ECPPM 2014

eWork and eBusiness in Architecture, Engineering and Construction

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CRC Press
Taylor & Francis Group
A BALKEMA BOOK

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CRC Press/Balkema is an imprint of the Taylor & Francis Group, an informa business

Typeset by MPS Limited, Chennai, India
Printed and bound in Great Britain by CPI Group (UK) Ltd, Croydon, CR0 4YY.

Published by: CRC Press/Balkema
P.O. Box 11320, 2301 EH Leiden, The Netherlands
e-mail: Pub.NL@taylorandfrancis.com
www.crcpress.com – www.taylorandfrancis.com

ISBN: 978-1-138-02710-7 (Hbk)
ISBN: 978-1-315-73695-2 (eBook-PDF)

eWork and eBusiness in Architecture, Engineering and Construction – Martens, Mahdavi & Scherer (Eds)
© 2015 Taylor & Francis Group, London, ISBN 978-1-138-02710-7

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© 2015 Taylor & Francis Group, London, ISBN 978-1-138-02710-7

Hospital campus design related with EeB challenges

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ABSTRACT: Energy efficiency and reduction of carbon emission of Healthcare buildings and districts are a key factor for a sustainable community since their energy use and carbon emission are among the highest of all building types. A hospital – which is a part of a healthcare district – uses 2.5 times more energy than an office in average. In order to cope with the energy, financial, political, societal and environmental crises, all healthcare districts in Europe are urgently seeking to substantially reduce their energy consumption and carbon emission by 30–50%. For this purpose, the design phase of new building projects as well as building retrofitting projects is the crucial moment for integrating multi-scale EeB solutions. At present and in the near future, clients, architects, technical designers, contractors, and end-users really need a breakthrough in designing energy-efficiency buildings integrated in the healthcare districts. STREAMER is an actual EU FP7 industry-driven collaborative research project on Energy-efficient Buildings (EeB) with cases of mixed-use healthcare districts. The research aims at 50% reduction of the energy use and carbon emission of new and retrofitted buildings in healthcare districts by optimising Semantics-driven Design methodologies with interoperable tools for Geo and Building Information Modelling (Semantic BIM and GIS) to validate the energy performance during the design stage. This paper presents the methodology defined within STREAMER to approach the organizational, distribution and functional aspects of Healthcare buildings in relation to their energy-related features. The typological, technical, distribution and functional characteristics of each building type is investigated and connected to the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions in order to define a compatibility matrix between various building typologies and their energy-related features and characteristics.

1 INTRODUCTION

The subject of Energy-efficient Buildings (EeB) is among the most urgent research priorities in the European Union (EU). In order to achieve the broadest impact, EeB approach needs to resolve challenges at the neighbourhood level, instead of only focusing on improvements of individual buildings (Koch et al., 2012).

A mixed-use healthcare district is the best real example of a neighbourhood or a campus area with an integrated energy system, which consists of various buildings (i.e. hospitals and clinics; research and educational buildings; temporary care homes; rehabilitation and sport facilities; offices, retails, and logistic buildings; power and control facilities). In almost every European city, there is at least 1 healthcare district. Its energy use could exceed that of 20,000 dwellings; therefore, its impact on the city's energy performance is enormous. Energy efficiency and reduction of carbon emission of Healthcare buildings and districts are a key factor for a sustainable community since their energy use and carbon emission are among the highest of all building types. A hospital – which is a part of a healthcare district – uses 2.5 times more energy than an office in average. There are some 15,000 hospitals in the EU responsible for at least 5% of the annual EU's carbon emission (~250 million tonnes). Healthcare accounts for nearly 10% of EU's GDP, and hospitals can take up to 60% of a country's health expenditure (BPIE, 2011; EuHPN, 2010; HOPE, 2012).

In order to cope with the energy, financial, political, societal and environmental crises, all healthcare districts in Europe are urgently seeking to substantially reduce their energy consumption and carbon emission by 30–50%. Therefore, they are planning new energy-efficient building projects as well as energy-efficiency retrofitting of the existing buildings. At present and in the near future, clients, architects, technical designers, contractors, and end-users really need a breakthrough in designing energy-efficiency buildings integrated in the healthcare districts.

Therefore, the design phase of new building projects as well as building retrofitting projects is the crucial moment for integrating multi-scale EeB solutions, requiring thus a new methodology in order to tackle the mentioned set of problems.

In order to achieve real EeB optimization, a new design methodology is required in three key areas in order to optimize and integrate:

1) building envelope and space layout;
2) medical, MEP and HVAC systems; and
3) building and neighbourhood energy grids (Singer et al., 2009; Johnson Control, 2010; Nedin, 2011).

For a better optimization and integration, it is a priority that the new design methodology needs to encompass all scales and all lifecycle phases of the built environment. The building envelope and space layout require an optimization in terms of innovative services and building operations within the neighbourhood and surrounding areas.

Moreover the new design methodology needs to solve the most crucial design failure that cause transmission loss/efficiency loss between equipment and buildings during operation, especially when modern equipment is installed in existing building or energy systems. Therefore, the medical, MEP and HVAC systems require an optimization in terms of cost-effectiveness, taking into account the inter-dependencies between building components and energy systems.

Last but not least, optimal interaction between the building's and neighbourhood's energy systems in the district should be operated through smart grid, smart use of district heating/cooling and energy generation.

Therefore, considering the multiple dimensions and scale levels the design has to cover, the new methodology needs to rely on the on the interoperability between Building Information Modelling (BIM) and Geospatial Information Systems (GIS) (Przybyla, 2010; Sebastian et al, 2013).

2 EU FP7 STREAMER

STREAMER is an industry-driven collaborative research project on Energy-efficient Buildings with cases of mixed-use healthcare districts.

STREAMER aims at 50% reduction of the energy use and carbon emission of new and retrofitted buildings in healthcare districts by optimizing Semantics-driven Design methodologies with interoperable tools for Geo and Building Information Modeling (Semantic BIM and GIS) to validate the energy performance during the design stage.

The EU FP7 project STREAMER relies on a strategy for a 4-year large-scale integrating collaborative project that coherently integrates two main innovation areas: EeB technology innovation, on one side, dealing with the design optimisation based on the building and district typologies as well as the EeB technologies and measures. Semantic design innovation, on the other side, dealing with new methodologies and tools to help clients, design teams, building operators and occupants in an effective design collaboration.

Considering the innovation areas defined, the crucial topics addressed by the research project are:

- the priority for the design phase of new buildings as well as the retrofit design of existing buildings integrated in the neighbourhood energy systems;
- the empirical validation of sustainable EeB solutions and new design tools using 4 real projects from 4 different EU countries, involving the stakeholders and building occupants through a participatory design approach in the Integrated Project Delivery. The building, district and project types, sizes and scopes are representative to the EU typologies. All cases are large-scale hospitals in mixed-used healthcare districts including offices and other buildings: NHS, Rotherham, UK; Rijnstate Ziekenhuis, Arnhem, The Netherlands; AOUC, Firenze, Italy; AP-HP, Paris, France.
- the latest advancements in BIM, GIS, Semantic and Parametric modeling and optimization techniques leading to major innovations in precedence based design methods and tools, virtual construction methods, and design and knowledge management practices.
- the active participation of industrial partners and direct synergies with other EeB research, demonstration and standardization projects.

The STREAMER consortium consists of 20 partners, including design engineering and construction companies; healthcare institutions; research organizations; and public bodies. Together they form the critical mass to assure high research quality and to realize EU-wide impact. The consortium partners represent 5 key professional, R&D and public policy domains, which are the most essential in developing, optimizing, validating and implementing new design methodologies for EeB: Professional domain of EeB and environmental design and engineering, with special expertise in sustainable building and urban design. Professional domain of building construction, operation, maintenance, and energy management, with special expertise in user-oriented lifecycle design and management. R&D domain of building and neighbourhood energy systems, with special expertise in building MEP/HVAC, neighbourhood energy systems, and renewable energy sources. R&D domain of advanced ICT for design practices, with special expertise in BIM, GIS, Semantic Web, Parametric Models, Ontologies, PLM, and the associated open standards IFC and CityGML. Public policy and commercial strategy EeB, focusing on sustainable management and transformation of healthcare real estate property. The supplier's practical knowhow (regarding medical equipment, building components and materials) is covered by technical designers, contractors, and hospitals in the consortium, with comprehensive experience in a very broad range of solutions, products and components. STREAMER openly, objectively and critically covers all available products and components – independent of a single manufacturer.

Healthcare districts are the best example and the most relevant context of EeB as they require urgent need and high potential to achieve radical energy-efficiency improvements. In addition, their high degree of complexity really requires most advanced holistic design methods and tools. Moreover, investment in energy-efficiency renewal and extension of healthcare districts is at the highest priority in the EU. Each year across Europe, billions of euros are invested in newly designed and retrofitted building projects of healthcare facilities. Even with the recent economic downturn, the number of major projects in the healthcare sector remains at historical highs.

3 INADEQUACY OF EXISTING DESIGN METHODOLOGIES

The STREAMER research project takes the inadequacy of existing design methodologies to create holistic Energy-efficient Building (EeB) solutions as the basis for identification of the innovation strategies to be adopted. State-of-the-art EeB technologies are available, but they can only function optimally if well-integrated in the design of the building and district energy systems, taking into account the whole lifecycle's impacts.

The current problems in designing are:

- Lack of a holistic approach to tackle multi-dimensional complexity. The design of a healthcare district is not only about technology, but also about healthcare-related services and building operations. The existing design methodologies are incapable of integrating knowledge from architectural, MEP, HVAC and medical domains. Neither can they retrieve the tacit knowledge from the experts, building operators and occupants.
- Lack of a multi-dimensional optimization (components – buildings – neighbourhood). The huge potentials of EeB optimization through holistic and systemic designs are unexploited. The improvements are still fragmented and limited to individual systems. Trial-and-error approach causes many ad hoc changes during the construction stage. This hampers the optimal configuration of the solutions for whole lifecycle benefits as the design solutions cannot cope with rapidly changing healthcare policies, processes and technologies.
- 'Re-inventing the wheel'. Very often the design process begins with an ad hoc and time consuming exploration of the problems and the possible solutions. A lot of changes occur during the planning/design stage that takes many years before realization. The building operation experience is not well apprehended due to inadequate post-occupancy evaluation. Most design teams are dismissed soon after the design or project delivery. The lessons-learned from previous design projects are ill-documented and not re-used by new design teams, causing a lack of precedence-based approach to designing new energy-efficient buildings (Nauta et al., 2009).

4 STREAMER APPROACH TO TYPOLOGY

In its starting phase the research project is working on the identification of the design criteria related to organisational, distribution and functional aspects. The typological, technical, distribution and functional characteristics of each building type is investigated and connected to the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions. STREAMER is also anticipating buildings/districts that have progressed beyond the limits of the traditional typologies, for instance the 'all-in-one' general hospital, or the limits of decentralisation. The most frequent typologies of existing health building and their invariant factors are analysed and compared.

The aim is to provide a specific typology approach in relation to the energy related features in order to define the design criteria for the modelling through the tools. This will result in a compatibility matrix between various building typologies and their energy-related features and characteristics.

The study has been conducted so far analyzing the taxonomy of typologies that should generate common "EeB typology models", in order to provide basis for comparison between typologies in terms of energy-related features and characteristics. Since the design of hospital involves many stake-holders the approach should be multidisciplinary, i.e. both the technical and non-technical aspects and parameters have to be considered. In particular the analysis of taxonomy should focus on these EeB morphology and features: model-based classification of hospital organizations and processes in activity-and-time dimension; climatic regions, demography, building age; architectural layout; medical and building control systems; and energy systems and grid types. The data and parameter gathered from this analysis should be compatible with and suitable for the semantic typology models of existing buildings and districts. These models contain the morphology of buildings/districts and the multi-dimensional representation of the existing objects in BIM and GIS, as well as the knowledge of the building operation, functional problems, and the optimization opportunities. The models cover component, system, building, and neighbourhood levels. During designing, these semantic models will be used as a baseline design, adapted and enriched with as-built information the actual performance data, and the building operators' and occupants' knowledge.

Considering the aim of STREAMER, the level to be considered in pursuing this study the district level, being the focus of Healthcare District (HD) rather than on Healthcare Buildings.

Indeed, different perspectives from which the typology is defined could be found. The typologies in all the angles impact in a variety of importance the actual layout of the buildings and the complex as a whole.

First, the typology can be defined according to the organizational perspective. The organization of the delivery of care in the district and in its surroundings can be based on patient groups (e.g. neurology, oncology, sensory organs) or it can be based on process features (e.g. acute, elective, complex, standardized).

One way to approach typologies is to look at the way how the spaces are ordered and the circulation of the building complex is set up. It is about the form proportion of the complex as a whole. In a healthcare district there are form typologies known as Pavilion, Backbone, Podium and Tower, Central atrium and others.

Besides, from a user's perspective it is more relevant that the spaces can accommodate their activities and therefore it is a common way in hospitals to group spaces in function typologies such as nursing, outpatients' clinic, emergency, intensive care, operating complex, etc. Traditionally, these groups can be recognised as departments in a hospital.

Looking at the spatial organization and the functional aggregative configurations, four main different levels can be considered to build up a Healthcare District:

- Single Spaces (S), level 1: the single spaces or rooms are the lowest spatial entity that can be identified by specific functions and properties (operating rooms, patient rooms, nurse offices, etc). Spaces can be classified considering both their functional and their technical properties and characteristics, including their energy-related features.
- Functional Area (U), level 2: the functional area is a group of spaces generally related to homogeneity of interdependencies between functions and spaces (wards, operating theatre blocks, etc). As well as the spaces, the units can be classified considering both their functional and technical properties and characteristics, including their energy-related features.
- Building (B), level 3: the building is a system that includes several units. Relationships, interdependencies and functional aggregative configurations between the units depend on the characteristic of the building. Properties and energy-related features of the buildings may be related to their typological and technical characteristics, to their functions, to their form.
- District (D), level 4: the District consists of several buildings. For the project the district level is useful for aggregation to test the proposed solutions in relation to the key performance indicators.

In addition to these main levels, a further detailing could be operated including intermediate levels, which could provide a more appropriate definition of the spatial organization and the functional aggregative configurations when needed. The intermediate levels identified are departments, block and centres. A department corresponds to the medical fields which functional areas belong to. Not necessarily functional areas within the same departments are grouped in terms of spatial relationship and proximity. A block consists in buildings which, according to their functions, are grouped and required to be considered as one organism. A pole is a group of blocks or buildings, which, according to their purpose or the medical discipline operated in, are characterized by a strong dependency in terms of spatial relationship.

From this perspective, each building could be labeled according to a layer that establish the characteristics and requirements of it. In this sense, each typology requires standard application of construction and technical performances. A classification of building typology could be operated according to the Building differentiation research study results. The Layers Approach divides the hospital into four layers, characterized by specific functions and energy profile. The first layer, the *hot floor*, involves the high-tech, capital intensive functions that are specific for hospitals. Hot floors areas are Theatres, ICU, ITU, HDU, SCBU, critical care, isolation departments, Oncology, MRI, PET, etc., which require enhanced level of clinical activity, therefore high energy usage. General in-patient ward areas and day patient recovery areas are included in the *hotel* layer. It provides for energy target depending on climate, noise and cultural. The opportunity to reduce energy in this areas could be provided with good design solutions. *Office* layer includes outpatient departments, non-enhanced treatment rooms, consulting rooms, offices, waiting areas, etc. Low level of ventilation and thermal comfort are necessary, thus it requires low energy targets.

Finally, the *industry* layer includes Pharmacy, laundry, catering, mortuary, energy centre, workshops. This layer is based on Individual specific requirements dependent on the function and the used equipment of each area.

From the perspective of building typology the application of energy-related features could be implemented according to the function and characteristic of the space.

Considering these premises, in STREAMER two different approaches and methodologies could be applied to define the typologies.

From the designer view, a top-down "outside in" approach could be applied. It defines the typology basing on the building characteristics such as hot floor, hotel, office and industry, as well as the campus-building taxonomy (e.g. backbone, pavilion, central hall, etc.) and organizational categories (e.g. patient flows and logistics, standardized or complex and acute or elective patient care). From the engineers view, instead, a bottom-up "inside out" approach that defines the typology based on the technical properties of the rooms (e.g. the energy-related features of an operating room, a patient room, a nurse office,etc.) and building/MEP systems (e.g. the energy-related features of a sandwich-panel facade system, a certain type of ventilation system etc.) could be applied.

The "outside/in" approach starts from the definition of the main typologies of Healthcare District. Typologies, matrix of relationships, interdependencies and functional aggregative configurations are analysed starting progressively from the district level to the single spaces level.

This approach makes easier the definition of a method for functional classification. The progressive breakdown of each level, from the Districts to the Spaces, creates groups (particularly Units and Spaces) always homogeneous that allow a congruent and logical identification of the relationships as they are related to spaces and areas characterized by similar functions.

Consequently a clear and congruent scheme of relationships, interdependencies and functional aggregative configurations allows to analyse and identify the non-technical "energy features" (e.g. how much an incorrect location of a space or activity may be an indirect factor of an increase of energy consumption).

On the other hand, the definition of relationships, interdependencies and functional aggregative configurations could be suitable for the functional classification rather than for the energy-related features definition. Since the classification of Spaces and Units do not depend on energy-related features, this approach could implement Units including Spaces not homogeneous from an "energy-related point of view"; it means that it could be difficult to define EeB Performance Indicators able to be applied, with the same criteria, to the different levels of the typology models (District/Building/Units/Spaces).

The "inside/out" approach takes the definition of spaces and Units included in the Healthcare District as the starting point for the design methodology. It is based on the categorization of units depending on the relationships, interdependencies and functional aggregative configurations of Single Spaces in each Unit. In turn, the building typologies is categorized according to the schemes of relationships, interdependencies and functional aggregative configurations of Units in each building. The same method is applied up to the district level.

Starting from the technical properties of Spaces (single spaces, rooms, etc.) allows the definition of energy performance at the early stage of analysis, entailing a classification of spaces on the basis of energy-related features. Moreover, data on energy-related features of single spaces depend on a smaller number of parameters, which besides can be defined unambiguously. Therefore, the definition of energy-related features at Spaces level allow a better control of the energy efficiency indicators a the highest level (Building and District level).

On the other hand, the "inside/out" approach jeopardizes the definition of the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions, as the aggregations of Spaces with equal energy-related characteristics do not correspond to the Units of a Hospital Building. In addition, the technical properties

Figure 1. Categorization of spaces in the outside/in and inside/out approaches.

of the single spaces are not enough to define the energy-related characteristics at the Units, Building and District levels, therefore different parameters should be analysed at each level.

Outside/in and inside/out approaches generate two different design criteria for the classification of spaces. The outside/in approach could operate a classification of spaces in terms of The Layers Approach at Building and District level (level 3 and level 4).

This classification does not strictly depends on energy-related features, rather it depends on functions. The classification of spaces is not homogeneous from the "energy-related point of view", entailing a difficulty in the definition of EeB Performance Indicators to be applied to the different levels of the typology models (District/Building/Units/Spaces).

On the other hand the inside/out approach starts from the analysis of the energy characteristics and performances of the single rooms at level 1. Therefore, classifying the Spaces on their technical properties and energy-related features (e.g. Class of energy performance) could frustrate the definition of the functional aggregative configurations based on the proximity and the interdependencies between spaces and functions. Aggregation of Spaces having the same energy-related characteristics could be not corresponding to the Units of a Hospital Building.

STREAMER proposes a design methodology based on the combination of these top-down and bottom-up approach to typology, with the aim of adopting them in parallel.

A method for analysing and classifying the Spaces (level 1) compatible with the two approaches can be implemented crossing the criteria of classification (the one based on the functional categories of the Bouwcollege method and the one related to the energy features).

STREAMER is taking the Units (level 2) as the common denominator for the definition of the typology model. The Units, i.e. the groups of spaces characterized by their homogeneity and interdependencies between functions hosted (wards, operating theatre blocks, etc.), allow to approach the model both from

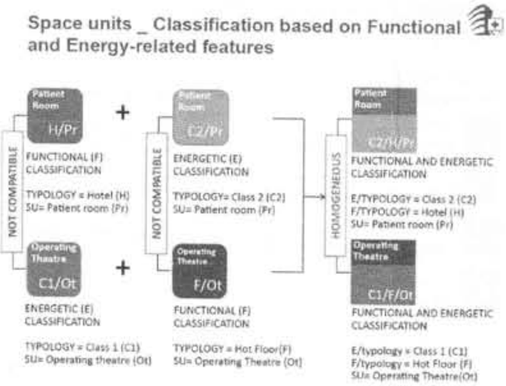

Figure 2. Categorization of Spaces according to the crossing methods.

the energy-related features and the functional point of view, as the EeB parameters are defined in the lower level of the single spaces (level 1), while the functional ones are defined in the upper level of Building and District (level 3 and level 4).

Therefore, the methodology follows these steps:

- Definition of a common breakdown of the Healthcare Districts and Hospital buildings in Units
- Identification of the Units with relation to The Layers Approach categories
- Breakdown of each Unit in single Spaces to be codified
- Implementation of the technical properties and energy-related features referred to the Spaces and the Units
- Definition of typologies based on the functional aggregative configurations of the Units in the Buildings and in the Districts.

5 CONCLUSION

Traditional design process is very time consuming and often inaccurate since it collects and converts the evidence and tacit knowledge regarding clinical protocols, patient's experience and expert's advice through consultations, focus groups, and quality circles. There are substantial difficulties in the design interpretation, communication and decision-making involving many different stakeholders (corporate directors, facility managers, medical specialists, building occupants, architects, engineers, contractors, etc.). In spite of a solid track-record in the field of healthcare building design, the existing approach remains subjective and full of uncertainties. It is difficult to comprehensively gain the knowledge of the energy use and energy reduction potentials per typology from the descriptions and specifications of the healthcare processes and equipment, which are widely available.

STREAMER design methodologies will turn around the existing approach – the starting point will be the validated solutions, not the unknowns. Decision-making will be based on inclusiveness in the design phase of both new and retrofitting projects, from the initial brief to the final design implementation.

The common parameters and the average energy use will be modelled according to the functional classification, space allocation and building configuration: *hot floor* (operation rooms, laboratories, etc.), *hotel* (patients room), *office* (workplaces), and *industry* (technical rooms, laundry rooms, supporting facilities, etc.).

At inter-building, neighbourhood and urban levels, the typological meta-design will be used in order to define the most effective strategy for energy-efficiency improvements depending on the factors, such as: environmental and urban scale; climate zones and geographical orientation; user's profile and demography. Healthcare districts will be classified based on the analysis of the European legislations, practices, and renewal programmes (high intensity care hospitals, primary care hospitals, houses for elderly, hospices, etc.).

ACKNOWLEDGEMENTS

The research leading to these results has received funding from the European Community's Seventh Framework Programme under Grant Agreement No. 608739 (Project STREAMER).

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