11	0.08	0.07	0.05	0.06	0.05	0.05	0.04	0.05	0.02	0.03	0.01	0.03	0.03	0.05	0.02		0.04	18
0.03	0.06	0.07	0.07	0.01	0.13	0.01	0.04	0.02	0.05	0.06	0.05	0.05	0.06	0.05	0.02	0.03	0.09	0.03	0.03	0.05	0.02		0.06	7
0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.02		1	

System showing the calculated global weightings resulting from the product of the factors

The GLOBAL WEIGHTINGS row is multiplied by each scores row and summed to produce a single score for each material. Finally, the scores are passed on to the <RESULTS> sheet in ranked order as GREEN UTILITY INDEX, and conclude the calculations performed by the <AMALGAMATOR>.

FINAL STEP: By clicking on the <NEXT> button, the user visualises the outcome of the evaluation process in the form of reports and maps. Results in MSDSS Analytical System project opens and users can automatically view displayed graphs and charts of the data associated with each material in real time.

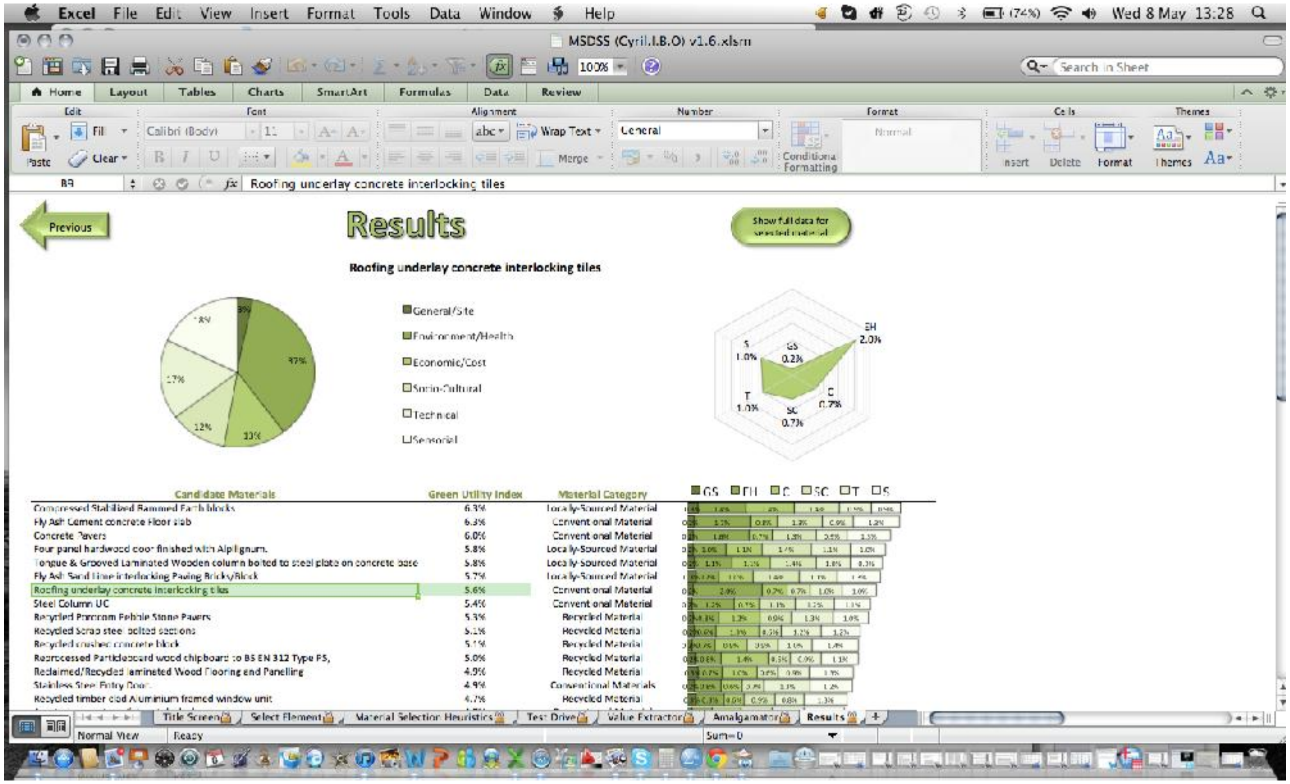


B3 Compressed Stabilized Rammed Earth blocks

Candidate Materials	Green Utility Index	Material Category
Compressed Stabilized Rammed Earth blocks	6.3%	Locally-Sourced Material
Fly Ash Cement concrete Floor slab	6.3%	Conventional Material
Concrete Pavers	6.0%	Conventional Material
Four panel hardwood door finished with Alpilignum.	5.8%	Locally-Sourced Material
Tongue & Grooved Laminated Wooden column bolted to steel plate on concrete base	5.8%	Locally-Sourced Material
Fly Ash Sand Lime interlocking Paving Bricks/Block	5.7%	Locally-Sourced Material
Roofing underlay concrete interlocking tiles	5.6%	Conventional Material
Steel Column UC	5.4%	Conventional Material
Recycled Porocom Pebble Stone Pavers	5.3%	Recycled Material
Recycled Scrap steel bolted sections	5.1%	Recycled Material
Recycled crushed concrete block	5.1%	Recycled Material
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5.	5.0%	Recycled Material
Reclaimed/Recycled laminated Wood Flooring and Panelling	4.9%	Recycled Material
Stainless Steel Entry Door.	4.9%	Conventional Materials
Recycled timber clad Aluminium framed window unit	4.7%	Recycled Material

Shows a sample of the menu from which the result is generated and how they are displayed

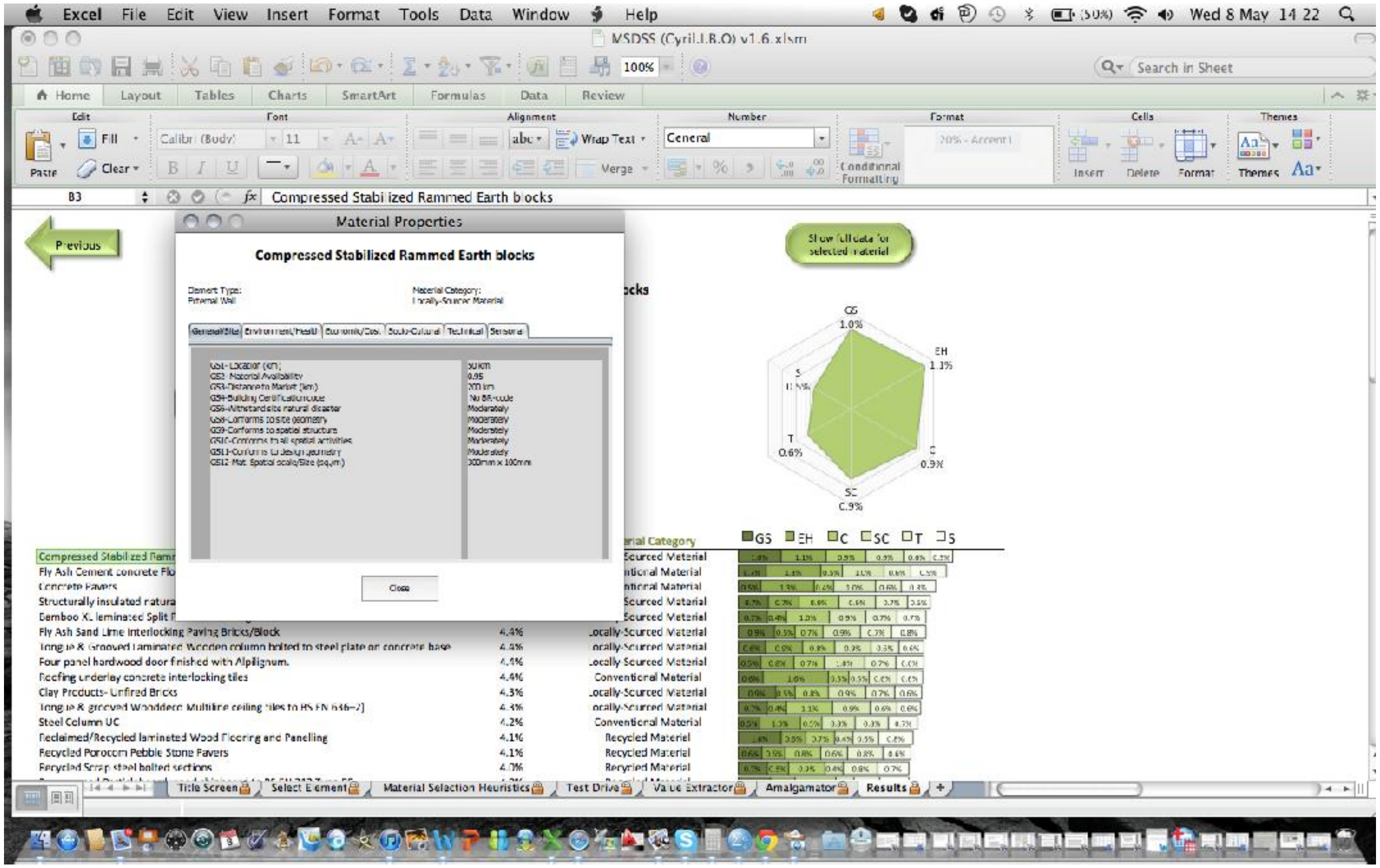
To preview reports in the result user interface menu, the users are to click the <result> button option to open the MSDSS reports menu so that users are able to select the report of their choice. The key function of this part of the system is the ability to generate simple tabular and graphical reports of the MSDSS analytical system evaluation data. The last option involves the clicking of the <SHOW FULL DATA FOR SELECTED MATERIALS> button. This option leads to the opening of the <MATERIAL PROPERTIES> window, which illustrates various properties of the selected building material/component. All graphs and charts displayed in all the three options are generated by and are based on user requirements. Here material data can be edited and subsequently displays the results in charts and graphs.



Candidate Materials	Green Utility Index	Material Category
Compressed Stabilized Rammed Earth blocks	6.3%	Locally-Sourced Material
Fly Ash Cement concrete Floor slab	6.3%	Conventional Material
Concrete Pavers	6.0%	Conventional Material
Four panel hardwood door finished with Alpilignum.	5.8%	Locally-Sourced Material
Tongue & Grooved Laminated Wooden column bolted to steel plate on concrete base	5.8%	Locally-Sourced Material
Fly Ash Sand Lime interlocking Paving Bricks/Block	5.7%	Locally-Sourced Material
Roofing underlay concrete interlocking tiles	5.6%	Conventional Material
Steel Column UC	5.4%	Conventional Material
Recycled Pronom Pebble Stone Pavers	5.3%	Recycled Material
Recycled Scrap steel bolted sections	5.1%	Recycled Material
Recycled crushed concrete block	5.1%	Recycled Material
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	5.0%	Recycled Material
Reclaimed/Recycled laminated Wood Flooring and Panelling	4.9%	Recycled Material
Stainless Steel Entry Door.	4.9%	Conventional Materials
Recycled timber clad Aluminium framed window unit	4.7%	Recycled Material

Sample of the MSDSS Analytical System report of user's preferred choice

Clicking on the <SHOW FULL DATA FOR SELECTED MATERIALS> button displays full material property values/details for the selected material. When a user selects a material, from the list in the result user interface based on his professional judgment, the objective data of the selected material is retrieved from the database.



B3 Compressed Stabilized Rammed Earth blocks

Material Properties

Compressed Stabilized Rammed Earth blocks

Element Type:
External Wall

Material Category:
Locally-Sourced Material

General/Site | Environment/Health | Economic/Cost | Socio-Cultural | Technical | Sensorial

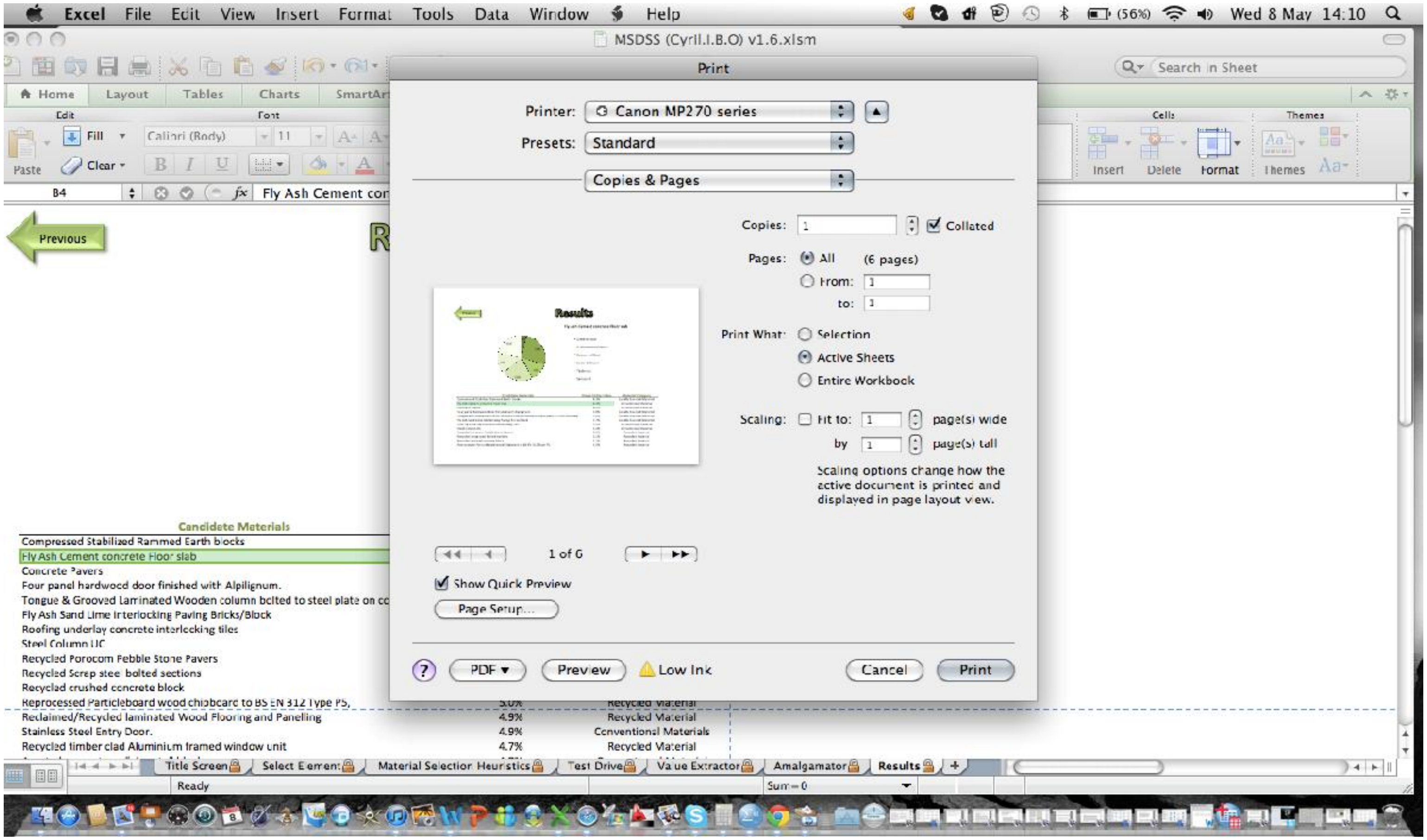
GS1-Location (km)	50 km
GS2-Material Availability	0.95
GS3-Distance to Market (km)	200 km
GS4-Building Certification code	No BR-code
GS6-Withstand site natural disaster	Moderately
GS8-Conforms to site geometry	Moderately
GS9-Conforms to spatial structure	Moderately
GS10-Conforms to all spatial activities	Moderately
GS11-Conforms to design geometry	Moderately
GS12 Mat. Spatial scale/Size (sq.m)	300mm x 100mm

Close

Compressed Stabilized Ramm		Sourced Material
Fly Ash Cement concrete Flo		ntional Material
Concrete Pavers		ntional Material
Structurally insulated natura		Sourced Material
Bamboo XL laminated Split F		Sourced Material
Fly Ash Sand Lime Interlocking Paving Bricks/Block	4.4%	Locally-Sourced Material
Tongue & Grooved Laminated Wooden column bolted to steel plate on concrete base	4.4%	Locally-Sourced Material
Four panel hardwood door finished with Alpilignum.	4.4%	Locally-Sourced Material
Roofing underlay concrete interlocking tiles	4.4%	Conventional Material
Clay Products- Unfired Bricks	4.3%	Locally-Sourced Material
Tongue & grooved Wooddeco Multiline ceiling tiles to BS EN 636-2]	4.3%	Locally-Sourced Material
Steel Column UC	4.2%	Conventional Material
Reclaimed/Recycled laminated Wood Flooring and Panelling	4.1%	Recycled Material
Recycled Porocom Pebble Stone Pavers	4.1%	Recycled Material
Recycled Scrap steel bolted sections	4.0%	Recycled Material

Generating detailed reports of the material properties from the MSDSS Reports Menu

The user may elect to either preview it on the screen, print it, or send it to a Word or Excel file for further analysis and formatting.



Fly Ash Cement concrete Floor slab

Printer: Canon MP270 series

Presets: Standard

Copies & Pages

Copies: 1 ☑ Collated

Pages: ● All (6 pages)

○ From: 1

to: 1

Print What: ○ Selection

● Active Sheets

○ Entire Workbook

Scaling: ☐ Fit to: 1 page(s) wide

by 1 page(s) tall

Scaling options change how the active document is printed and displayed in page layout view.

1 of 6

☑ Show Quick Preview

Candidete Materials

Compressed Stabilized Rammed Earth blocks

Fly Ash Cement concrete Floor slab

Concrete Pavers

Four panel hardwood door finished with Alpilignum.

Tongue & Grooved Laminated Wooden column bolted to steel plate on co

Fly Ash Sand Lime Interlocking Paving Bricks/Block

Roofing underlay concrete interlocking tiles

Steel Column UC

Recycled Porocom Pebble Stone Pavers

Recycled Scrap steel bolted sections

Recycled crushed concrete block

Reprocessed Particleboard wood chipboard to BS EN 312 Type P5, 5.0% Recycled Material

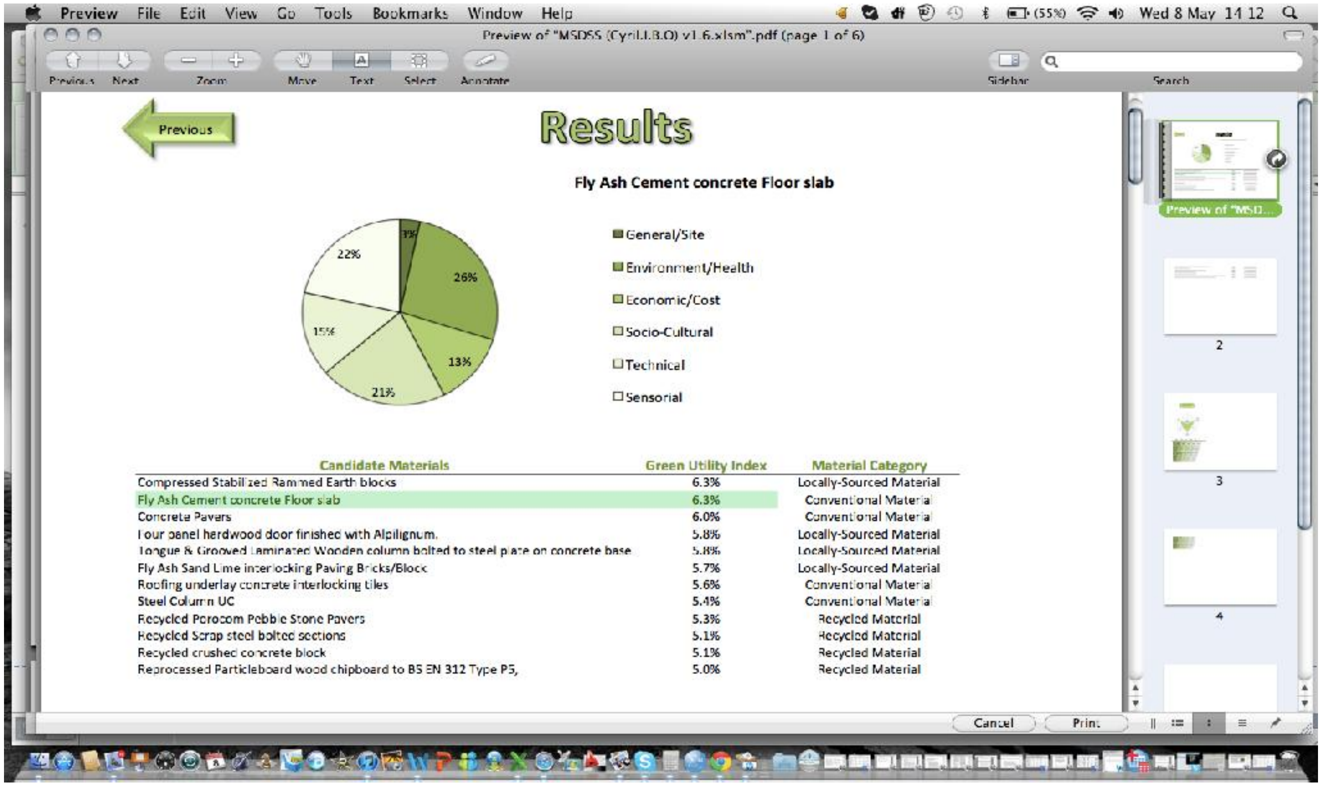
Reclaimed/Recycled laminated Wood Flooring and Panelling 4.9% Recycled Material

Stainless Steel Entry Door. 4.9% Conventional Materials

Recycled timber clad Aluminium framed window unit 4.7% Recycled Material

Generating printing details for the selected materials

This option also provides a user with the prospect of adjusting the printing format based on the printing data as shown above.



Results

Fly Ash Cement concrete Floor slab

Candidate Materials	Green Utility Index	Material Category
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Tongue & Grooved Laminated Wooden column bolted to steel plate on concrete base	5.8%	Locally-Sourced Material
Fly Ash Sand Lime interlocking Paving Bricks/Block	5.7%	Locally-Sourced Material
Roofing underlay concrete interlocking tiles	5.6%	Conventional Material
Steel Column UC	5.4%	Conventional Material
Recycled Porocom Pebble Stone Pavers	5.3%	Recycled Material
Recycled Scrap steel bolted sections	5.1%	Recycled Material
Recycled crushed concrete block	5.1%	Recycled Material
Reprocessed Particleboard wood chipboard to BS EN 312 Type P5,	5.0%	Recycled Material

Sample printout preview in PDF format

Peer-review history:
The peer review history for this paper can be accessed here:
http://www.sciencedomain.org/review-history.php?iid=290&id=22&aid=2231