IOP Conf. Series: Materials Science and Engineering **245** (2017) 042081 doi:10.1088/1757-899X/245/4/042081

Application of the Life Cycle Analysis and the Building Information Modelling Software in the Architectural Climate Change-Oriented Design Process

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Abstract. Whereas World's climate is changing (inter alia, under the influence of architecture activity), the author attempts to reorientations design practice primarily in a direction the use and adapt to the climatic conditions. Architectural Design using in early stages of the architectural Design Process of the building, among other Life Cycle Analysis (LCA) and digital analytical tools BIM (Building Information Modelling) defines the overriding requirements which the designer/architect should meet. The first part, the text characterized the architecture activity influences (by consumption, pollution, waste, etc.) and the use of building materials (embodied energy, embodied carbon, Global Warming Potential, etc.) within the meaning of the direct negative environmental impact. The second part, the paper presents the revision of the methods and analytical techniques prevent negative influences. Firstly, showing the study of the building by using the Life Cycle Analysis of the structure (e.g. materials) and functioning (e.g. energy consumptions) of the architectural object (stages: before use, use, after use). Secondly, the use of digital analytical tools for determining the benefits of running multi-faceted simulations in terms of environmental factors (exposure to light, shade, wind) directly affecting shaping the form of the building. The conclusion, author's research results highlight the fact that indicates the possibility of building design using the above-mentioned elements (LCA, BIM) causes correction, early designs decisions in the design process of architectural form, minimizing the impact on nature, environment. The work refers directly to the architectural-environmental dimensions, orienting the design process of buildings in respect of widely comprehended climatic changes.

1. Introduction

According to the Regenerative Design philosophy consumed matter must be levelled, compensated, restored as well as renewed by energy, materials and creation of sustainable systems, which combine the needs of human beings in symbiosis with nature. Next issue is the term of Resilience which makes predictions easier as well as helps making the right decisions based on the previous moves, errors, injuries, etc. as well as flora, fauna, bones, skin, psyche (nature), characterized by author in earlier works. A holistic approach to the design process will help to reduce the negative impact of architectural objects on the environment, within the meaning of sustainable development. Such a body of knowledge enables to carry out the design process in a conscious and organized way taking into account the important rules.

It is necessary to determines that in nature all living organisms are part of a stable environment. The two main aspects that should be combined and researched with attention to the climate change impact, are: material and energy. A number of negative impacts on the environment entails measurable effects by climate change. The humanity presently emphasizes the transforms, egg. architectural objects, into an important physical problem. The design process (and designers) must cope with difficult tasks in a prism of the total benefits to humanity, not to fuelling the spiral of negative environmental footprints. Energy is now a need for the proper functioning architecture (in everyday life) and also have further deepened by the material requirements which also have a negative impact on nature. Solutions of those negative footprint elements, can be minimalized by using the Life Cycle Analysis (LCA) and digital analytical tools BIM (Building Information Modelling) - at the same time - which define suitable shapes of architectural objects in an improvement of the climate changes. Moreover in the living environment (the buildings) peoples spend over 90% of 24-hour day time [1]. Architectural elements cannot meet up and keep up with current climate change, so it is necessary to adapt to. It shows how important is the design of the better architecture, using appropriate techniques that can meet these requirements, named as holistic aspirations in dimension better design process of the architectural living environment.

Finally, an architect constructs an axis between architectural and ecological ideas in the harmonious arrangement of a building-environment. Correct energetic, functional, material solutions in a thoughtful design process lead to the concept of regeneration.

2. The impact of architecture on the environment

First of all, during production of materials, the man consumes fossil fuels and exploits natural resources. As a result, the common ecosystem becomes polluted by waste. All over the world people produce large amounts of materials and they get rid of similar amounts of them. Re-use of the material has a long tradition. New architectural objects resulting from re-use and reconsumption of material are becoming more sustainable than before. An important advantage of re-used elements is that they do not have to be made from scratch but only can be re-used and adapted to the needs, expectations and lifestyles of the future user. One of the key issues in the re-use of resources is the design process in line with the 3Rs rule (reduce, reuse, recycle). The design process (taking into account the terms "3R" having in mind the cycles of life) determines the most important aspect of the fourth "R" - rethink - meaning re-think / analyse solutions set up by an interdisciplinary integrated project team.

Traditionally, the process of material production also uses up natural resources. Energy consumption for the production of building materials is strongly associated with the emission of carbon dioxide. According to Commonwealth Scientific and Industrial Research Organization (CSIRO) building energy (embodied energy) in materials used in the construction of an average household is responsible for roughly 15 years of energy consumption use for heating, cooling, ventilation, lighting, equipment and facilities [2].

Australian Greenhouse Office has developed guidelines that reduce the amount of building energy. Milne, Reardon says, these are "projects with long life and adaptability; providing materials which can easily be separated; sourcing of materials from demolitions and construction waste products, reused or recycled; choice of materials with a low coefficient of energy; to obtain information from suppliers about the product and share this information" [3]. Therefore, it is important to make an informed choice of materials, which during or after use of the building will be recycled, reused and / or stored in a landfill. Being aware of this sequence of events is important from the point of view of ecology and has a great importance for sustainable development, in other cities. Matos, Wagner [4] approximates the amount of raw materials used for the production on the territory of the US which increased from 161 million tonnes in 1900 to 2.8 billion tonnes in 1995. Building materials constitute about 75% of energy consumption and only 8% of them were considered as renewable. On the other hand, Construction And Demolition Waste - C&D study of the European Commission in 1999 [5] shows that "in the European Union C&D amounts to approximately 180 million tonnes each year. Which is more than 480 kg per person. In the EU-15 reused or recycled it is only 28%. Landfilling the other 72% (approximately 130 million tonnes

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per year) at a density of 1.0 requires the equivalent of a brand new landfill 10m deep and roughly 13 square km in surface area every year.”

3. Architecture life cycle of materials

Author analysing the meaning of the term ‘material’ indicates meaning of combination: substances and energy. Means, every building needs material to come into being. Moreover, every material needs a certain amount of energy and raw material to come into being. These factors also affect to the life cycle / existence of a thing / building. To determine the effect of materials used for the formation of an architectural object on the environment, their life cycle should be traced, from the extraction and processing of raw materials through the production process> distribution and transport> construction of the facility> use of the building (cited above) to the demolition and re-use - recycling - demolition waste or landfill in case of all analysed materials.

The method of this assessment, life cycle assessment (LCA), allows to estimate any kind of material impact on the environment and its resources. Examination with the LCA method is carried out in four steps defined by the International Organization for Standardization matters - ISO (International Standard Organization) in /PN-EN/ ISO 14040 and 14041:

- The first step is to determine the purpose and the scope of research.
- The second step is the inventory of a set of relevant inputs and outputs in the system of the product.
- The third step is to assess the potential impact of the material on the environment associated with the inputs and outputs of the system.
- The fourth step is the interpretation of the results of analysis and assessment of individual phases in relation to the purpose of research.

To meet the requirements of a new design process for innovative construction techniques, it is necessary to incorporate methods (qualitative methods, semi-quantitative, quantitative) and analysis of a life cycle. The use of these methods reduces the operating costs of a facility and has an environmental impact in the manufacturing process of materials. It is also becoming an important element of the information in the design process. [6]

Life cycles are needed to determine the algorithms of suitability of products / objects and the impact that they have on the environment in the chain of existence. The variability and elasticity present in the life cycle of the architectural structure, understood as the design life of the component parts of the object, Wołoszyn [7] defines as follows: "main structure> 80 years; external and internal walls> 40 years; plasterwork and external decor> 15 years; technical equipment, sanitary installations> 10 years; telecommunications equipment and computers > 5 years “. If in the initial phase of the life of individual elements they are poorly designed, then, over many years of their life they will become disrupted. Therefore, it is important to determine the target viability of each object, and thus the service life of used materials, and then finally save all the information in the data bank.

Destruction of objects raises the question of what happens to waste after demolition (after a life) of objects. Densley-Tingley [8] specifies that a lack of base (bank) information, data and project which takes into account the second life of materials makes it impossible to determine their full life cycle, which is also important for the meaning of embodied energy.

In the selection of construction materials, building energy (embodied energy) and carbon incarnate (embodied carbon) are of particular importance. They have an impact on the ecological character of the produced product. These values show the life cycle and the amount of incarnate carbon in various sectors. The importance of embedded energy was defined by Cambridge Engineering Selector, Granta Design Ltd, UK and Centre for Building Performance Research. Approximate figures are given in the Table of Embodied Energy Coefficients [9].

3.1 Research – Life Cycle Analysis of materials, Single Family House

First of all, it necessary to quote the research on the value of the embedded energy in the existing building stock was conducted in Sweden, Germany and Denmark. These studies by asset construction inventory had to determine the potential reuse of materials used in the structures of the tested objects. Various types of indicators were used in the inventory: the use of the material (kg / m^2 / year)% recycling, embedded energy and production of carbon dioxide. An example of re-using products and materials to construct residential buildings are projects by Udden and Nya Udden, in Sweden approximated in Eklund, Dahlgren, Dagersten, Sundbaum studies [10]. An American studio SINGLE speed DESIGN erected a Big Dig House (2006) using materials from demolition (design from deconstruction) of Boston central traffic artery Interstate 93 (BigDig); it also enabled the realization of the idea of the Big Dig Building (2005). Next, Superuse Studios, design studio 2012Architekten from the Netherlands, promotes architecture with recycling (upcycling), both in their search, and projects. Finally, a full picture of the end of the life cycle of waste materials, i.e. garbage (tyres, bottles, cans, paper, etc.) and local materials (ground, wood, etc.) for re-use, is reflected in individual realizations: Earthship Houses - Michael Reynolds; SECU - Sustainable Emerging City Unit (material strawpanels) EiABC; Japanese Pavilion (material: paper), EXPO 2000 Hanover - Shigeru Ban; Corrugated Cardboard Pod (material: corrugated cardboard), 2nd year project Newbern Al., USA 2001 - Gabriel Comstock, Amy Jo Holtz, Andrew Olds; PHZ2 (material: discarded cardboard), Welterbe Zollverein Essen, Germany 2008-2010 - Dratz & Dratz Architekten, Strohhaus (material: straw waste), Eschenz, Switzerland 2005 - Felix Jerusalem.

Design process takes into account the element of re-used matter is complimentary Design for (and from) Deconstruction and Adaptive Reuse, 4R rules (Reduce, Reuse, Recycle, Rethink), which creating life cycle of material in the spheric of meaning eco-logical architecture in the achieving the aim of Regenerative Design. Those definitions are the main author issues in research field about the life cycle of a building matter. It shows that it is possible to re-use existing matter resources, prolonging life cycles without the need for their elimination in a landfill; and the introduction of environmentally friendly solutions to a lesser extent affecting the environment in a life cycle of exploitation. It also shows that architects see many opportunities for ecological use of various structural elements, materials, waste (adaptive reuse, recycling, upcyling, etc.), as well as designing, taking into account the dismantling (design for deconstruction) in the construction of architectural objects. Is therefore necessary to aware of the record and exchange the above mentioned information and experiences.

Summarizing above, the author together with students from Hungarian, Budapest, Szent István University, Ybl Miklós Faculty of Architecture and Civil Engineering and Polish, West Pomeranian University of Technology Szczecin, Faculty of Civil Engineering and Architecture took on the developed single family houses to the analysis spectrum of material using among others Life Cycle Analysis (LCA). Workshops in Budapest helps indicate how much materials stock in the building influences on environment in the first phase, means Product and Construction Process Stage. Students using EPD – Environmental Product Declaration, for each material (in time horizon 100 years, with site transportation distance 50km) of the 150sqm House structure, counting materiality of the ecological footprint.

Total ecological influence from Life Cycle Analysis - LCA of 150sqm Single Family House giving: Global Warming Potential 41067,7kgCO_2; Primary Energy 683437,6MJ (578787,3MJ of non-renewable and 104650,2MJ renewable primary energy); Water Consumption 102611,5m^3; Hazardous Waste 47431,8kg/m^3; Radioactive Waste 5,6kg/m^3. Results Most important element influencing on the condition of the Climate on Earth is GWP - Global Warming Potential. The GWP aspect shows in the first stage of material 41067,7kgCO_2 in 100-year time horizon. Recalculate it is 2,7kgCO_2, per year, per sqm. But it is only first stage (Before Use), next in Use Stage shows calculations of functional energy consumption 45,5kWh/sqm, per year. Remembering current emissivity ratio in Poland of 1kWh is 0,798kgCO_2, counting the influence are 36,3kgCO_2, per sqm, per year; so it means the 150sqm Single Family House have GWP equal = 544.994,1kgCO_2 in the 100 year, time horizon.

It is important to mention that, the above calculations approximate the result from one home, because the students were divided into two groups and the result of second group was different. But to understand the idea which builds influence on the environment the author has decided to bring one calculation result. Next, necessary information about EPD’s is that most of them not have enough numbers to prepare next life stages (Use Stage, End of Life Stage) of materials. (Figure 1)

A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	B6	B7	C1	C2	C3	C4	D
MD	MD	MD	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND	MND

Figure 1. An example from table of a developed EPD.

The next works, bring architecture materials distribution, of the life cycle point of view, e.g. Design for/from Deconstruction, 4R rules. Works are from activity of Student Scientific Society Eko-Architektura members (author is the superior of SSS E-A). Projects attempted to design how to use second life materials. (Figure 2) The project which proposes replacing the traditional way of erecting a building with sea containers is notable (Figure 2A). A similar transformation was proposed in the draft of a detached house (Figure 2B). In both projects carried out in the framework of SSS E-A adaptation diversity of containers was proved. Participants also showed different possibilities for the free development of the architecture of the building. Another project explored frighter deck (ship sheathing) equipment used to cover the facade of a building (Figure 2C). In considerations of design the thing which was taken into account was the availability of local materials due to the nature of the shipbuilding city of Szczecin. Another example of the use of materials is a house model based on Earthship principles. The model has been analysed in the Ecotect software, which enabled to indicate correct energy solutions (Figure 2D). Of course these are reflections of workshop / academic level not applicable directly in the matter of materials. However, they outline the recycling aspect overlooked in wider design. The conclusion is that the absence of a solid widely available recording and use of information of experiences causes a conceptual or visionary nature of the projects.

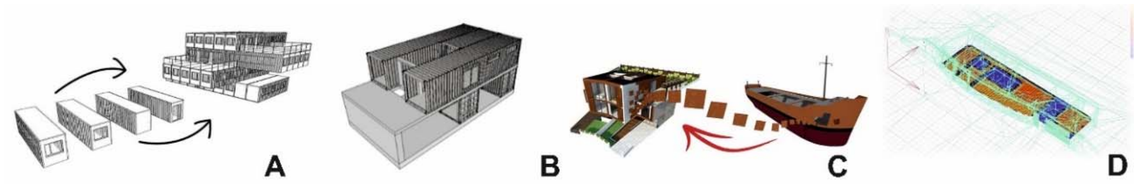

Figure 2. Projects attempted to design how to use second life materials.

All workshops issues cover aspects of matter (material) - embedded energy and recycling in the wider sense. At the same time, they determine the scope of the author's research with all elements in the design process (DNA) of the bank material, as well as individual approach design with smooth morphology solutions outlined by the author of the paper.

4. The Building Information Modelling (BIM) in urban design

Author in 2016 [11], together with the students from Latvian, Riga International Study of Economics and Business Administration, Faculty of Architecture and Design, took on the developed / redesign the urban structure which was subjected to the analysis spectrum. The workshops were based to integrated design process using BIM analytical tools in the field of urban. Students worked using Autodesk Ecotect and Flow Design software. The software enabled the characterization of the initial concepts in terms of factors: shadows, light exposure, sound/noise and wind. The results characterized advantages and disadvantages of elaborated terrain.

The work was divided into four phases:

- The First Phase, envisages the conversion, transposition models of design concepts to the CAD software. The concepts, which was largely contained in the mockups or drawings technique.
- The Second Phase, determined the design concepts in BIM analysis software, by factors: light exposure, shading, sound/noise and wind.
- The Third Phase, conducted result indirect of the analytical research with the use of digital tools, in the direction of specification, advantages and disadvantages on analyzed area.

- The Fourth Phase, was the phase in which participants transformed urban assumptions in terms of the results of the third phase, and repeated again the analysis to achieve the best results, in terms of the factors, achieving/reaching the optimum of effect.

It is important to mention that, the results from the inputs - outputs, define the transformation of the urban area or buildings and give directions for further research. (Figure 3) Study paid special attention and effort was made, to draft conclusions after the first error resulting from the analysis. With respect to the interpretation of results in projects, followed changes in terms of factors on the principles of: separation and moving the buildings, creating openings between objects, reforestation, etc. All solutions seek to optimize energy efficiency (because it is the biggest element of environmental pollution, and find a pro-ecological solutions to solve it) and the conscious shaping of a convenience living conditions.

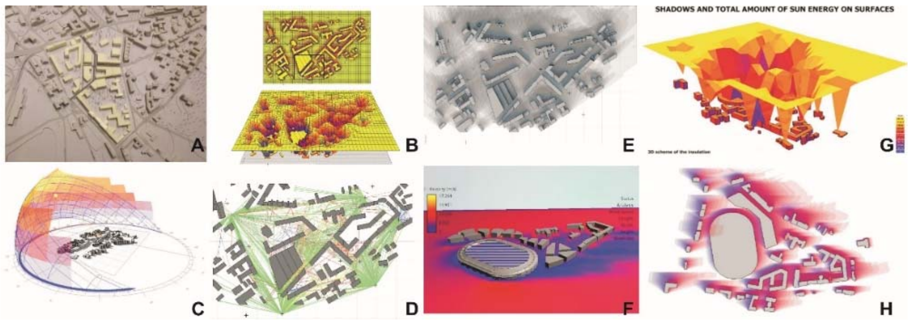

Figure 3. Results from BIM software urban structure analysis [11]. A. Physical model, B. Model transposition to the software, C. Sunlight analysis on surfaces determine the amount of passive energy, D. Sound/noise analysis, E. Analysis of the year shadow range, F. Wind analysis, G. Shadow analysis taking into account the annual passive energy distribution, H. Colorful of the shadow range.

4.1 Research: The urban and architectural design by Building Information Modeling (BIM)

Freedom of creation which offering a computer programs in terms of lot of transformation and lead the design process, allows a broader view of the context of the macro scale – urban, and micro scale - architecture. The current archaic approach to design substances built creates simple and the same empty formal solutions. The scale of urban planning and architecture, without proper context, variant pro-ecological solutions, condemning the whole process to fail, against the background of challenges for designers in terms of sustainable development, in the era of ecological anthropopressure crisis. Workshops range to indicate the possibility of designing the urban area assimilating the methods of analysis by digital tools for content and direction of the investment process, energy self-sufficiency designed objects at the level of urban design.

Study showing a possibility of understand the design of ecological character at urban site. The design process of the holistic aspect of the architectural design was focusing on the scope a number of factors affecting the ecological character of the building and located in the urban structure. The urban scale and building scale, creating by a multi-dimensional analysis and ultimately the decisions taken by the evaluation in software reaches a dimension that meets the criteria in a 'Form follows Energy' [12] or Form follows Environment. Transformations of workshops concepts formulated by factors led the design process in the hierarchy of conclusions and submission to the discussion on the planned space taking attention advantages and disadvantages. The cases result shows that the objects should be redesign the form, in the context of Form follows Energy / Environment. Awareness of results (after preliminary analyses) and analytical thinking leads to increased concentration over action plan towards of the correct solutions. This makes it possible to transform objects (in the early design process achieving the desired aesthetic and ecological effect) into passive houses and urban planning to meet strict green requirements (as in certifications BREEAM, LEED DGNB). Studies about the urban or architectural form in terms of energy efficiency (because the Use of building is the biggest element of environmental pollution) giving possibilities to change shapes of the objects using digital analytical tools to determine the optimal shape by climatic factors. (Figure 4)

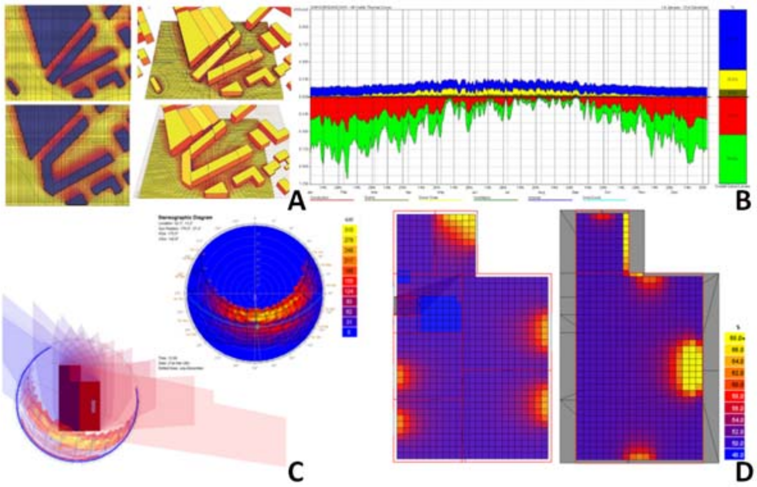

Figure 4. Results from BIM software analysis. A. Shading analysis of surface sun exposure which attempts to re-design object structures; B. Thermal analysis – passive gains; C. Shadow range and sun exposure; D. Internal solar access.

5. Conclusions

The results of the study work show the direction of a contemporary architectural design adapted to the changing world climate. Which should become an important issue for the current early design process of urban planning and architecture. Because architecture should primarily be minimizing the environment impact but also lead to the adaptability of architecture in a changing environment. Combining two aspects of the Life Cycle Analysis - LCA and digital analytical software tools including Building Information Modelling - BIM in the early stage of the design process indicates an achievement of a high-level ecological goal. The first indicated of correct urban design solutions using the factors: light, shadow, wind, sound; cause reasonable and conscious shaping of the design area for architecture. Then, analysis subject of the individual architectural objects –building- using again BIM (created and based on the principles Form follows Energy ect.) and LCA (verifying by results of Ecological Footprint), an analysis which indicates in the early design process results in the conscious selection of materials and shape of 'house' form, the solutions of eco-friendly architecture. Therefore, it should be assumed that the two aspects of LCA and BIM in urban and architecture are future in this regard and influences each other. Because proper architecture cannot exist without the correct solution of urban planning and vice versa (Figure 5).

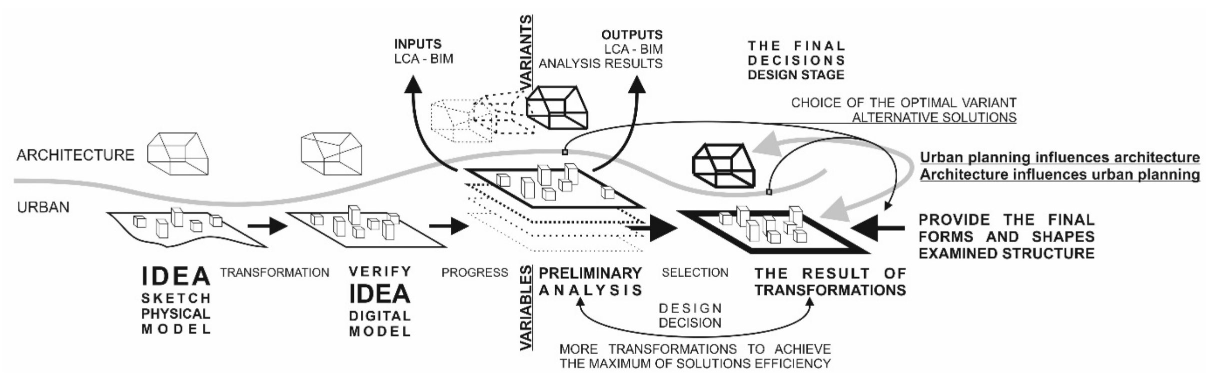

Figure 5. Scheme of the design process of architecture or / and urban planning with using LCA and BIM analysis. Following advantages in design process from analysis: time and freedom of transformation, variability and multifaceted of solutions, wide spectrum of analyses, maximization of the solutions efficiency.

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Acknowledgment(s)
Author would like to thank RISEBA, Szent István University and also members of Student Scientific Society Eko-Architektura from West Pomeranian University of Technology Szczecin for their cooperation, which results was used to as the material in the paper.

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