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ScienceDirect

Procedia Engineering 00 (2017) 000–000

Procedia Engineering

www.elsevier.com/locate/procedia

International High- Performance Built Environment Conference – A Sustainable Built Environment Conference 2016 Series (SBE16), iHBE 2016

The Use of Facade Mockups in in LCA Based Architectural Design.

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Abstract

Life Cycle Assessment is increasingly becoming important in façade architectural design. The presented research aims to describe an LCA architectural design approach based on the use of a Façade Mockup. The approach is applied and tested for the design Telecom Sustainable Campus' façade, in Rome. It is studied how a mockup could facilitate a more thorough LCA-based design processes, and how it could be the medium between design domains and the various stakeholders.

Peer-review under responsibility of the organizing committee iHBE 2016.

Keywords: Life Cycle Assesment; Architectural Design; Façade; Mockup

1. Introduction

The recent discussions about climate change have intensified the importance of the life cycle assessments. With the reduction of the operational energy demand, the energy associated with the building substance gained relevance. Whilst the operational energy currently matches the amount of energy needed for the erection and demolition of a building, this relation changes when the required energy to operate the building falls to almost zero, as it is planned by the current European Directive. The topic of LCA raises of interest, as voluntary certification systems such as DGNB and BREEAM demand its application. In addition, more frequently architectural design competition asks for façade LCA. Yet, there is quite a gap between intentions and architectural design applications. At the time of writing, there are no relevant records of LCA included in the architectural design processes. LCA remains a specialist domain, far from being a domain of architects. That is for multiple causes, ranging from the deficit of

Peer-review under responsibility of the organizing committee iHBE 2016.

knowledge of designers to the lack of architectural friendly tools capable of linking a quantitative approach to a qualitative creative design thinking.

Architects begin to become familiar with the concept of LCA and accepted its significance, but they are not yet able to include it in the planning process [1]. LCA is still a new way to approach design, and there is not yet, a range of experimented design approaches to it. LCA has not been extensively applied in architectural processes since it is perceived as a hindrance to design creation, as too convoluted, and time-consuming. However, Life Cycle concerns should actively affect design preferences, especially facades' design [2]. Hence, it is key examining methods and tools that support a quantitative yet qualitative framework, which is fully suitable for the comparison of façade options. Current LCA-based design approaches and tools are not entirely applicable by architects to their design process. Some of the software tools have way too much information tending to be overwhelming for architects. Typical LCA tools, such as Gabi, SimaPro, or OpenLCA, have been developed for the LCA of products or processes. From a designer point of view, these tools are not practical, because they do not mesh with the design process [3].

The literature on new approaches to integrating LCA into the architectural design process mainly focuses on BIM. It is evident that BIM models are today essential to LCA calculation. The main reason is that LCA tools have not completely transitioned their processes to integrate with BIM is that they are not simple to be read by some of the stakeholders in the design process [4]. In addition, simple tools which are BIM integrated are easy to generate LCA output, but often too superficial in their analysis. Now, for architects, it is essential to use tools that allow not only to evaluate the building LCA as a whole, but that facilitate the focus on individual building elements. Methods for the LCA based design should be rooted in the present state of development of tools and should lift the dormant potential of existing façade design praxis. Physical models and 1:1 mockups of building systems, specifically of the façade, are regularly integrated into the act of design creation and verification. Understanding how they could be blended into the LCA design process is the theme of the article.

2. Digital and Physical LCA

To support LCA-based Façade design process, it is crucial to apply tools rendering LCA, while appraising design alternatives. The combination of digital tools with physical models is investigated as a way to reduce the strains of managing LCA without sacrificing reliable data access, and directing time and energy to the creative design aspects.

Digital Tool. Just lately, two tools are adapting their features to encounter architect's needs, and they were both tested according to research scopes: Tally [5] and the SBS tool [6]. The first is BIM-based. With Tally, mass and volume can be extracted from a BIM Model without entailing new calculations once Façade design options are generated. The program builds a report comprising all of the graphics needed for a full environmental impact assessment of the project. However, Tally is not applicable for non-US designs since it is based on US data. A further weakness is that the % of the recycled component (e.g., for metals) cannot be specified, albeit it has a tremendous impact in a façade LCA. Another scrutinised tool, the SBS tool can be used by design professionals. It could support the measure of single functional units, and it creates excel data outputs which are customizable for the facade. Recognising that the transmission of volumetric information from a BIM model to the tool is not possible, the volumetric data needs to be "copied and pasted" from BIM volumetric quantity take offs.

Physical model. It is recorded that the use of mockups is standard practice for Façade testing. Their application to sustain LCA thinking is studied with a focus on façade designs that don't use standard (off-the-shelf) components and implement more complex forms. Custom systems should be project-hyper-specific and potentially more LCA saving could be achieved. While virtual models and BIM models are not completely understood by the construction team members, the fabricators and the design teams; the use of a mockup is likely to engage more players in an LCA approach. Design Variations suggested by the LCA could be assessed involving all of the stakeholders in the dialogue. Its use strengthens the evaluation of some the LCA-based solution throughout the design process, pondering architectural, constructive, and performative and LCA values. Because it is a full-scale replica of a facade, it is natural that the mockup also serves as a last-round visual mockup; the final check on design aesthetics for the architect. The hypothesis of this research is that a mockup is functionally complementary to architectural LCA simulation tools such as Tally or SBS. The integration of digital tools and mockups here formulated is tested in the design of the Telecom Italia New Headquarter Façade. A “Flexible Mockup” is conceptualised and built so that material and products made by different manufacturers are interchangeable.

3. Case Study: The Telecom Building Facade

The method, consisting of coupling digital tools and mockups for LCA study, is applied to the design of the New Telecom Headquarters Façade system. The 80.000 square meters complex is in the zone of EUR, in Rome (fig.1) and comprises three towers of seventeen floors and four podium buildings constituted of four levels. It was made in the 50s, and the original envelope was displaced in the 80s. Only the load-bearing structure was left. In addition to the request of reducing the energy demand for the operation as much as possible, the competition requirements enforced a Facade LCA evaluation. The background idea is that state-of-the-art energy measures command for façade with very high insulation thicknesses, extremely insulated thermal windows, and heavy mechanical system integration. All of these solutions would require high embodied energy, both for production and disposal. The façade development is operated with the SBS tool and a BIM model in the competition phase, and the SBS tools coupled with a Facade Mockup in the design development. Albeit the indicators of LCA are many (primary energy, renewable and non-renewable, global warming potential, ozone depletion potential, acidification potential, eutrophication potential, photochemical ozone creation potential and abiotic resource depletion), embodied energy (EE) and global warming potential (GWP) are the used indicators. This is to preserve the practicability of the study in coherence with the architectural design process [7, 8].

Fig. 1. Birds Eye View of the Designed Complex. In the Center is the Telecom Italia Sustainable Campus

The design process began with preparation, which consisted of preparatory studies, research, feasibility studies. This work was carried out by the competition initiators. A Facade design was refined, the geometry fixed and the material specified in a generic way. While key performance indicators circumscribed the choice of material (e.g., Travertine), their precise quality properties and the suppliers were not chosen yet, these decisions were taken later through the adoption of the experimental mockup. The façade consists of 3d Travertine panels which vary in shape and dimension depending on the solar exposure, natural light reflection and the angles of view. Aluminium profiles and metal grid constituted the preliminary horizontal shadings (fig.2). The Evaluation of EE and GWP of the designed Façade through LCA was not sufficient on its own, so two benchmarks were taken for comparison (fig.3). A simple curtain wall implies an EE of 61.411 MJ, while a typical double skin façade and the designed facade have an impact which is a 30% higher than the curtain wall. Still, other analyses such as costs, energy performance, daylight, sound insulation and exterior views were integrated during the decision process, highlighting the 3d travertine facade solution as the most performative. The aspiration of the following mockup based LCA refinements was to reduce the Embodied Energy to equal the impacts of the standard curtain wall used as a benchmark.

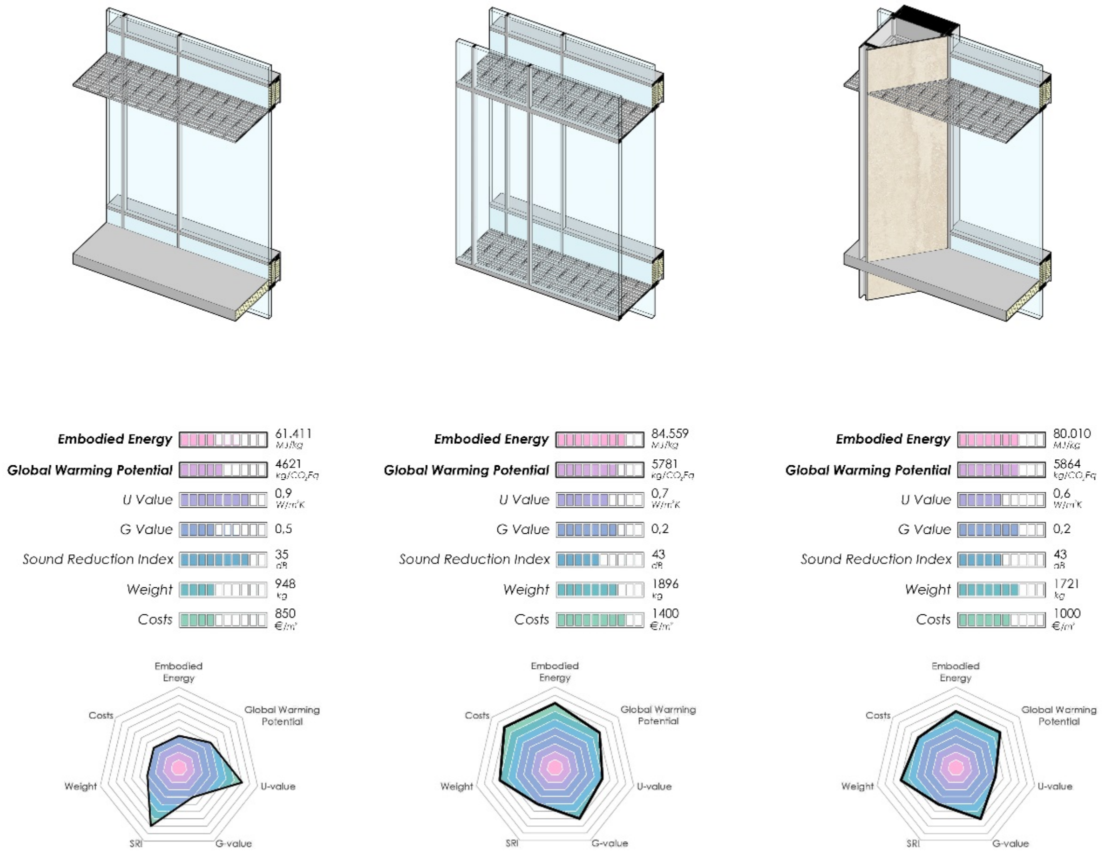

Fig. 2 Preliminary Comparison of LCA outputs and other Key Performance Indicators.

4. Refinements by the use of a “flexible” Mockup

In order to minimise the environmental impact of the façade design, improvements were tested coupling a mockup with the SBS tool. The mockup was conceived as modular in its nature allowing to change individual components such as the type of stone panels, the kind of glass, the kind of horizontal external shading system, the internal finishes, different types of roller shading blinds and the metallic components of the facade. Several design options could thus be built and visually verified, while the SBS tool gave LCA information of each alternative. The mock-up allowed discussing the end of life of components. The impacts from the use stage raised from any replacement needed during the 60-year study period and any maintenance required. This information was delivered material suppliers and façade experts. The life service standard data provided by SBS was overwritten. Materials with high impact indexes such as steel and aluminium have greater durability and possibility to be recycled during the disposal phase. Most consumer products are produced by a single manufacturer which could recycle or dispose of them in a controlled way. The mockup was further modified to allow a "design for disassembly" (fig.3). It was indeed noticed that products made by different manufacturers are often inseparably connected, and this was avoided. In order to provide an idea of what the mockup combined with the LCA tool offered, there is a list of decision made by coupling the LCA and visual / constructive tests (table 1):

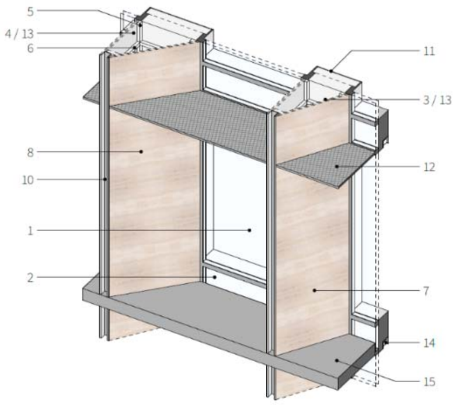

Fig. 3 The selected Façade System. Variations of the Functional Unit.

Table 1. The selected Façade System. Variations of the Functional Unit.

An example of a column heading	Embodied Energy (MJ)	Global warming potential (Kg/CO2Eq.)
Initial Mockup Configuration	86.156	5998
Glass Type Optimization (From 3 To 2 Panes)	82.219	5946
External Shading System From A Metal Box To A Perforated Light Metal Grid	81.302	5931
Travertine Thickness Reduction	80.156	5872
Use Of A Locally Sourced Travertine	80.010	5864
Metal Component Recycled Content Optimization	62.620	5827

1) Glass. (fig.3 element 1) A triple glass made by 8 mm of HST Guardian Extra clear – 18 mm Argon – 6 mm Ultra clear – 18 mm Argon – 8 mm Guardian Extra clear, was initially selected according to energy simulation results. The high impact of the glass led to the final choice of a double glass with thermal and visual performance accustomed to the specific design which determined a significant reduction of the Embodied Energy (4.6% reduction). The glass types could be visually compared with the mockup colours.

2) The shading system consisted on two different profile alternated: a fully opaque metal box (15) and perforated panels (12). The mockup, was carried outside the testing facility, and a few daylighting discussion ended with the adoption of the perforated metal grids, which is a favourable solution in term of visual glare avoidance, it matches the need of reducing LCA impacts and the overall construction costs.
3) Travertine panels' thickness was optimised in relation to visual aesthetical factors, transportation and manoeuvrability. Two scenarios have been assessed. The first one consisting on a pane of 36mm thick without substructure and the second one consisting of a thin slab of 12mm thick with a supporting aluminium honeycomb panel. In the first case, the Embodied Energy related to the travertine slab was found to be 1.278 MJ/Kg with a total weight of 829 Kg. The thinner travertine slab supported with a honeycomb panel determine a total of 1.580 MJ/Kg and a weight of 286 Kg. The solution chosen had higher environmental impact per se (about 23%), but a 66% lighter structure is significant save if transportation impacts are accounted, furthermore the cost could be significantly reduced. A lighter panel means the reduction of secondary LCA impacts including and lighter metal structural support system, the amount of metal needed was reduced. The use of a mockup clearly shows that the incidence of thickness is not changing the aesthetic of the façade, thus convincing all of the stakeholders of the quality of the choice.

Fig. 4. A Mockup was coupled with the LCA tool. On the left it is noticeable the different type of compared Travertines.

4) Travertine type. Travertine is the component that needed a certain attention in the choice of its origin. This calcareous sedimentary rock is very common in Italy, especially in the Alps and the Apennines. Therefore, three main Italian quarries were compared. Each quarry had a different aesthetic as shown in the mockup pictures (fig.4). Depending on where the Travertine was extracted, the texture, the pattern and the colour change. The four compared sites were Tivoli, Perugia and Siena, and The Alps, which are respectively 30, 140, 200 and 1000 kilometres away from the construction site. Transport could be modelled in SBS (life cycle stage A4 according to EN15978). Usually professional do not model transports in their LCA, but it was found to be a very impacting parameter. On the base of the Telecom project, it was soon found that distance is a parameter that needs to be decided at the early stage of design, due to his high impact.
5) Metal components. The amount of metal was reduced by the use of lighter panels. Theoretically, metals offer a very high content of recycled material. Aluminium and steel have an extremely high recycling potential as the energy intensive process is not necessary for secondary material. A % threshold was set. Recycling

aspects have a huge impact, and it was the factor that allows for LCA optimisation more than any other. Recycle content was impacting even more than façade geometry.

5. Discussion: How the physical mockup influenced the LCA design process.

The integration of environmental evaluation during the design process with a mockup led to a greater awareness of all of the involved implication of design decisions. A deeper understating of the environmental footprint has been a valuable information while evaluating the best option between several technical solutions. The refinements operated via the use of the mockup have had significant influence reducing the predicted Embodied energy impact by the 28%. In this stage components and materials, properties could be optimised. The Mockup facilitated finding the optimal solution. Choosing an adequate degree of abstraction of some components and having the ability to test some, helped to focus on the design’s main ambitions.

The research has shown that there is a gap between physical models and their digital counterparts. Physical mockup allowed exploring space, scale, materials and other considerations along with LCA. BIM models, rendering, details and sections were much harder to be understood from some of the stakeholders, in particular, the client and who had the budget control. The mockup thus addressed issues like buildability and economy, together with the architectural relation between inside and outside, front and back, structure and detail, darkness and light far better than any rendering or 3D model. It was recorded that although a BIM model was existing, all of the discussion of LCA gravitated around the physical mockup. All of the stakeholders gained engagement of more senses, and their knowledge could be collected in the LCA tool (e.g. providing the end of life of some of the components).

On the base of a dialogue with the façade manufacturers facilitated by the mockup, more realistic "replacement indexes" could be inserted in LCA tool (SBS tool). This parameter could be determined to take into account the service life estimated for each facade component. The “replacement index” could be discussed with the product suppliers and façade engineers for each element and material. This information when inputted in the LCA tool, overwriting standard data, allows for a more accurate yet very efficient and timely, decision process. By creating a physical model, it was possible to plan strategies for disassembly as a function of LCA considerations. Connections could be verified, with a level of comprehension that was higher of the one offered by BIM models. Functional testing of the installed materials, how they transition into each other, and visual factors could be pondered in accordance to LCA impacts.

6. Conclusion

The transition from a complex evaluation of LCA in research to the application in the design phase is the focus of the paper. Based on a review, the use LCA programs are far from facilitating LCA architectural thinking. It is here tested the use of a façade mockup as a complementary tool. It is here presented a two stages approach to the reduction of a façade life cycle environmental impact. The approach suggests that geometry and main material categorization happens in stage 1, while refinements are defined in phase 2, with a mockup. In the second stage, which is the main focus of the research, the architect refines material and components.

It is found out that Mockup is a tool that allows qualitative and LCA quantitative decision. The physicality of the mockup is a potential pivot of the discussion. The relevance of a material choice was regarded as serious because the environmental consequences were tangible with the association of data to the physical artefact. The architect receives visual feedback of the LCA implications, and construction scenarios can be interactively tested. The mockup helps designers and the various stakeholders who are all able to read, understand and establish a dialogue. Via the use of purely virtual models, the ecological impact is not immediately recognisable by the full team, including the client, which is the main decision maker. Areas for improvement found with the mockup led to a reduction of embodied energy of the 28%.

Acknowledgements

The Author wants to thanks, Matteo Saitta and Daniel Nielsen for their collaboration. The Telecom Italia Project team was coordinated by UNO-A and included the author of the paper, BEMaa, Calzoni Architetti, Studio Bodega, Studio Iorio, General Planning, Stefano Tropea. The project was led by Luca Piraino and Paolo Mazzoleni. Ombra Bruno was the architect involved in the LCA design process.

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