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Eva Vaništa Lazarević, Aleksandra Krstić - Furundžić, Aleksandra Đukić, Milena Vukmirović

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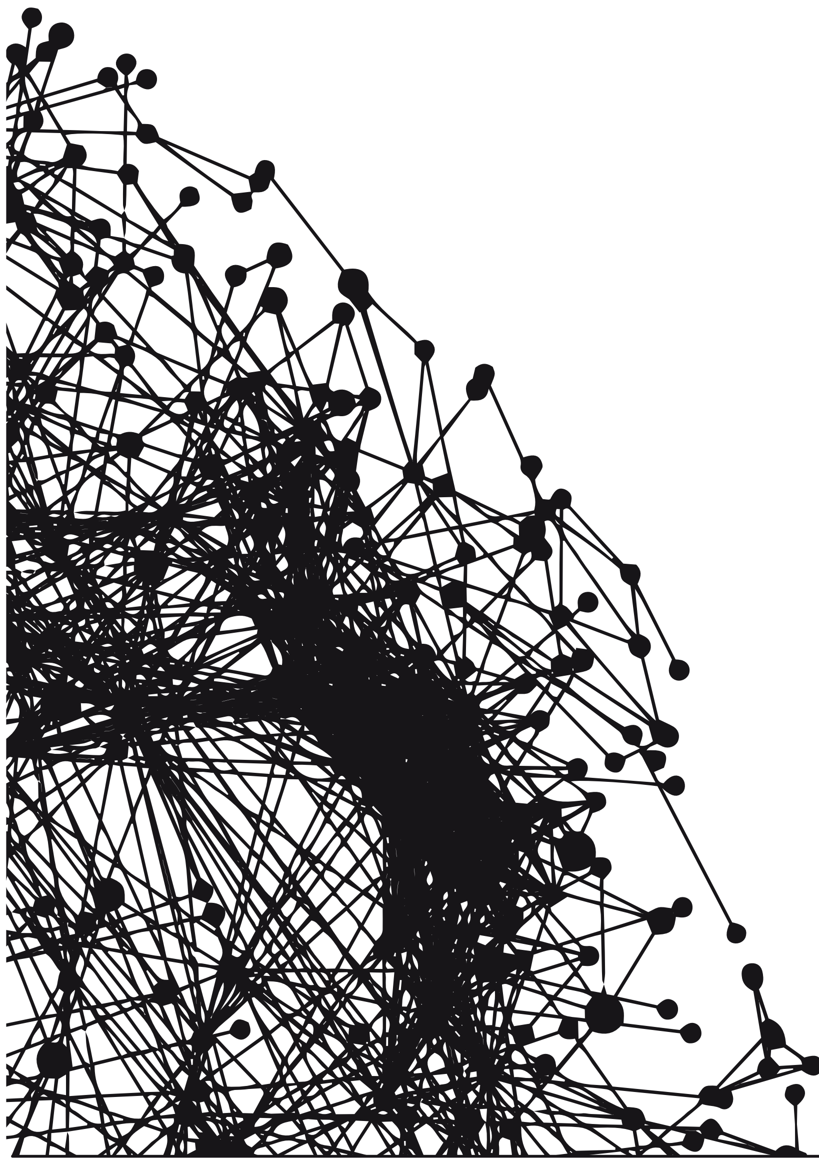

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INTEGRATED DESIGN OF STRUCTURAL SYSTEMS

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Abstract

This paper deals with the concept of integrated structural design, within an integrated approach to the design and evaluation of buildings, for the purpose of achieving ecological quality of buildings, in line with recommendations for sustainable building development. Integrated structural design refers to reduction of negative environmental impact and resource consumption, with a simultaneous increase in life quality and health and safety in the built environment. Integrated structural design is based on targeted integrated performances of a building throughout its life cycle. This type of structural design is based on a systemic approach, in which the structure of the building is seen as a functional unit, i.e., as a sub-system of the building, whose behaviour is directed towards the aim of the system-building – ecological quality. In this process, a structure cannot be understood, and thus evaluated, without understanding its relationship with the specific function of architectural space. This systematic approach in its practical operationalization has the design of system-buildings of different relationships and connections among sub-systems, building structure and construction materials, that is, the design of buildings of various quantitative and qualitative properties, with a higher common property – ecological quality.

Keywords: sustainable building, ecological quality of buildings, integrated building design, integrated structural design

Introduction

Activities related to the buildings, in addition to affecting the quality of life and the economy, are most responsible for environmental damage (A. Nenadović i M. Nenadović, 2002). It is necessary to reduce the negative environmental impacts and resource consumption due to the construction, use and demolition of buildings, with a simultaneous increase in quality of life and health and safety in the built environment (Working Group for Sustainable Construction, 2001, 11). In order to achieve the stated aims, special attention should be paid to the design of buildings, since the "design is in the base of problem of the relationship of people and the environment and the changes in those relationships" (Blagojevic and Ćirović, 2011, 24), that is, up to "80% of a product, service or system's environmental cost is determined at the design stage" (Design Council, 2002, 10). Building design "based on the principles of sustainable development" (Law on Planning and Construction of the Republic of Serbia, clause 3) implies an integrated approach (Working Group for Sustainable Construction, 2001, 13), based on the systemic analysis of social, economic and environmental aspects (Birkeland, 2002, 7). It is a holistic approach, based on targeted integrated performances of buildings throughout their life cycle, that is, on integration of project objectives, as well as the integral quality assessment of the designed solutions in accordance with the quantitative and qualitative indicators of ecological quality of buildings (Nenadović, 2014). This type of design involves research strategies that transcend disciplinary boundaries, in order to comprehend the relations between building subsystems, including the building structure and structural materials, as well as the behaviour of these sub-systems directed towards achieving the goal of the system-building – ecological quality. The result of this systemic approach, in its practical operationalization, is a conception of system-buildings of different relations between sub-systems, that is, conception of buildings of various quantitative and qualitative properties, with a higher common property – ecological quality.

Ecological quality of buildings

The key theme within the integrated approach to building design is the establishment of multiple design sub-goals in function of achieving the main goal - ecological quality (Nenadović, 2014). When it comes to the design of building subsystems, including the design of building structure, building can be taken as the system boundary, that is, as the system which is attributable to ecological quality (Bell, and Morse, 2008, 12). Life cycle of a building is taken for the time frame during which the ecological quality of a building is assessed (European Committee for Standardization, 2011). Ecological quality can be interpreted as the „extent to which performances of the building meet the needs and expectations of its users, which refer to social and economic well-being achieved with simultaneous protection and improvement of the environment throughout the life cycle of the building" (Nenadović, 2014, 21), while its determination may be carried out according to the criteria and indicators for assessing the ecological quality of buildings (Nenadović, 2014). The subjects of the analysis are the effects on the global and local environment throughout the life cycle of the building. The objective is to reduce harmful emissions into air, water and land, as well as increase the efficiency of resource use (Commission of the European Communities, 2005, 5). It is also necessary to consider the extent to which performances of the building meet the needs[190] and expectations of its users during the use phase of the building. Two key aspects of quality of the architectural space should be considered during design: functional and symbolic (Giuliani and Feldman, 1993; Williams, Patterson, Roggenbuck, and Watson, 1992). These aspects concern the consideration of the conditions that should support the users' activities, that is, the possibilities of space to stimulate the desired experiences (Kyle, and Chick, 2007; Williams, Patterson, Roggenbuck, and Watson, 1992; Božović-Stamenović, 1997, 65-66). The objective is

[190] These are fundamental human needs (Max-Neef, 1991, 32-33).

the realisation of architectural spaces that contribute to quality of human life, that is, well-being, through preservation and improvement of their health, and incitement of the sense of security, amenity and harmony with the living environment (Nenadović, 2014, 28). In addition, it is necessary to estimate the life cycle costs of the building[191], as well as the ability to maintain the value of the building (Menger, 1871; Ćirović, Jovović i Luković, 2010), wherein it should be kept in mind that users are interested in buildings that can meet their needs to a greater extent, that is, to improve the quality of their activities, while simultaneously reducing operating and maintenance costs (Construction Task Force, 1998).

Integrated design of structural systems

Integrated building design, as a process that enables achievement of ecological quality, implies involvement of clients, contractors, construction professionals, end users, as well as early and intense involvement of all members of the design team, whose members make decisions together in accordance with a shared vision and a holistic understanding of the project (Ritchie, 1995; Busby Perkins + Will, and Stantec Consulting, 2007). Non-linear, iterative design process (Knudstrup, 2004) is based on multiple, often various forms of knowledge and processes (Moe, 2008, 6-7). In the process of integrated building design concepts are evaluated through the aggregation of fact and value judgments, in accordance with the quantitative and qualitative indicators of ecological quality (Nenadović, 2014). In this process, the decision-making becomes an art of finding the best compromise with the aim to optimize the performances of the building as a whole, rather than to optimize its individual components (A. Nenadović and M. Nenadović, 2004, 240). In the context of the above, in the process of integrated building design, design of building structure is based on targeted integrated building performances throughout its life cycle. Integrated structural design is a systemic approach, within which the building structure is designed as a functional unit, that is, as a subsystem of a building whose behaviour is directed towards the aim of system-building – ecological quality (Nenadović, 2014).

One of many examples of buildings conceived through the process of integrated design is PowerGen headquarters building (Figure 1), the project pioneered energy-efficiency in the office sector, which was designed by Bennetts Associates, who "achieve the high levels of sustainability" through "multi-disciplinary, investigative approach to design" (Bennetts Associates, n.d.). During the design, a strategy for reducing the energy required for heating, cooling and lighting of the space, based on the use of passive techniques, was applied. The choice of structural material was crucial. Reinforced concrete structure was intended to act as thermal mass which

[191] Primarily, it is necessary to consider the possibility of reducing operating and maintenance costs, given that these costs constitute the largest part of the life cycle cost (Krstic and Marenjak, 2012). These costs are primarily affected by durability and reliability of the building, space adaptability, space utilization and energy efficiency of building, which are largely determined by the solution of a building structure (Nenadović, 2014).

contributes to the control of indoor climate by reducing the thermal leaps. Concrete floor structure is shaped in accordance with the requirements related to the proper acoustics, lighting and thermal performances of workspace (larger surface thermal absorption), and in accordance with the requirement of "elegant" (O'Neill, Shaw, and Flynn, 1996) and structurally efficient solution.

Figure 1. Bennetts Associates, PowerGen headquarters building, Coventry, UK, 1994, construction, interior. [Source: O'Neill, B.T., Shaw, G., and Flynn, M. (1996). *Project Profile: PowerGen Headquarters*. British Cement Association; http://www.bennettsassociates.com/portfolio/9109/]

Improvement of building performances in the context of sustainability, based on adequate materialization and shaping of building structure, was also achieved in Portcullis House (Figure 2), a project by Michael Hopkins and Partners, (today Hopkins Architects), and in Wessex Water Operations Centre (Figure 3), a project by Bennetts Associates. Proposed solution of the structure, which is, according to Peter Smith "one of the most aesthetically and environmentally suitable methods of achieving radiative thermal mass" (Smith 2005, 136), is derived from a philosophy that is based on "the integration, rather than the duplication of elements" and design approach that “synthesizes creative imagination and rational logic" (Hopkins Architects, n.d.). Structurally efficient, arched reinforced concrete floor structure[192] is exposed from the bottom surface, thus improving the effectiveness of thermal mass. In winter, the structure accumulates heat during the day and then radiates it to the internal space during the night. In summer, the cooler night air passes through the cavities and cools the plates, which then cool the space during the day, that is, reduce the temperature maximum[193].

[192] Thanks to the structurally efficient, vaulted floor structure, 50% less concrete than in the case of traditional flat reinforced concrete plate was embedded, which reduced embodied energy of a building.

[193] The solution does not imply suspended ceiling, but raised floor within which the installations are distributed.

Figures 2 and 3. Arched reinforced concrete floor structure in Portcullis House, London, UK, 2001, designed by Michael Hopkins and Partners and in Wessex Water Operations Centre, Bath, UK, 2000, designed by Bennetts Associates. [Sources: Smith, P. F. (2005). *Architecture In A Climate Of Change: A Guide to Sustainable Design*. Elsevier/Architectural Press. 137; http://www.bennettsassociates.com/practice/sustainability/]

In office building of Building Research Establishment organisation, a project by Feilden Clegg Bradley Studios which promotes social and environmental sustainability and which pursues research-led design, vaulted reinforced concrete floor structure (Figure 4) is holistically designed in order to satisfy multiple functions. Load bearing floor structure, i.e., vaulted slabs and specially shaped beams, are initially shaped according to the requirement for effective air paths through the building, within the system of natural ventilation of indoor building spaces which should ensure air comfort for users. The shape of the slabs and beams allows a deeper penetration of daylight and thus greater light comfort. The design team used the mass of the exposed concrete shells, in conjunction with active and passive strategies for heating and cooling, in order to control the temperature changes in the indoor environment[194]. With sinusoidal profile of the floor structure the surface of the ceiling is maximised, in function of the more effective modification of interior space temperature. Cooling of indoor space during the summer is achieved by night ventilation. During the night, in addition to ventilation through windows, air is retracted directly into the floor structure channels, thus providing its additional cooling. Cooling the indoor space in summer is further improved by circulation of cold water through pipes embedded in the floor slab. During the winter, minimal amount of air needed for the ventilation of indoor spaces runs through floor structure channels. The air is heated this way, thus reducing the need for heating. During the winter, heated water runs through pipes embedded in the floor slabs (Harrison, 2006, 3).

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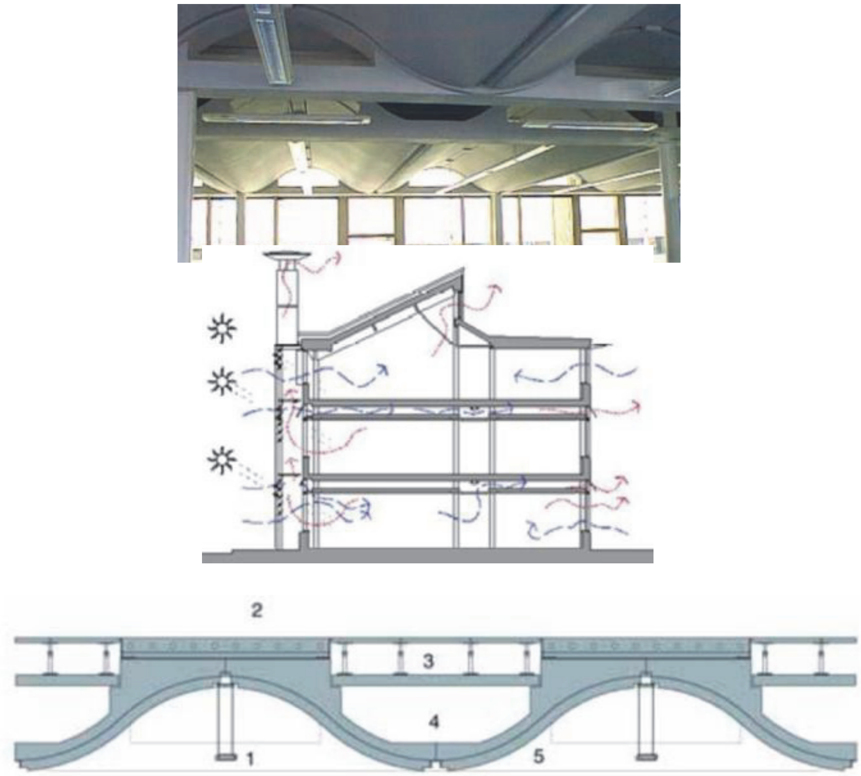
[194] New European directive changes the approach to evaluation of the energy performances of buildings, within which attention is given to the internal elements of the building, including the building structure, in addition to the building facade and the question of its tightness (Directive 2010/31/EU, 2010). The importance of passive techniques in context of heating and cooling is emphasized.



1- luminaires, 2 – layer with embedded system for heating and cooling, 3- raised floor, 4 –ventilation channel, 5- prefabricated vaulted concrete shell with a layer of concrete poured on site

Figure 4. Feilden Clegg Bradley Studios, building of BRE organisation, Garston, UK, 1996, interior, ventilation strategy illustrated in cross-section, cross-section through sinusoidal floor structure [Sources: Harrison, C. (2006). *The Environmental Building, The Building Research Establishment (BRE) Office Building*. Case Study; Fielden Clegg Architects]

The above examples of office buildings point to possibilities that open through application of the methodological concept of integrated, multidisciplinary, research-led design, which is based on thinking outside of the standard solutions. They also point to importance of this new approach to design, especially having in mind the attitude according to which architecture allows us to influence social change and respond positively to the environmental crisis (Feilden Clegg Bradley Studios, n.d.).

Conclusion

This paper points to new aspects of structural design within an integrated approach to building design, as well as to the complexity and plurality of answers in the area of structural engineering directed towards the achievement of the ecological quality of buildings. In view of the complex nature of the integrated design of buildings which assumes the study of problems of the system - building from the standpoint of different interrelated disciplines and research strategy that transcends disciplinary boundaries, it is necessary, above all, to explore new models of education of designers involved in the design of buildings, in order to prepare them for multidisciplinary optimization of design solutions based on multiple analysis of many aspects of ecological quality, in function of effective application of this methodological concept in design practice.

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