SUSTAINABILITY INDICATORS FOR BUILDINGS: NETWORK ANALYSIS AND VISUALIZATION

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Abstract
Nowadays rating systems to assess the sustainability of the built environment are available worldwide. The idea that a rating system based on indicators and a sustainability score can guarantee architectural quality, reliability, energy efficiency, economic convenience and finally a sustainability label, produces an increased value of the building on the real estate market giving an "aura" of advanced product to the building itself. It is well known that different rating systems can give a different sustainability score because similar areas of evaluation in different rating systems are not equal in term of indicators' weight. Moreover, the continuous updating of the rating systems tries to include in the assessment procedures a tailored vision coming from field experience. The building rating systems were born in the last 15 years (i.e. 1998-2004), while rating systems for urban districts are more recent (2009-2012). The paper provides a survey on the more influential and worldwide diffused rating systems, highlighting the differences in terms of organization and relationship between evaluation areas and comparing existing rating schemes with recent EU research projects and initiatives such as the "Common European framework for Sustainable Building Assessment" (CESBA) framework. The paper aims to report the preliminary analysis on the similarities and differences among rating systems, towards a harmonization of sustainability practices to be applied to new and existing buildings. A network analysis and visualization tool has been applied to show the structural analogies among rating systems through an innovative methodological approach which aims to enable a further development in this field by linking more directly these tools with computational tools used in the building lifecycle.

Keywords:
Sustainable buildings; sustainability rating systems; network analysis; visualization techniques

1 INTRODUCTION

Rating systems have been being used in the world since approximately 15 years as tools to enable a holistic view of sustainability in building and, more recently, district design practices. The Report of the World Commission on Environment and Development "Our Common Future", known worldwide as Bruntland report [1] dated 1987 promoted the starting point to develop, in roughly 10 years a systemic vision of sustainability in buildings based on the three pillars of environment, economic and society. Sustainability rating systems started mainly as environmental assessment tools, but evolved into more general tools (including environmental, economic and societal dimensions), used today in different countries [2,3], in some cases customized for specific national characteristics.

Translating a rating system into regional or local realities is not an easy task, because of a different cultural, economic and environmental (i.e. geography, climate) background [4,5]. Even though there is not always strong evidence of the whole improvement of the certified buildings in

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DOI 10.3218/3774-6_98, ISBN 978-3-7281-3774-6, http://vdf.ch/expanding-boundaries.html

comparison with not certified buildings [6] and a relevant variability can be encountered with respect to specific indicators and evaluation areas [7,8] in the wide panorama of rating tools. Despite the growing number of design and assessment tools, a particular set of tools appears to dominate the real estate market. The building environmental assessment tools, such as LEED (the oldest), BREEAM and SBC have significantly affected both the public and the market awareness and the perception of what a sustainable building is. Some topics, included in the rating systems, such as energy performance, has, in most countries, a required level based on the national baseline requirements. In some countries where limited attention is devoted to energy problems, these tools are used as design guidelines, instead of their original objective as assessment tools [9]. A side effect of this mindset is that rating systems, which are mainly structured as check lists, are used simply to reach a useful quality threshold for market placement of the real estate properties, rather than concentrating on a real project optimization. For example, while in general we can aim at achieving a high score, in some cases local, economic, structural or technological constraints could be optimally satisfied even with a lower score and in a more rational way, responsive to the original building purpose [10]. Intrinsically, the value of the rating systems is in the holistic view including specific topics strongly correlated between them that are not so evident in the check list structure [11,12].

2 VISION AND VISUALIZATION

Because of the multiplicity of rating systems, we are currently in a situation where everybody is making “truth claims” [13] on ways to develop sustainable designs based on diverse epistemic criteria and worldviews. In fact, it does not seem possible to keep up with the major problem that has brought forth this concept into scene such as the crisis of perception triggered by an out-dated mechanistic/modernist worldview, which is related with “anthropocentric” worldview.

Conceptualizations about the world are strongly tied to the dominant worldviews. Our worldview shapes our values, theories and preconceptions and these, in turn, determine the problems we perceive, the knowledge we seek and the actions we take [14]. Developments especially in the field of physics and biology, and then in systemic revealed that the mechanistic worldview gave a misrepresentation of the world. Through an anthropocentric approach to nature, this worldview deciphered world phenomena as a deterministic clockwork based on a Cartesian approach that can be analysed and understood by the division of the whole into its parts. This difference in perception has actually prepared the ground for the loss of synch between human’s time and nature’s time, and by consequence has induced sustainability problems. Furthermore, it has rendered human minds unable to comprehend the challenge of sustainability. While favouring notions such as simplicity, certainty and immediacy, it has served to impede adaptive learning deemed essential for sustainability [15]. Researchers revealed that the world is not built upon such deterministic relationships that can be analysed through the so-called part and whole division suggested by analytical thinking. The major problems of our times cannot be understood in isolation. They are systemic problems, which means that they are interconnected and interdependent [16]. Current literature underscores the fact that world phenomena are formed of networked elements, which have complex and nonlinear characteristics. Therefore, sustainability can only be addressed through a holistic thinking that enables humans to conceive the world out of networked elements, as outlined in Fig.1 [17].

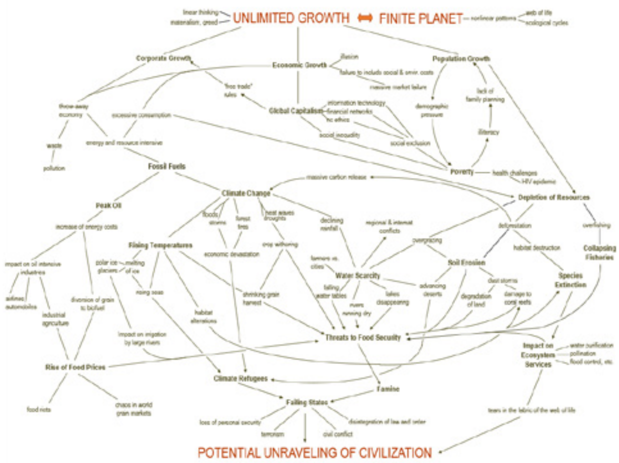

Fig. 1: Conceptual Map (source F. Capra, 1995).

The conceptual map in Fig. 1 dates back to 1995, nowadays new visualization tools are available to show connections and to reveal the overall structure of the organization of information.

The research starts with the analysis of the areas on which the sustainability criteria are structured in the selected rating systems. By applying advanced analysis and visualization techniques relationships and overlapping are revealed together with the lack of parameters or connections among some significant factors affecting building sustainability.

3 DATA COLLECTION, ANALYSIS AND VISUALIZATION

3.1 Rating systems or protocols

The essential data used in the present study is derived from a more extensive research on rating systems for building and district scale and it is focused on the building level. The selected protocols are the following ones:

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- LEED: Leadership in Energy and Environmental Design;
- BREEAM: Building Research Establishment Environmental Assessment Methodology;
- SBC: Sustainable Building Council;
- DGNB: Deutsche Gesellschaft für Nachhaltiges Bauen;
- ITACA: Istituto per l'innovazione e la Trasparenza degli appalti e la Compatibilità Ambientale.

The protocols have been selected considering age, updating, diffusion, flexibility and applicability. Table 1 resumes the chronological data and the country of origin of each protocol.

Name	Year	Update	Country
LEED	1998	2014	USA
BREEAM	1993	2013	UK
SBC	1996	2012	Canada
DGNB	2004	2012	Germany
ITACA	2004	2012	Italy

Table 1: Selected rating systems.

LEED and BREEAM and SBC are international tools of the first generation (started 10-15 years ago) while DGNB is a second generation tool and ITACA is a national rating system coming from SBC (see Table 2). In Table 2 the institute and diffusion of the tools are specified while in Table 3 the areas of rating system, the number of typologies of building end-uses considered and the number of quality level or score are resumed.

Name	Institute	Diffusion
LEED	USGBC, GBC Italia	International
BREEAM	BRE Global (SBA)	International
SBC	SBC*	International
DGNB	SBC*, SBA**	International
ITACA	Itaca, iiSBE, SBA*	National

*Sustainable building Council
**Sustainable Building Alliance

Table 2: Institute and diffusion of rating systems.

Name	Areas	Typology	Levels
LEED	7	8	4
BREEAM	10	10	5
SBC	6	9	score
DGNB	6	10	3
ITACA	5	5	score

Table 3: Areas, typologies and levels.

3.2 Analysis and visualization tool

The analysis and visualization tool adopted in this research is Gephi. Gephi is an open-source network analysis and visualization software package written in Java on the NetBeans platform [18] initially developed by students of the University of Technology of Compiègne (UTC) [19] in France. Gephi has been used in a several projects in academia, for large-scale network analysis problems (e.g. social networks, technological networks, etc.).

4 RESULTS

4.1 Visualization of connected criteria

Each rating system has different evaluation areas used to gain points to achieve a sustainability level. These areas have different names and mixed contents but they present many similarities that can be detected by means of network analysis. For this reason, we started to analyse every single protocol as a network and we found in LEED very interesting characteristics. Each rating system can be represented by a tree of areas and sub indicators (Fig. 2-5) but only LEED (in its user manual) includes for each indicator the connection with other indicators providing a more interesting map of correlation among credits and design choices in different areas (Fig. 6). The visualization tool allows to analyse statistically the relevant network metrics of nodes and edges, providing also a range of algorithms to distribute the conceptual map configuration and to set visualization options in order to put in evidence different relations (Fig. 7).

Fig. 2: Network visualisation of BREEAM areas and indicators.

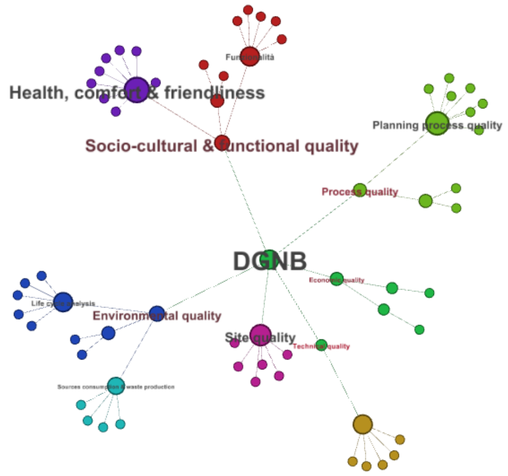

Fig. 3: Network visualisation of DGNB areas and indicators with partition defined by modularity class.

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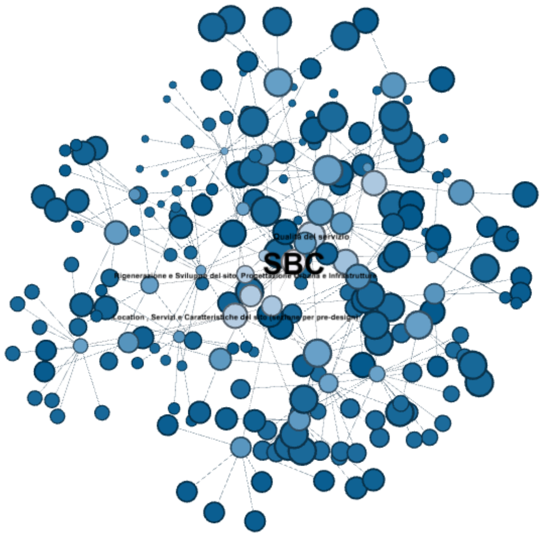

Fig. 4: Network visualization of SBC areas and indicators with colours defined by closeness/centrality.

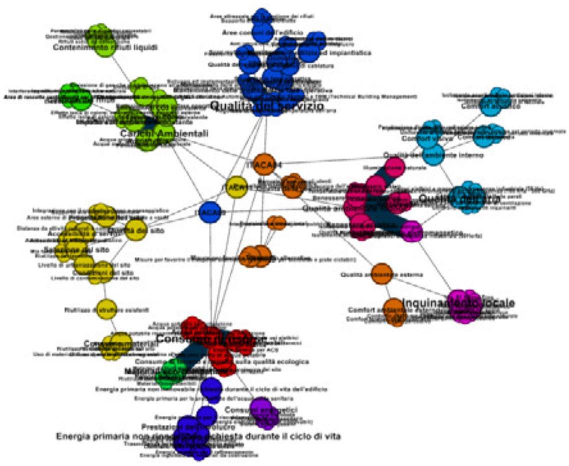

Fig. 5: Network visualisation of ITACA areas and indicators with partition defined by modularity class.

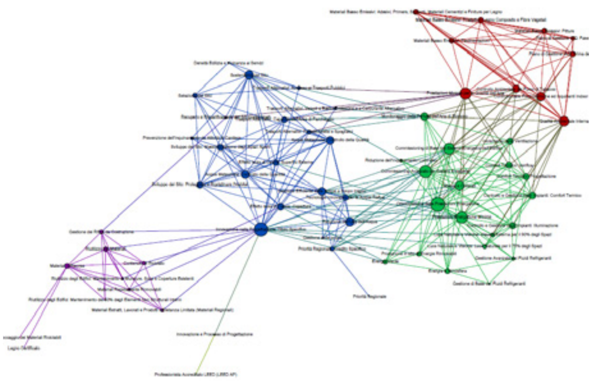

Fig. 6: Network visualization of LEED areas and indicators and connections between them with colours defined by clustering.

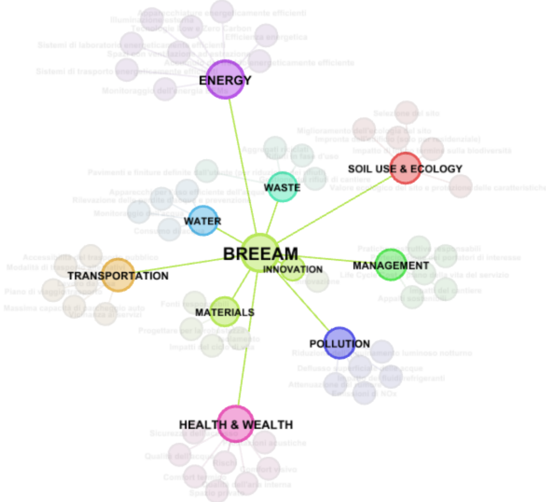

Fig. 7: Network visualization of BREEAM areas.

4.2 Statistical analyses on the network

The statistical analyses that can be performed to examine networks with respect to their metrics are reported in Table 4. The network visualization can be enriched with more information such as weights/credits in multi-criteria analysis and scoring; these elements are not considered at this stage of the development of the research and will be investigated more in depth in further developments. In the LEED map where the criteria connections are provided by the user manual and these data have been added in the map, it's possible to verify a much higher clustering coefficient of the network (zero for other protocols where the indicators connections have not yet been introduced). A value greater than zero could also be found for ITACA map where an analysis on evolution of the criteria in the tool from the first version (2004), to the intermediate version (2009) and finally to the current version (2011) has been performed.

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	LEED	BREEAM	SBTool	DGNB	ITACA
Network overview					
Average degree	9.39	1.97	1.99	1.97	2.23
Avg. Weighted degree	9.39	1.97	1.99	1.97	2.49
Network diameter	6	4	6	6	8
Graph density	0.15	0.03	0.01	0.03	0.01
Modularity	0.46	0.75	0.86	0.76	0.79
Connected components	1	1	1	1	2
Node overview					
Avg. Clustering coefficient	0.59	0	0	0	0.02
Edge Overview					
Avg. path length	2.52	3.42	5.25	4.54	4.91

Table 4: Preliminary analysis on the sustainability rating system networks for the main tools.

4.3 Shared areas of evaluation

The analysis can be developed to define relation and overlapping (or knowledge “holes” to focus on) checking the shared areas of evaluation of the different rating systems (Fig. 8). In the network the areas shared by two tools are red while the green ones are shared by three tools and the yellow one is shared by the whole rating systems. The areas related to economics and socio-cultural issues are taken into account only in DGNB and SBC; LEED and BREEAM are more connected in comparison with the other tools nevertheless the weight that any tool gives to the areas is different and this is a further element of research, as expressed before.

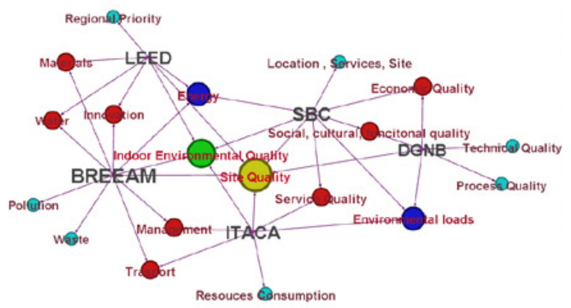

Fig. 8: Shared areas by different protocols.

5 DISCUSSION

The development of effective building energy and environmental assessment tools and practices is necessary to ensure efficient design and operation [20]. Efforts to connect in a whole systemic vision the different tools gave origin to relevant European research projects [21]. In the EU Superbuilding Project [22] a synoptic definition of the imperative areas of evaluation is provided and extensively described for the different phases of the sustainability evaluation (design phase, construction phase, operation phase). Further, CESBA (*Common European Sustainable Building Assessment)* is a recent initiative aimed at harmonizing the evaluation areas and tools for assessment. A visualization of the shared areas between CESBA and the synthesis of the EU Superbuilding Project is presented in Fig. 9, showing the main differences.

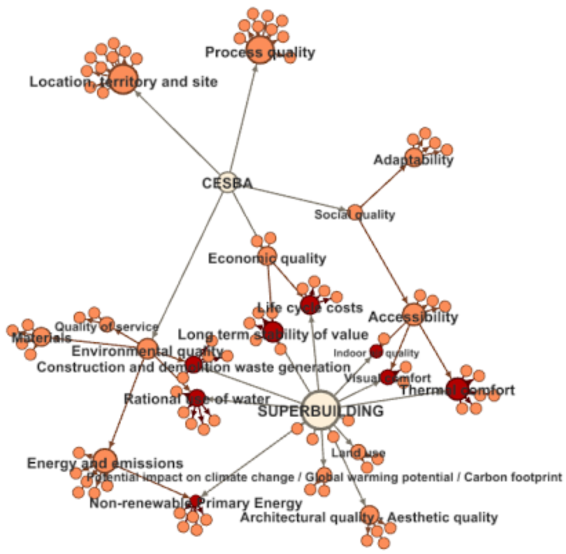

Fig. 9: Areas shared by harmonization frameworks CESBA and EU Superbuilding Project.

6 CONCLUSIONS

The use of network analysis and visualization techniques to compare sustainability assessment tools is aimed at improving the applicability of these tools for design and operation purposes. In the microscale visualization, it can be used to underline the effects of technological solutions on different aspects in interconnected areas; in the macroscale, a holistic view of the building should promote an innovative design and problem solving approach through system thinking. Finally, the structural analogies among different rating systems can be explored for a further development in the field, obtainable by linking more directly the relevant information contained in the rating systems with the computational tools used in the building lifecycle, for effective decision-making, and, in a future perspective, directly with data acquired by means of multiple devices, within the “Internet of Things” paradigm.

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