Selection of key Sustainable Indicators to Steel Buildings in Early Design Phases

Joana B. Andrade
Building Physics & Technology Laboratory, School of Engineering, University of Minho, Guimarães, Portugal, joana.andrade@civil.umninho.pt

Susana M. Vieira
Building Physics & Technology Laboratory, School of Engineering, University of Minho, Guimarães, Portugal, susanamachado.vieira@gmail.com

Luís Bragança
Department of Civil Engineering, School of Engineering, University of Minho, Guimarães, Portugal, braganca@civil.uminho.pt

ABSTRACT: The construction industry attempts to produce buildings with the least possible environmental impact. However, construction activities still greatly impacting the environment; therefore, it is necessary to consider a sustainable project approach, based on its performance. Sustainability is an important issue to consider in design, due to environmental concerns and economic and social issues, promoting the architectural quality and economic advantages.

This paper aims to identify the phases that a design project should pass through, emphasising the importance and ability of earlier ones to influence the level of sustainability, performance and life cost over project life. Then one intends to select a set of sustainability indicators, based on a pre-set list, predicting its adaptability to the conceptual and pre-design phases under steel buildings.

The output of this paper is aimed to aid the development of a tool/concepts that would enable designers to compare and evaluate the consequences of different design solutions, based on preliminary data and facilitate the collaboration between various partners and client and eventually yield a sustainable and high performance building through its life cycle.

1 INTRODUCTION

"*Instead of trying to 'force fit' sustainable principles into an existing and often unreceptive manufacturing system, it may be useful to approach the subject from the opposite direction, and consider how functional objects might be designed and manufactured to be compatible with principles of sustainable development*" (Walter, 2006).

Sustainability is an important issue to consider in design; not just due to the environmental concerns but also economic and social issues, as they promote architectural quality and have economic advantages (ECDGE, 1999). Sustainable design besides contributing to more comfortable and pleasant for living spaces, allows economic savings through efficient design while the buildings' environmental footprint is reduced.

The importance of considering sustainability in design stage meets the need for finding long-term solutions that warrant well-being and minimize the needs for natural resources as land use, biodiversity, water, air and energy. If a project is well planned and sustainable criteria are included in its early approach, the possibility to influence impacts is greater and the cost of criteria implementation is greatly reduced, as illustrated in Figure 1. Improvement of the building's sustainability performance must begin already in the design stage, as the potential of optimisation in project early phases is higher and the impacts of changes of the building and the construction costs are low.

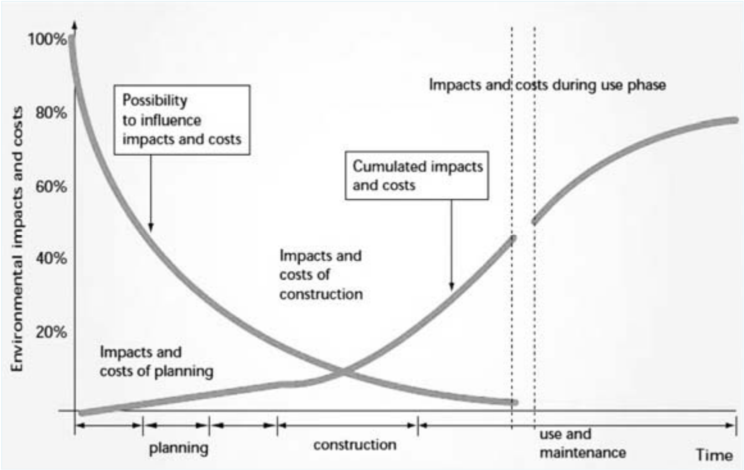


Figure 1. Influence of design decisions on life-cycle impacts and costs (Kohler & Moffatt, 2003)

A building's project obey to general criteria that allows its development on later stages; usually, main criteria respond to functional, economic, social and time requirements. However, those issues are not enough to create a consistent base to achieve optimal results for the building. New criteria and approach, that are usually not considered, can bring advantages to the project, favouring the improvement of its performance and reducing its final cost (Deru, 2004). The sooner the project goals are defined, the more integrated new criteria become, obtaining better results.

Steel construction meets numerous sustainable benefits, ensuring them each time steel is used. Steel relates directly to several important sustainable issues and requires a multi-disciplinary/criteria whole life thinking to inform decision making. The process of improvement and innovation must be a continuous one. In this context, an integrated design process is fundamental to sustainable construction, and so it is to steel construction. Decisions made at the initial design stage have the greatest effect on the overall sustainability impact of the construction project as the lifetime of the building.

The aim of this paper is to identify the phases that a design project should pass through, emphasising the importance and ability of earlier ones to influence the level of sustainability, performance and life cost over project life. Then there was the need to select a set of sustainability indicators, based on a pre-set list and its adaptability to the conceptual and pre-design phases, in the scope of steel buildings. The framework of this paper is divided into two steps: first, it seeks to identify and describe project design phases, recognizing the main tasks of each one; secondly, and taking into account the earlier design phases, it is made an analysis of a pre-set list of indicators and an assessment of how they can be regarded with the information available in the design stages focused.

The output of this paper is aimed to aid the development of a tool/concepts that will enable designers to compare and evaluate the consequences of different design solutions, based on preliminary data and facilitate the collaboration between various partners and client and eventually yield a sustainable and high performance building through its life cycle. The object of the assessment is the building; it does not include the characteristics of the building site nor its neighbourhood. The scope of the analysis encompasses all stages from material production stage to end-of-life stage.

2 DESIGN PHASES

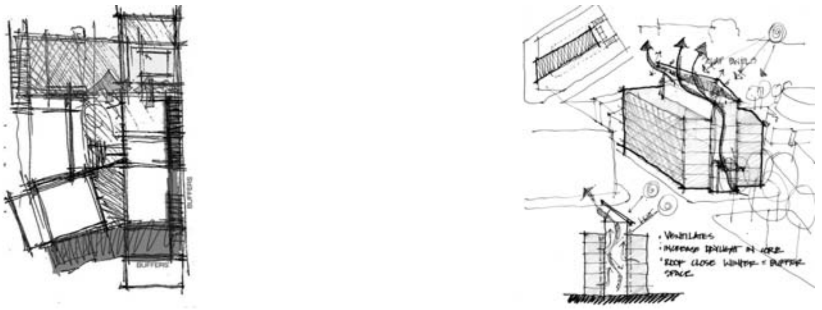
A sustainable design needs an integrated design process and a more involved approach than a conventional design process. Ensure the high quality of design is to ensure an approach based on building performance, an integrated and interdisciplinary project team working through an integrated planning and preparing project to its best performance. Thus, the design process is very important to facilitate the intended use, because most decisions that will determine building performance in-use will be made at this stage.

A building project is developed by a sequence of phases. The concept of design phases is related to a set of consecutive actions that guides the development process. These actions are grouped in stages, by their level of priority, forming each phase of the project. It is important to consider the value of each action/goal/objective, predicting its importance on buildings performance and its influence on the projects final cost, in order to implement each one at the adequate moment. Houvila (1999) mentioned that a performance approach is essential to manage life cycle requirements of a building during its conception.

Although different names are given by different authors, the phases of a building project and its goals are generally the same.

The project starts with the definition of its objectives and with the moment where the client meets the project team and exposes the goals for the building project. During this initial phase, clients and design team share information seeking to develop the building's concept. The architectural programming is required to define key requirements and constraints towards project quality. Type of architecture, formal and functional aspects must be discussed as well as indoor and outdoor quality desired by the client. Information of the site must be available and if it is not appropriated for construction, elsewhere should be suggested; subjects as room and building functional, environmental and spatial performance, comfort practices, energy requirements (…) should be addressed, as well as concerns on building use, heating, cooling, lighting, ventilation, water, waste, site works and materials. Additionally, it is at this stage that procurement method, project and sustainability procedures, building design life time, organisational structure, maintenance, project cost and timescale, etc. are dealt with. Next, the following approach commences implementing the earlier defined objectives. (Abdul-Kadir & Price, 1995, Bunz et al., 2006; Ministry of the Environment, 2008; Hanna & Skiffington, 2010; RIBA, 2011; Wakita & Linde, 2003). Several publications emphasise the importance of this phase to the performance of the building in its operational phase (Wakita & Linde, 2003, Bunz et al., 2006). However, decision-making tools are rare (Haroglu & Thorpe, 2009, Macmillan et al., 2001). At this phase all clients' interests and design team members such as architects, engineers and all needed specialists are involved. In a first period, it put into practice the clients' instructions and exposing the project team proposal; decisions at this early stage are of the utmost importance while project is provisional and open to change.

To the scope of this paper, the aforementioned tasks will be grouped into one single design stage - the conceptual stage. Hence, it is hereby understood as the preliminary design phase of the building, in which the overall system configuration is defined, and schematics drawings and layouts will provide an early project configuration, as seen in Figure 2. At this stage, the availability of data is very poor and any assessment has to be based mainly on assumptions. At this stage of design there are no drawings or any other details about the building. The only information about the building shape is the area of construction and the height of the building. From these elements, all other data need to be estimated. Based on the available input data, the following aspects need to be fulfilled in this stage: the selection of the type of the superstructure of the building; a bill of materials for the structure (estimation); a bill of materials for the envelope (e.g., areas of external and internal walls, area of floors, area of roof, etc) (estimation).



a) spaces first idea/ local implementation

b) first attempt to integrate desired sustainability measures / exterior appearance

Figure 2. Examples of what occurs in conceptual design phase

The next stage of the project begins after the approval of sketch studies; the team design commences the implementation of the working drawings for the construction of the project. Once again different designations are given to this phase – Development phase, pre-project and basic project (ECDGE, 1999), design development (Ministry of the Environment, 2008) (RIBA, 2011). It is also split in two moments, the preliminary project or pre-design and the basic project.

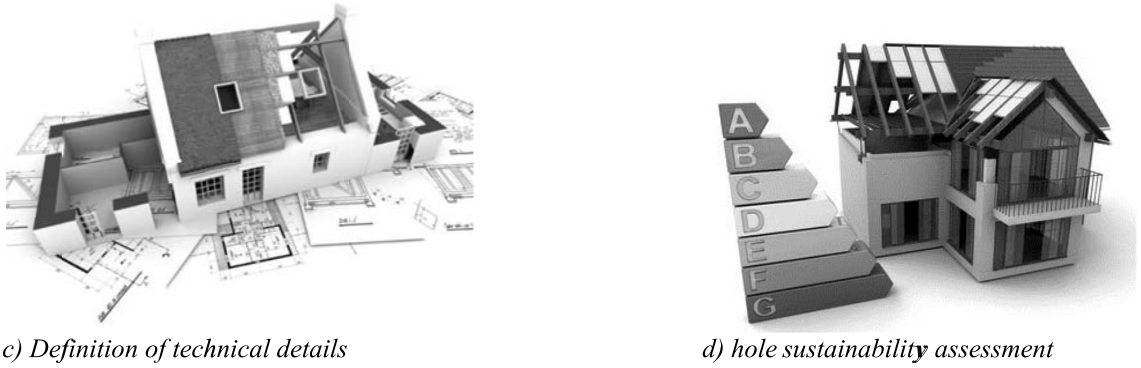
At this moment first moment, the general form of the building is developed through plans, sections and elevations; the provisional information addressed in earlier phases is confirmed or modified. The actual/chosen solution must be compatible with initial requirements and within the various applicable regulations; the functional relationships between different elements, spaces and volumes must be examined, as well as the base programming, according to any amendments agreed between the client and the design team.

Type of construction is generally defined and the materials are proposed during the meetings with the clients. Aspects like exterior and interior wall finishes, flooring, plumbing fixtures, hardware design, type of masonry, roofing materials, etc., shall be decided in this stage. Building equipment as types of windows and doors and their manufacturer, the elevator type and manufacturer, the mechanical system, electrical fixtures are also to be identified in this phase. This kind of information, when taken together, facilitates an estimate of construction cost. Still, work of every technical specialist must be coordinated, the public authorities must be consulted and initial investigations of comfort and environment should be confirmed.

To the scope of this paper and research, this phase will be addressed as pre-design phase and together with the conceptual phase will be the paper's goal. All the other phases are left out of it.

The data available in this stage enables a better definition of the structural system. In this stage it is expected to have information (drawings) about the plans and elevations of the building. The level of detail of the building enables a much more accurate definition of the bill of materials. Based on the available input data, the following aspects need to be fulfilled in this stage: a complete bill of materials for the structure and envelope and the definition of the building orientation (Fig. 3).

a) Definition of plans, sections and elevations



c) Definition of technical details

d) hole sustainability assessment

Figure 3. Examples of what occurs in pre-design phase

Figure 4 summarizes the sequence of the phases, moments and data improvement of a building project that from now on will be used in this research.

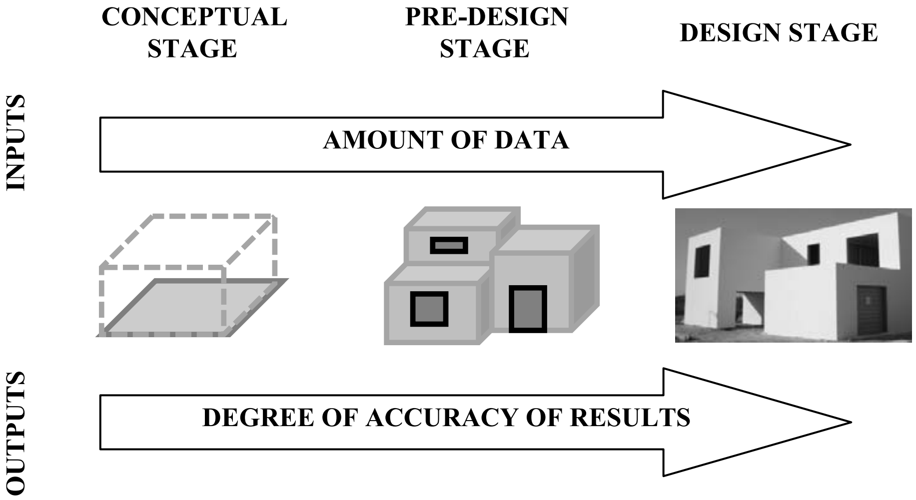


Figure 4. Design stages of a building

Each phase is characterized by a set of key tasks that lead to gathering information needed and to the development of the building architecture and features.

In a conventional design process these steps can be understood as a linear process, but sequential work routines may be unable to support any adequate design optimization efforts during individual decoupled phases, which of course lead to higher expenditure. In this approach the architect and the client agree on a design concept, consisting of a general massing schema, orientation, fenestration and (usually) the general exterior appearance, in addition to basic materials. The structural, building physics, mechanical and electrical engineers are then asked to implement the design and to suggest appropriate systems. Although this is vastly over simplified, this kind of process is one that is followed by the overwhelming majority of general-purpose design firm.

On the other hand, a sustainable design needs an integrated design process; it requires the involvement of the whole design team and the iteraction between phases. The design team maintains a high level of communication throughout the design process and must work well together to resolve all issues and concerns on the project. According to the attitude of the design team is critical and members must be able to form a collaborative framework for the project.

3 SELECTION OF INDICATORS

3.1 *Introduction*

The indicators proposed for the buildings analysis, are collected from the new CEN standards for Sustainable Construction Construction (Directive 2001/91/EC, 2002; EN 15643-1:2010; FprEN 15643-2:2010; prEN 15643-3:2010; prEN 15643-4:2010; FprEN 15978, 2011) and existing sustainability assessment methodologies. Notwithstanding, for the assessment of the social component, indicators from the research project PERFECTION (2011) were also included.

Two types of indicators are proposed: core indicators and additional indicators. Core indicators are used in the conceptual stage, whereas additional indicators are only used in the next stage, pre-design stage, as illustrated in Figure 5. Core indicators showed to be the best solution for the conceptual stage. It will be available in buildings' elements database, allowing the relative comparison between different construction solutions proposed. This set of indicators will be available per square or cubic meter, being independent from the whole building dimensions. Moreover, core indicators may be used as a simple and faster assessment, while using both categories – core and additional indicators – gives a more complete and exact evaluation, ensuring sustainability at all fronts of action.

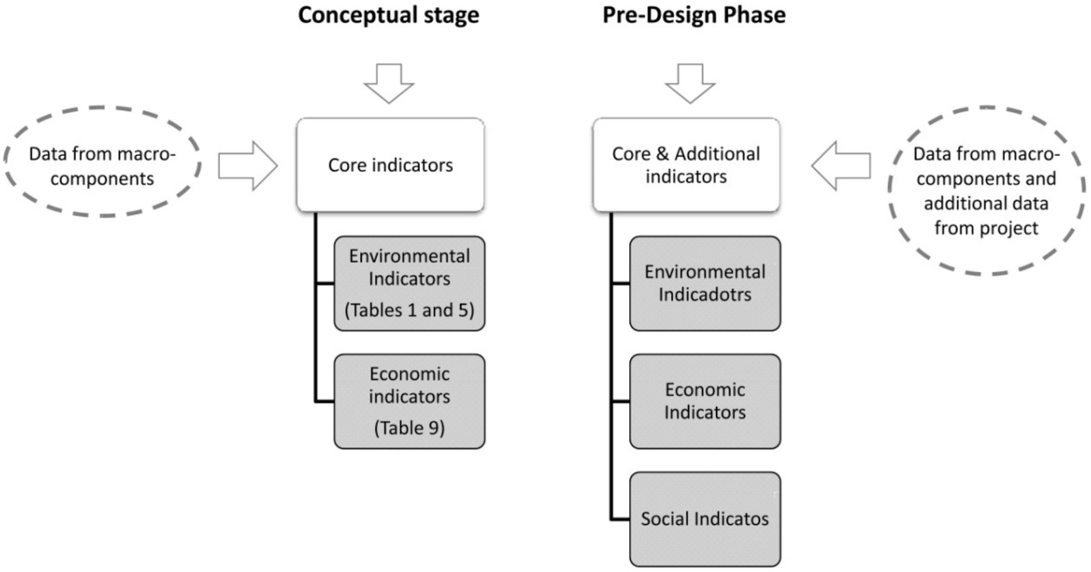


Figure 5. Core indicators and additional indicators

3.2 *Environmental Indicators*

3.2.1 *Environmental Impacts – core indicators*

Environmental impacts category is composed by one single indicator - *Aggregated value of environmental impact* - which in turn gathers seven sub-indicators proposed in FprEN 15643-2 :2010, listed in Table 1. These sub-indicators are evaluated based on characterization factors and input flows.

Normal lifecycle impact estimator software (as SimaPro or GaBi) can be used to estimate these values. As in project conceptual stage the exact amount or construction technology to be used are under determination, a database of the buildings' envelope elements and its environmental life-cycle impact is needed. Based on a comparison, the designers will be able to determine which of the selected group of solutions is the one with less environmental impact or resource use.

Table 1. Sub-indicators describing environmental impact indicator.

Indicator	Unit
Global warming potential, GWP	kg CO_2 equiv
Depletion potential of the stratospheric ozone layer, ODP;	kg CFC 11 equiv
Acidification potential of land and water; AP;	kg SO^{2-} equiv
Eutrophication potential, EP;	kg $(PO_4)^{3-}$ equiv
Formation potential of tropospheric ozone photochemical oxidants, POCP;	kg Ethene equiv.
Abiotic Resource Depletion Potential for elements; ADP_elements	kg Sb equiv
Abiotic Resource Depletion Potential of fossil fuels ADP_fossil fuels	MJ

3.2.2 *Resource Use*

Similarly to the previous category, the resource use is also composed by one single indicator - *Aggregated value of resource use* - describing different environmental aspects in the subject as presented in Table 2 (FprEN 15643-2 :2010). The sub-indicators describe the use of renewable, non-renewable primary energy and water resources. These sub-indicators are assessed directly from input flows.

Table 2. Sub-indicators describing resource use

Indicator	Unit
Use of renewable primary energy excluding energy resources used as raw material	MJ, net calorific value
Use of renewable primary energy resources used as raw material	MJ, net calorific value
Use of non-renewable primary energy excluding primary energy resources used as raw material	MJ, net calorific value
Use of non-renewable primary energy resources used as raw material	MJ, net calorific value
Use of secondary material	kg
Use of renewable secondary fuels	MJ
Use of non-renewable secondary fuels	MJ

3.2.3 *Additional Environmental Information*

The indicators describing the additional environmental information are listed in Table 3 and Table 4 and are assessed directly from output flows. The waste disposal category shall be addressed considering the following indicators: (i) hazardous waste disposed; (ii) non-hazardous waste disposed; (iii) radioactive waste disposed. Indicators describing the output flows leaving the system shall address: (i) Components for re-use; (ii) Materials for recycling, and (iii) Materials for energy recovery (not being waste incineration). The method for exported energy is still under assessment. This indicator is listed in FprEN 15643-2: 2010 but no method is presented.

Table 3. Indicators describing waste categories

Indicator	Unit
Hazardous waste disposed	kg
Non-hazardous waste disposed	Kg
Radioactive waste disposed	Kg

Table 4. Indicators describing the output flows leaving the system.

Indicator	Unit
Components for re-use	kg
Materials for recycling	Kg
Materials for energy recovery (not being waste incineration)	Kg
Exported energy	Mj for each energy carrier

3.2.4 *Energy – core indicator*

Total Primary Energy Demand describes the energy consumption predicted to the operational phase, summarized in Table 5. Guidelines for energy consumption impose the reduction and improvement of energy efficiency and consumption (WHO, 2012). For that reason, the total demand for primary energy shall be minimized and the share of renewable energy shall be maximized while reducing the share of non-renewable energy, during the building's life cycle. This indicator should account for estimation of (i) energy use for space heating, (ii) energy use for space cooling, (iii) energy use for domestic hot water production and, (iv)others energy use. To assess energy performance, an algorithm to compute operational energy at early design stage needs to be developed. Several existing methods as: (i) RCCTE (Portuguese code of practice for thermal behaviour and energy efficiency of residential buildings); (ii) ISO 13790 monthly approach and (iii) Design Builder/Energy Plus, represent some possibilities as a base of the need algorithm.

Table 5. Indicators describing Energy impacts

Indicator	Unit
Total Primary Energy Demands and share of renewable and non-renewable primary energy resources (in operation phase)	kWh/m^2·year

3.3 *Social Indicators*

3.3.1 *Accessibility*

Accessibility is the ability of a space to be entered with ease. The social performance category of accessibility addresses the provisions included in the building to facilitate access to and use of its facilities (building services) particularly for those with special needs, e.g. the physically disabled, elderly, parents with small children. Table 6 presents the proposed indicators in this category.

Table 6. Indicators describing accessibility

Indicator	Unit
Accessibility for people with specific needs	--
Access to building services	--

3.3.2 *Functionality*

This category engages indicators related to the easiness in using the building by people, like adaptability to new uses, the easiness of movement inside the building, the efficiency of a space to its function, etc. Table 7 presents the proposed indicators in this category.

Adaptability is the ability of the object of assessments or parts thereof to be changed or modified to make suitable for a particular use. The social performance of *adaptability* indicator assesses the provisions included in the building that allow it to be modified to make it suitable for a particular purpose, which may be a change of use or adaptation of its current use. One of steel buildings qualities is its adaptability and flexibility to conversion.

Robustness is the structure's capacity to suffer disproportionate or progressive collapse from a natural or manmade hazard. It is mentioned and considered across codes and standards but is mentioned as a quality or attribute a designer should ensure each structure has. Steel structures are very ductile, having a great seismic activity response, e.g.

Area efficiency is an index for the utilization of floor space inside buildings. It should be handled as economical as possible, as they have impacts in environmental (materials usage), costs and social aspects (suitability to intended use).

Maintenance operation and management indicator assesses the consequences for users and the neighbourhood of maintenance activities needed to maintain the building in a state in which it can perform its required functions or to restore its technical performance when a fault occurs. It is an expression of the quality of design of the building, its construction, the maintainability of its structure, surfaces and services, and the quality of the maintenance plan. Impacts of maintenance activities in steel buildings should be reduced, as there is less materials' losses, noise, damage of indoor air quality (dust) and 'design for maintenance' is possible.

Table 7. Indicators describing functionality

Indicator	Unit
Adaptability / flexibility to conversion	--
Durability / Design for robustness	--
Space efficiency	--
Maintenance operation and management	--

For the assessment of *adaptability* indicator the following sub-indicators shall be assessed: (i) the building's ability to accommodate individual user requirements, (ii) the building's ability to accommodate the change of user requirements, (iii) the building's ability to accommodate technical changes, and (iv) the building's ability to accommodate the change of use.

In the Design for robustness the following sub-indicators shall be assessed: (i) evidence of professional requirements evidence of design aspects. The assessment can be based on normative document and Open House Project also presents an example of a methodology.

For the assessment of *maintenance* indicator the following sub-indicators shall be assessed: (i) the provision of an operation, maintenance and cleaning plan and log book for the building, (ii) health and comfort impacts for the users during maintenance, (iii) the frequency and time needed for regular maintenance, (e.g. noise, magnitude and duration of any short-, medium- and long- term effects on indoor air quality), (iv) the usability of the building while maintenance tasks are being carried, e.g. as a ratio of expected maintenance and cleaning duration causing disruption to days of normal use).

3.3.3 *Health and Comfort*

For health and comfort category the performance indicators have been grouped into four core indicators: (i) acoustic comfort, (ii) visual comfort, (iii) indoor air quality and (iv) thermal comfort. Each core indicator is described by several performance indicators, listed in Table 8.

Table 8. Indicators describing accessibility

Indicator	Unit
Acoustic comfort	dB(A)
Visual Comfort	--
Indoor air quality	--
Thermal comfort	--

The *acoustic comfort* indicator aims to ensure a low level interference and background noise, providing healthy and acoustically comfort conditions in buildings. It shall be divided in the following sub-indicators: (i) background noise, (ii) reverberation time, (iii) speech intelligibility, and (iv) structural vibrations. The assessment of these aspects should be based on the acoustic properties of materials, legal limits and typical calculations during design.

Visual comfort is accomplished by balance between sufficient illumination level and direct and reflected glare avoidance, suitability of artificial light to specific needs, view that informs about time of day, location, weather conditions etc., spectral colour in the room, etc. The affinity of steel structures with highly glazed facades and the “lightness” and long-spanning capability of steel structures is capable of ensuring a great performance in this indicator.

In this indicator the following sub-indicators shall be assessed: (i) availability of daylight throughout the building; (ii) availability of daylight in regularly used work areas; (iii) view to the outside; (iv) Preventing glare in daylight; (v) Preventing glare in artificial light; (vi) Colour rendering. Assessment methods are to be defined later on the project.

Indoor air quality (IAQ) is one of the most important factors in a building performance; otherwise the building wouldn’t satisfy its major job – held people inside. IAQ affects directly the occupants’ health, comfort, and their ability to conduct their activities. Hence, to assure a good indoor air quality performance the following sub-indicators shall be considered: (i) Indoor air contamination with the most relevant indoor air pollutants and (ii) Ventilation.

Thermal Comfort indicator is aimed to ensure a comfortable thermal environment inside the building both in summer and winter conditions. A pleasant temperature inside buildings promotes productivity and well-being of occupants. As it is well-known each person has its own thermal sensations and so it is the designers’ job to provide average conditions for comfort within which occupants will adapt. This indicator shall be divided and assessed in the following sub-indicators: (i) temperature; (ii) mean radiant temperature; (iii) air velocity and (iv) air humidity.

3.3.4 *Safety and Security*

The social performance category safety and security is a measure of the capacity of a building to resist projected current and future loadings from e.g. rain, heavy wind, snow, flooding, fire, earthquake, explosion, landslides, etc. as well as security from criminality and security from disruption of utility supply. It is a measure of the buildings ability to provide safe and secure shelter during exceptional events that have a potential impact on the safety for its users and occupants, the building’s ability to maintain its function and appearance and minimise any disruption as a result of these exceptional events. For the assessment of safety and security the following aspects shall be assessed: (i) Resistance to climate change, (ii) Personal safety and security against intruders and vandalism, (iii) Security of interruptions of utility supply.

3.4 *Economic Indicators*

3.4.1 *Life Cycle Cost – core indicators*

The indicators describing life cycle cost are listed in Table 9.

Construction costs are all the costs related to each process needed to build the building. This indicator includes: (i) the cost of material acquisition and transportation, (ii) the cost of construction equipment, and (iii) the cost of man-power. Most of these costs are usually calculated based on the bill of materials and unit costs provided in the project. These costs usually occur in the first or second years of the building life cycle. However, due to the long time-period of analysis, it may be assumed that they occur in the first year, as the base year, of the Building life cycle.

Maintenance costs include all costs occurring over the service life of the building, in order to keep it according to the required condition. End-of-life costs refer to the end-of-life activities such as the total or partial demolition of the building and the removal of the demolition waste to its final destination. These costs may be estimated based on scenarios and best practices.

Thus, the authors will take advantage of the work done by Fuller and Peterson (1995) and use their approach to implement costs quantification.

Table 9. Indicators describing Life Cycle costs

Indicator	Unit
Construction costs	€/m^2
Operation costs	€/m^2
End-of-life costs	€/m^2

3.5 *Summary of selected core indicator*

Table 10 summarizes the core indicators proposed.

Table 10. List of selected indicators

Environmental Indicators		
Environmental Impact	1	Global warming potential
	2	Depletion potential of the stratospheric ozone layer
	3	Acidification potential of land and water
	4	Eutrophication potential
	5	Formation potential of tropospheric ozone photochemical oxidants
	6	Abiotic Resource Depletion Potential for elements
	7	Abiotic Resource Depletion Potential of fossil fuels
Energy	8	Total Primary Energy Demand
Economic Indicators		
Life Cycle Costs	9	Construction costs
	10	Operation costs
	11	End-of-life costs

4 CONCLUSIONS

The aim of this paper was to determine which sustainable indicators could be assessed in the initial phases of a design project.

For that, an initial study was needed to clarify the contents of the early stages of design of a building. It can be concluded that although different names are given, most of the available literature identifies the same stages. From the several designations and stages, the following were selected to be under the scope of this project:

- Conceptual phase – begins when the client meets the design team and the objectives of the project are defined. Represents a preliminary design phase of the building, in which the overall system configuration is defined, and schematics drawings and layouts will provide an early project configuration, type of architecture and formal and functional aspects. Lack of specific data.

- Pre-design phase – starts with the implementation of the working drawings, the general form of the building is developed through plans, sections and elevations; the provisional information addressed in the conceptual phase is confirmed or modified.

Secondly, several methodologies and European Standards and projects were analysed, as well as the first analysis made to indicators, to determine the final set of key indicators that should be considered in this methodology, supporting assessing and management of project process, during earlier phases. A great list of indicators had come up. However it was impossible to include all of them in the key indicators list due to many aspects. Firstly, conceptual phase deals with fuzzy and often lack of information, which unable to address several indicators (specially related to social and functional aspects). Secondly, the huge amount of indicators could discourage designers to use the methodology as it would take much time to apply. With this in mind two groups of indicators were settled: (i) core indicators and, (ii) additional indicators. Core indicators shall be used in the conceptual stage, whereas additional indicators are only used in the latter stages (pre-design).

The core indicators shall regard indicators that could be addressed under the macro-components information, and few information available in conceptual phase. On the other hand, additional indicators compile all the other indicators. In this sense, core indicators consist in environmental impacts and costs, which can be previously included in the database, relying in buildings envelope elements database information and in an estimation of the operational energy demands, obtained by combining the available data at the conceptual phase (buildings' implementation, e.g) and the macro-components possibilities.

Additional indicators comprise all the other environmental aspects and the social and functional issues.

Concluding, from this study, the selected core indicators to be addressed in the conceptual design phase were the eight primary environmental indicators usually proposed and addressed by CEN prEN 15643-2 :2010 and three cost related indicators which allow estimating the Life cycle costs of a building.

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REFERENCES

Abdul-Kadir, M. R. & Price, A. D. F. 1995. Conceptual phase of construction projects. *International Journal of Project Management,* 13**,** 387-393.

Balcomb, J. D. & Curtner, A. Multi-criteria decision-making process for buildings. *In: Energy Conversion Engineering Conference and Exhibit, 2000. (IECEC) 35th Intersociety, 2000*. 528-535 vol.1.

Bunz, K.R., Henze,G.P. & Tiller, D.K. Survey of Sustainable Building Design Practices in North America, Europe, and Asia. *ASCE Journal of Architectural Engineering (2006) March*, pp. 33 – 62.

CIB. 1982. Working with the performance approach to building. *Report of Working Commission W60, Publication 64, 30p*.

Deru, M. & Torcellini, P. 2004. Improving Sustainability of Buildings Through a Performance-Based Design Approach. *World Renewable Energy Congress VIII and Expo*. Denver: Colorado.

Directive 2002/91/EC oh the European Parliament and oh the Council of 16 December 2002 on the energy performance of buildings.

European Commission Directorate General XVII for Energy. 1999. A green Vitruvius: Principles and practise of sustainable architectural design. James & James Science Publishers. London.

EN 15643-1_2010. Sustainability of construction works – Sustainability assessment of buildings – Part 1: General framework. CEN/TC 350.

FprEN 15643-2:2010, Sustainability of construction works - Assessment of buildings - Part 2: Framework for the assessment of environmental performance. CEN/TC350

FprEN 15978:2011. Sustainability of construction works – Assessment of environmental performance of buildings – Calculation method. CEN/TC 350.

Fuller, S. Petersen, S. 1995. Life-cycle costing manual for the Federal energy management program. NIST Handbook 135

Hanna, A.S. & Skiffington, M.A. 2010. Effect of Preconstruction Planning Effort on Sheet Metal Project Performance. *ASCE Journal of Construction Engineering and Management 136(2010) 2, pp 235 – 241.*

Haroglu H., Glass, J. & Thorpe T. 2009. A study of professional perspectives on structural frame selection. Construction Management and Economics, 27(2009)12, pp. 1209 — 1217.

Huovila, P. 1999. Managing the Life Cycle Requirements of Facilities. *CIB W078 WORKSHOP on.* Rotterdam (Netherlands): in-house publishing.

Kerzner, H. 1984. Project Management: A System Approach to Planning, Scheduling and Controlling (2nd ed) Van Nostrand Reinhold, USA.

Kohler, N. & Moffatt, S. 2003. Life-cycle analysis of the built environment. *UNEP Industry and Environment. United Nations Environment Programme Division of Technology, Industry and Economics publication.*

Macmillan, S., Steele, J., Austin, S., Kirby, P. & Robin, S. 2001. Development and verification of a generic framework for conceptual design. *Design Studies,* 22**,** 169-191.

MINISTRY FOR THE ENVIRONMENT - Manatū Mō Te Taiao. 2008. Integrated Whole Building Design Guidelines, Wellington, New Zealand.

OPEN HOUSE. 2011. Version 1.0. Reference for Case studies.

PERFECTION, 2011. PERFECTION – Performance Indicators for Health, Comfort and safety of the Indoor Environment. FP7 Grant number 212998.

Portland Cement Association. 2012. Available online at: http://www.cement.org/basics/concretebasics_concretebasics.asp. [assessed in January 2012].

prEN 15643-3:2010. Sustainability of construction works - Sustainability assessment of buildings - Part 3: Framework for the assessment of social performance. CEN/TC350

prEN 15643-4:2010. Sustainability of construction works - Sustainability assessment of building - Part 4: Framework for the assessment of economic performance. CEN/TC 350

ROYAL INSTITUTE OF BRITISH ARCHITECTS. 2011. Green Overlay to RIBA Outline Plan of Work. RIBA Publishing. London, United Kingdom. ISBN 978 85946 4410.

Wakita, O. & Lind, R. 2003. The Professional Practice of Architectural Working Drawings**.** 3rd edition. John Wiley & Sons. New York, USA.

WALTER, S. 2006. Sustainable by Design - Explorations in Theory and Practice. 1st ed. London, Earthscan

World Health Organization. 2012. Water, health and ecosystems. On-line at: http://www.who.int/heli/risks/water/water/en/. [assessed in February 2012].

World Steel Association. 2012. Available on-line at: http://www.worldsteel.org.[assessed in February 2012].

Yu, A. T. W., Shen, Q., Kelly, J. & Hunter, K. 2008. Comparative study of the variables in construction project briefing/architectural programming. *Journal of Construction Engineering and Management,* 134**,** 122-138.