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Matching Life Cycle Thinking and design process in a BIM-oriented working environment

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Abstract

In the construction sector, the integration of life cycle approach and the implementation of the related methodologies are even more considered as a turning point to promote sustainability. To support Architectural, Engineering and Construction firms in life cycle design, a framework is proposed to implement Life Cycle Thinking in design process, according to different process' phases and empowering different actors. The framework is presented from the conceptual to the technical perspective, selecting Building Information Modeling as the most suitable tool currently spread in practice and able to handle the wide range of information required and the plurality of interactions between the actors involved. The outcome is a well-framed and organized set of life cycle data to orient decision-making process and enforce life cycle design for environmental but also wider (e.g. economic) purpose.

1. Introduction

Worldwide, the growing awareness of sustainability and environmental goals boosts the ongoing process of transformation and increasingly complexity of building sector, bringing out new pressure and more radical changing (Deamer and Bernstein, 2010; BCG, 2016). Indeed, while until a short time ago environmental targets were seen as constraints, today they are even more considered as a way to improve performance and increase competitiveness. For that reason, Architectural, Engineering and Construction (AEC) firms – as key actors jointly responsible for the built environment – are changing step by step the current practice (Dalla Valle et al., 2016). The transformation process involves all the firms' assets: tangible resources, such as materials, buildings, plant, equipment, tools, money; and intangible resources, such as knowledge, organization and intelligence of people (Sinopoli, 1997).

In this context, the integration of Life Cycle Thinking (LCT) represents a turning point to support sustainable practice, promoting environmentally-friendly strategies and business models. In fact, understood as a learning process, LCT helps to identify hotspots where actions are most effective and thus to improve resource efficiency with environmental, social and economic benefits (UN environment, 2017).

1.1. Life Cycle Thinking in design process

Actually, LCT is not so far established and embedded in design and construction practice. It represents a challenging task, due to the complexities of buildings, the wide range of requirements to be achieved and the plurality of practitioners and disciplines involved. Furthermore, it demands within the practice a shift both in thinking (first step) and in process (second step).

Indeed, during the design process, buildings should be considered not as objects, but rather as unique systems where each individual part affects and is in relationships with the others. Moreover, each part and in turn the building as a whole should be envisioned and designed keeping in mind their entire life cycle and not involving only the construction or use phase. In this way, products are evaluated in relation to the proprieties and performance provided as well as, for instance, in relation to the following hotspots: amount of material demanded, distance between factory and site, energy and water used for the installation, maintenance required, waste derived, reuse and recycle possibilities.

In addition, to face the complexities of buildings as systems and the amount of information and choices required during the decision-making, a shift in process is needed to change management in the way of participating. In our age of specialization, one person cannot address all buildings data and aspects: different competences must be involved, bringing their specific knowledge and interacting to look at the whole considering the entire life cycle. This requires not only an understanding that every building system is in relation with other systems and the surrounding environment, but it also demands a holistic process where everybody integrates their work rather than design their systems in isolation. For this reason, the challenge is twofold. Not only buildings need to be designed as systems, the design team itself need to function as a system (Boecker et al., 2009). In this way, all design members have to understand how the decisions undertaken by each affect the decision made by all other, with the aim to jointly design and achieve sustainable and high-performance buildings.

1.2. Life Cycle Thinking in design process within a BIM environment

As results, building sector demands a new process that encourages design teams and construction professionals to strengthen the two main tendencies in action. On one hand, the understanding of the building in a systematic way. On the other, the interaction with a much higher level of communication, collaboration and communication for reducing environmental impacts and costs. The advancement of technology certainly supports the transition of building sector in that direction, providing a wide range of tools to help practitioners in the enlightenment of buildings as systems and as parts of a larger system of its context (Boddy et al., 2007; Rezgui et al., 2011; Riese, 2012; Ortiz et al., 2009).

Moreover, Building Information Modeling (BIM) is even more adopted in AEC practice to face the hard tasks distinctive for the construction sector, as stated by its denomination. The term “Building” concerns the physical characteristics of the model and stresses its capability to virtually recreate the facility considering the project-based tangible features. The term “Information” concerns the intangible characteristics of the model and stresses its capability to organize the set of facility’s data in a meaningful and actionable manner. Lastly, the term “Modelling” concerns the act of shaping, forming, presenting and scoping the facility and stresses its capability to enable multiple stakeholders to collaboratively design, construct and operate (Succar and Kassem, 2015). BIM is therefore conceived as a database that embedded, display and calculates graphical/tangible and non-graphical/intangible information, linking each part and data of the systems and forming a reliable basis for decisions in the whole project life cycle. For this purpose, it was conceived and tailored to fit all the multitude of practice and projects, providing the maximum flexibility but requiring a lot of effort to arrange all data in an efficient and effective way.

In this context, to support AEC firm in life cycle design, the paper presents a framework able to orient and streamline the design process in line with LCT. The framework is envisioned within a BIM-oriented working environment to be spread and as much as possible well-integrated in AEC practice, providing a worthy support in the shifting both in thinking and in process.

2. Framework proposal

For a long time, the construction sector was material oriented in the approach to design, since it was focused on the palette of products necessary to produce sustainable buildings. However, “products are of limited value if viewed only as things that are added to building to make it green” (Boecker et al., 2009). Nowadays, sustainable goals call even more for a different mind-set, asking practitioners to change their mental model and way of practice, from stuff (i.e. products and technologies) to purposeful systems- and life cycle-thinking.

To this end, a framework was developed with the aim to integrate LCT in design and construction practice. To facilitate its implementation and to truly orient decision-making starting from the early stage of the project, the framework was tailored to fit the peculiarities of design process’ phases.

2.1. Basic matrix of the framework

The framework results from a matrix that combines life cycle perspective with AEC firms design process. In particular, to put into effect LCT, that represents a general mind-set, Life Cycle Assessment (LCA) was taken as reference frame, providing an added value since depicts an international standardized methodology. The framework spring thus from environmental issues but with wider purpose, representing for instance the elementary frame for economic issues. In this way, the underlying basic matrix of the framework is established, in the horizontal axis, by the different stages of life cycle from cradle to grave and, in the vertical axis, by the different phases of design process.

LCT is thus depicted by LCA methodology with the connected stages and set of data. It was analyzed according to European Standard (EN 15978:2011) and EPD Product Category Rules of building, the only available at building level (EPD PCR 531:2014). Therefore, the identification of life cycle stages follows the typically classification prescribed by the standards: product stage, construction stage, use stage, end of life stage, benefits and loads beyond the system boundary. Instead, design process phases were pointed out referring to the supporting materials developed by international and national institutions (UNEP, 2014; AIA, 2014; RIBA, 2013). In this case, due to the different partitioning, the terminology was harmonized splitting the design process in five main phases: concept phase, design phase, construction phase, in use phase and end of life phase. Note that despite the similarity of the terms, life cycle stages do not correspond to those of design process. In fact, for example, the design phase should take into consideration all life cycle stages, while the process in use phase should consider the life cycle use stage but also the product stage with regards to the maintenance and operational activities. In the following paragraphs, to avoid the ambiguity of terminology, the word “stage” refers to life cycle approach, while the word “phase” refers to design process.

Starting from the basic matrix, the framework interrelates design process with life cycle approach setting out the following assets: i) the life cycle information required; ii) the actors engaged to gather that type of data; and iii) the related tools and sources used to provide that data.

2.2. Framework explanation from life cycle perspective

To face the complexity of the systems and to handle the large amount of data, the framework was developed taking as a starting point life cycle standards and extracting from them the complete list of life cycle information. In this way, the framework helps in the data collection required to perform the inventory phase of an LCA study, identifying the actors in charge and the tools and sources suggested in relation to each process phase, as depicted for example for the production phase in Fig.1.

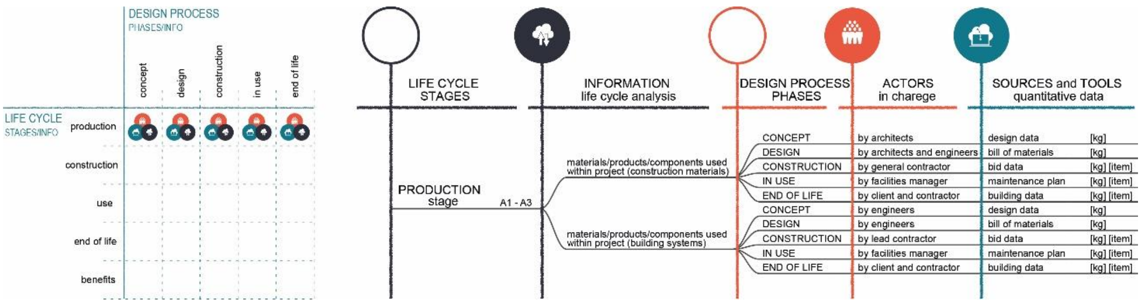

Figure 1: Framework explanation from life cycle perspective – production stage

However, it is important to underline that the framework focus only on life cycle quantitative data, since they represent the type of information directly demanded by AEC firms and therefore to bear in mind during the design process. As a consequence, environmental and economic data, conventionally required for the inventory phase respectively of an LCA and an LCC, are not reported since not tied to design practice, but rather attributed to literature, database or primary data, according to the phase of process and the type of information.

2.3. Framework explanation from design process perspective

Despite set up starting from life cycle stages, the framework can be reversed by explicating it in relation to the design process phases. In this way, it supports the implementation of life cycle practice, encouraging designers and practitioners in life cycle design and operations and orienting the decision-making with the aim to reduce the impacts and streamline the process. Indeed, for each phase of the process are pointed out the life cycle information to be considered, the actors who can collect that data and the source and tools where information can be taken. In the following paragraphs a synopsis is provided to briefly explain the framework according to the design process phases. Nevertheless, it is worth mentioning that the framework recommends the most virtuous life cycle-oriented practice and so its application depends case by case on how deeply life cycle perspective is integrated in design process and on how it is required by the project at issue.

The first phase of the design process is the concept phase. This phase does not assume a key role in finding information but rather in setting targets to be achieved in the subsequent stages. For that reason, providing the whole list of life cycle information, the framework supports practitioners in selecting and fixing life cycle-oriented targets for the project, such as the reduction of energy consumption, the use of recycled materials and the limitation of emissions. In addition, the framework affects the preliminary strategical design decisions, encouraging practitioners to evaluate with a life cycle perspective the different design concept, such as the choice to reuse existing structures or to opt for alternative solutions like expansions, renovations or new construction. Moreover, it orients the decision-making about the structure and the building envelope, stressing design team in esteem materials altenatives in a life cycle way. All these decisions are crucial from a life cycle perspective and must be defined and shared with the design team as well as the clients from the inception of the project to have an effect on the whole decision making process.

Shifting the design from a traditional to a life cycle perspective, the design phase should embrace all life cycle stages, with the exception of repair and refurbishment, since they refer to activities that cannot be predicted in advance. In this way, the design team is encouraged by the framework to deal as soon as possible with all the different stages, using LCT as a decision-making aid and checking the compliance with the settled targets. For the product stage, as a common practice, they should choose the building components and systems, considering the relative amount of materials. For the construction stage, they should select the manufacturers not only in relation to the products and performance provided but also considering, for instance, the distance from the factory to the site. For the use stage, they should esteem the energy and water demand as well as the maintenance and replacement process of both materials and systems and the emission of finishes. Finally, for the end of life stage, they should account the materials diverted to landfill and the potential materials to be reused or recycled. Starting from the early phases of the process, designers and engineers are responsible for the collection of the above-mentioned information, collaborating in some case with manufacturers and empowering therefore the respective fields of expertise. Concerning source and tools, in this phase a key role is played, on one hand, by the bill of quantities and, on the other, by software simulations, even if some information could refer to products or also literature data.

As the previous one, the construction phase, involving both the preparation of bid documents and the execution of works, must take into account all life cycle stages, considering the information embedded in the design phase as thresholds for the decision-making process. In this way, this is a progressive definition of the set of information, with deepened data especially regarding the construction process and the specific life cycle information of the materials selected for the building. Here quantitative data turn out to be more accurate and reliable: the amount of materials and related data refers not to metric estimate but to tender documents and the information about construction and installation process refers not to literature data but, possibly, to real data measured on site. Instead, concerning the additional information, such as materials, transport, energy and water used on site during the construction process, they are included by means of tender specifications or local measurements. In this phase, the actors involved are mainly general contractor and sub-contractors, for the most specific and demanding aspects.

The use phase of the design process must monitor the current state of buildings, taking into account all the life cycle stages with the exception of the construction stage. Certainly, the use stage assumes a key role, on one hand, for maintenance and facility process and, on the other, for energy and water consumption. Indeed, during the operational phase, it is possible to compare, confirm or adjust the value derived from software simulations with the real consumption. Moreover, it is possible to check if the maintenance and replacement activities were confirmed as predicted in the previous phase, recording at the same time the information about repair and refurbishment operations. Here, the selection of the new building materials must be done with the same life cycle parameters adopted during the design phase and thus embracing from the production to the end of life stage of the products to be added. The actors in charge for gathering that type of data are facility managers and, if expected, the commissioning authority.

Finally, the end of life phase should consider the end of life stage with the addition of the related possible benefits beyond the system boundary. Here, like happens in the previous phase, the life cycle information embedded in the framework are taken as thresholds and are deepened, confirmed or adjusted in relation to real data. As in the construction phase, the actors engaged are the general contractors responsible for deconstruction, demolition, transportation, waste treatment and disposal or reuse, recycling and recovery process.

2.4. Framework within a BIM-oriented working environment

To face the hard tasks and consistently with the trends currently underway in AEC practice, BIM is identified as the most suitable tool to embed the suggested framework and thus to shift it from the theorethical to the practical level. Indeed, it allows to create over time a project-based and well-framed set of data of the facility along the whole life cycle. Since BIM provides the maximum flexibility to tailor different practice and to fit the data needed, the implementation of the framework lets to arrange all data in an efficient and effective way and to progressively develop the life cycle database during the design process by means of the following steps. The first step is the insertion of life cycle information within BIM, enriching the set of information just embedded in the model and connecting when possible the data with the relative parametric objects. The second step is the grouping of information according to the phase of the design process, including a wider range of data with the advancement of the process. The third step is the insertion for each life cycle information of the additional linked data, such as the actors involved and source used. In this way, the responsible parties are able to input individually the life cycle quantitative data and build up the shared model database in the course of the process.

3. Discussion

The proposed framework supports the implementation of life cycle practice within building sectors, by matching the large amount of life cycle information with the different phases of design process and setting out the related actors involved and tools used. The application of the framework in practice reveals several potentialities. The first key factor is that all life cycle quantitative data are collected progressively in one-record, according to the different phases of the design process. The second key factor is that life cycle information are gradually defined, specified and detailed in conjunction with the process phases, becoming even more accurate, reliable and corresponding to reality. The third key factor is that life cycle data are gathered in every phase process by different actors, empowering the responsible parties for the choices and activities taken in their expertise area.

Moreover, by joining the framework within a BIM-oriented environment, the same understanding of BIM turns out to be enhanced. The traditional vision of BIM as a shared platform of exchange among different practitioners and stakeholders and as a life cycle information database of the facility, will be definitely proved and disclosed. Matching life cycle perspective and design process, BIM becomes a feasible supporting tool and process to reduce impacts and optimize building process. In the evaluation of a project, in fact, if the life cycle quantitative information are lowered in value with the progressive advancement of the process, necessarily at the end they will cause low impacts. However, this statement is effective only when the same items and materials are considered during the design process (e.g. specific type of concrete), changing progressively the related quantities. By contrast, the reasoning lapses when items and materials are replaced during the process (e.g. switching EPS with mineral wool). Here, the arrangement with environmental and/or economic data is demanded to make comparable the different materials in question.

The establishment in one-record of the life cycle information of the building in question, from inception onward, represents an added value for all the actors involved in the process. In fact, from early design to even the decommissioning phase, all the stakeholders in charge and/or allowed contribute information to and extract information from the building virtual model, providing a lifelong view of the facility. In this way life cycle BIM allows a continuous built-up of know-how, meeting and reinforcing two shared goals. On one hand, it enables a seamless flow of information across the process phases and stakeholders. On the other, it provides a life cycle database strategical for clients to have full control of the facility and thus a more efficient asset management and crucial for practitioners to compare their input data with the others and thus broaden their know-how for the following projects.

Nevertheless, in this perspective, it is important to not underestimate the following AEC main barriers. First of all, the fact that construction sector is considered resistant to change, whereas the suggested framework demands a radical shifting both in thinking and process. In addition, the framework implementation presumes the BIM equipment of all the AEC firms involved. Nowadays the uptake and maturity of BIM vary considerably from country to country and from company to company, according to their size and position. Another barrier is the need of a “wide and open” BIM, with the aim to integrate the entire value chain and to provide full interoperability of software and open access to it. While the technical challenges are likely to be overcome in the next future, it might be more difficult to change the existing processes and to enhance collaboration and data sharing. Lastly, the fact that digital technologies will realize their full potential only if they are widely adopted and regulated by norms and standards. This task is crucial to create a fertile environment for the digitalization of the construction sector and it is demanded to the government, as regulator and incubator as well as often a key project owner.

To conclude, it is worth mentioning that the proposed framework was developed on the basis of LCA methodology (environmental impacts) but can easily represents the input data frame also of Life Cycle Costing – LCC methodology (economic impacts) and with greater effort of Social Life Cycle Assessment – S-LCA methodology (social impacts).

4. Conclusion

Due to the high impacts of buildings at a global scale, the implementation of the aforesaid methodologies into the design process represents the forthcoming challenge of the construction sector. To this end, the integration of the suggested framework into a BIM-oriented working environment turn out to be crucial for two main reasons. Firstly, since BIM is nowadays widespread, to support, foster and put into action LCT in practice. Secondly, to orient the decision-making of all the actors involved starting from the early phases of the process and to streamline the building process.

Whereas BIM and life cycle methodologies are both available and the construction sector is just involved in the process of transformation and change management, the need is to seize the opportunity, orient the process development in the right direction and figure out how to exploit the most of it.

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