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TOWARDS SUSTAINABILITY THROUGH ENERGY EFFICIENT BUILDINGS‘ DESIGN: SEMANTIC LABELS[1]

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Abstract. When designing buildings, it is a challenge to take into account Energy Efficiency in the early design stage. This is especially difficult for hospital designs, because these buildings comprise many different room types and functions. This greatly increases the number of design directions available. Choices made early on in the design process have a large impact on the final performance of the building. However, the lack of detailing available in early designs makes it hard to evaluate them in terms of Key Performance Indicators. The Semantic Labels developed as part of the STREAMER project provide a way to address this problem, by allowing structured capture of the most relevant aspects of the Program of Requirements. Using this method, design rules can be applied to early building designs to detect and correct inconsistencies or suboptimal solutions. Also, using default values for label values, an early design can already be evaluated using simulation tools. The Semantic labels describe standard values for Construction (floor height and strength, accessibility), Hygiene class (from public spaces to operational theatres), Equipment (electric power requirements, safety), User profile (when the room is used), Comfort class (like daylight) and Access security (who can enter). Design rules may express conditions like the preferred spatial separation between rooms, or whether rooms should be placed at outer walls, but may also highlight incompatibilities in e.g. access requirements and user profiles.
The Early Design Configurator, also under development as part of the STREAMER project, uses the Semantic Labels to allow automatic conversion of a Programme of Requirements, into an initial Building Information Modeling (BIM) design proposal that respects the design rules.

Keywords: sustainability, energy efficiency; BIM; early design; semantic technology; design rules

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1. Introduction

Innovative solutions for sustainability is an area of scientific interest, which will maintain its urgency for the nearest decade, at least (e.g. Rezk et al. 2016; Šimelytė et al. 2016; Strielkowski et al. 2016; Razminienė et al. 2016). Energy efficiency in the built environment is an important part of this.

Designing complex buildings involves the integration of many stakeholder group perspectives, and requires optimization against a large number of Key Performance Indicators (KPIs). This is especially true for hospitals, where functions that include a wide range of different requirements have to be integrated into a single design solution. Energy efficiency is an important requirement: hospitals use on average 2.5 times more energy per square meter of gross floor area than a typical office building. This is due to the high rate of ventilation required as well as the round-the-clock nature of many healthcare processes (Health Building Note 00-10, 2013). Quality is another important area where designs have to meet or exceed KPIs. This group of KPIs generally includes requirements on the salutogenic performance of the built environment (Evidence Based Healthcare Design, or Healing Environment (Fotler et al. 2000), as well as operational quality requirements in terms of logistics and safety. A third group of KPIs relates to construction and operational costs.

Design decisions influence the values attained for these KPIs. It is generally recognised that decisions with the greatest impact on eventual building performance are taken in early phases of the design process (Guruz et al, 2014). In later design stages, design freedoms are increasingly constrained and it becomes more and more difficult to change key aspects of the design. It is therefore important to be able to assess the building's expected performance in terms of KPIs as soon as possible, and to be able to compare different design alternatives in those terms.

Where the configuration of rooms in a building influences its overall KPI performance, choices in building typology and building envelope technology impact on energy efficiency. Requirements for new build or refurbishment projects typically contain: the number of treatement rooms, offices, hotel rooms etcetera is however often specified in the early design. The starting point for creating early designs is generally a specification of the number of different types of rooms required, in the form of a Programme of Requirements. However, this type of document generally includes very limited performance data at room level.

A major problem in early design generation and assessment is that names assigned to spatial elements during the initial phase of a design, do not define either the properties or the performance values for that spatial element. Another problem is that creating different designs and comparing them in terms of energy efficiency, quality, and cost is very labour-intensive.

In this paper, we introduce a method that facilitates the generation and evaluation of different design alternatives in early stages. The work is based on the results of the FP7 STREAMER project, EU Grant 608739. The STREAMER project addresses the design of energy-efficient healthcare districts, addressing the design stage, especially the early design, where decisions are made with respect to topology and system choices, that have large effects on the resulting building performance. The approach in the project is to create different design alternatives that can be evaluated on the basis of KPIs for energy performance, cost and quality.

The names assigned to spatial elements (rooms) provide only very cursory information about the function of that spatial element (room) and the allowed or possible values for its properties. This can vary from country to country and even from region to region. Historical development of healthcare and hospitals, climate differences and differences in legislation all contribute to this. However, to use an automated early design process and to perform an evaluation, at least (some) properties of spatial elements, construction elements and systems need to have values assigned.

The proposed approach makes use of semantic labels. The basic idea is to assign labels to the room names or functions. These labels provide structured information on the types of properties and performance value associated with that room. Thus, allocation of allowed or default value ranges for properties can be done in an easy and structured way during the early design stage. Default values can be replaced with more detailed information as and when this becomes available during the design process, gradually enriching the design and allowing for more precise assessments of various KPIs. If the semantic labels of a spatial element in the design are known, the values assigned to its properties can easily be checked for compliance with the range of allowed values associated with this semantic label. Additionally, the semantic labels enable the definition of design rules that can be created to make tacit knowledge of various stakeholders (designers, users) explicit.

2. Earlier work

Performance expectations for healthcare buildings are changing rapidly. The development of new technologies often results in the need for new room types. Hybrid operating theatres are a case in point. Here, new imaging techniques have led to the development of new types of surgical procedure, predominantly minimally invasive techniques. These techniques lead to improved treatment outcomes, but also place new requirements on operating theatre equipment, which in turn lead to new demands on spatial and technical configuration. This example shows that it is virtually impossible to develop a functional and technical room definition on the basis of its name only.

Previous work has been done in the field on definition and classification of room names in a hospital setting. These studies have, however, been limited to one country each (e.g. Sweden, Great Britain (Health Building Note 00-10, 2013), and have tended to focus on developing definitions for the room names themselves. They have not addressed the functional requirements of a specific room type.

Several room classification systems are available (e.g. OmniClass (Likhitruangsilp et al. 2014, Abdirad et al. 2015, Knopp-Trendafilova et al. 2009) and UniClass (Ei-Diraby et al. 2005, Maradza et al. 2014, Dael et al. 2006)). These classification systems have been mainly developed for the benefit of the construction industry. They are useful for many purposes, from organizing project library materials, product literature, and project information, to providing classification structures for electronic databases. The classification systems are rich in product level, and are a way of standardising available information. It is possible to define spaces or rooms using the structure these systems provide. The OnmiClass system defined a number of spaces in hospitals. However, spaces and rooms need to be defined on the basis of room type (room name) and the classification systems do not allow for standardisation for all hospitals in all countries.

Besides classification systems focused on products, systems are also available that manage and facilitate the development of a programme of requirements at room level. Briefbuilder (Van Ree et al. 2006) and dRofus (dRofus) are examples of such systems. These systems support key activities in the design phase of a project such as planning and mapping of spaces and functions, as well as registration and verification of the requirements for each space.

These systems also support data exchange through the IFC (Industry Foundation Classes) standard, and provide a databases with pre-defined rooms. These pre-defined rooms can be adapted for a specific (hospital) project. However, to do so accurately a lot of detailed information is needed that is generally not yet available in the early design phase.

The Netherlands Board for Healtcare Institutions developed the so-called layers approach to hospital design (Netherlands Board for Healthcare Institutions, 2007). This approach was mainly focused on reducing the investment and operational cost of a hospital. The approach allocates functions to four different spatial environment typologies based on their functional and technical characteristics. These tyopologies are referred to as “layers”: 1) hot floor environment, 2) hotel environment, 3) office environment and 4) industry environment.. Important drivers in applying the layers approach are simplification of the design challenge, reduction of investment and operational costs, and improvement of use flexibility.

In its strictest typological application, each layer constitutes a separate building block with functional and technical specifications optimized for that layer (e.g. ceiling height, build quality, type of HVAC equipment, operatining hours and the expected life span of the building block). Nowadays, many architects in the Netherlands use this approach to cluster functions based on their building characteristics. In practical application assignment of functions to layers is done more pragmatically, taking into account logistical and medical operational requirements as well as typology. This approach is very suitable for defining the functional areas and departments, but has limitations for application to room level design specifications. Any room may have a different set of specifications according to the typological environment within which it is situated.

Based on the survey of earlier work outlined above, we concluded that there is no consistent system available to define rooms based on the requirements in a hospital setting that could be used during an automated early design process. We also concluded that the OmniClass and UniClass system, Briefbuilder and dRofus are too detailed and the layer approach too generic for use during the early design phase.

3. Semantic labels

Once the strategic decision to build or rebuild a hospital or part thereof, the initial input for a design process generally consists of an estimate of the specific floor area required, based on the expected volume of activities. For the latter, some high-level estimate is usually employed, based on the expected annual number of patients, the size of the catchment area, or another production related figure. At this very early stage, the number of different rooms and their sizes are not defined clearly. Only the logistical relations with the other parts of the hospital are specified. In the subsequent phase, room types and numbers, are defined without, however, information being specified on the properties needed for the rooms. The resulting initial layout may be inefficient, because a number of aspects contributing to a balanced design decision – such as energy considerations - are as yet unspecified. Pushing the design process forward on the basis of spatial relationsip requirements alone, often causes problems during the more detailed design when it transpires that these spatial relationship driven design choices negatively affect other (technical) properties.

The use of semantic labels can be a valuable tool in the early design phase, allowing designers to assign additional properties and values to spatial elements (room) with a view to developing a proposed clustering of spatial elements (rooms) on the basis of a more balanced set of performance requirements. Thus, for instance, functions could be clustered on the basis of their energy consumption and operational hours as well as on their spatial relationship requirements.

Additionally, the semantic labels can help evaluation of early designs. The labels provide allowable value ranges for properties against which early designs can be checked. This step can be repeated for each newly created design in any design phase to verify if designs are still valid and continue to comply with the fundamental requirements.

Thus, semantic labels are both helpful during the early design stage and continue to be useful as the design process progesses, as more properties and/or requirements can be added to the properties of a spatial elements (rooms), and/or default values and requirements defined in the semantic labels can be overwritten as more accurate or detailed information becomes available.

A central concept used in the STREAMER project is the healthcare district (HD). A HD describes the specific area where a hospital is (or will be) located, taking account of the hospital's interactions with other functions within this area. A HD provides the opportunity for a hospital to align its energy needs and consumption patterns with those of the surrounding area, for instance capitalizing on temporary peaks and troughs in energy demand. This helps create more energy efficient and sustainable healthcare districts. When considered in its full extent, the concept of semantic labels addresses all the elements that define a healthcare district (HD) at its various levels. It must be noted that although the labels convey semantics (on the expected use or requirement), the labels are not stored in an ontology structure.

Taking into account the spatial and functional organization of healthcare districts and the possible configurations of existing typologies, four different levels can be defined (De Hoogh et al. 2014):

a. District level. A district consists of several buildings. This level can be further partitioned or organized, depending on its administrative, functional or technical characteristics. Accordingly, the structure of a HD can include: compounds, centres, departments, etc.Application of semantic labels at this level is indirect only, that is by inference of the consequences at district levels of the application of labels at lower levels.
b. Building level. Properties and energy-related features of the buildings may be related to their typological and technical characteristics, to their functions or to their shape. At building level, the applicable labels include different scales on which the building can be scored. At this level, the semantic model includes only one object: the building.
c. Functional area level. A functional area is a group of spaces exhibiting strong interdependencies between functions and spaces (wards, operating theatre blocks, etc.). A functional area can be classified considering both its functional and technical properties and characteristics, including the energy-related features of the latter.
d. Room level. Rooms are the lowest level spatial entity that can be identified by specific functions and properties (e.g. 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.

For the building level, functional areas level and room level, the set of labels that can be applied depends on the consistency between the nature of the labels and the specific characteristics of the objects. For example an operating theatre belongs to the hot floor functional area. It must accordingly be situated in a building that complies with these requirements (see Tabel 2). This implies, high levels of cleanliness (e.g. hygiene meaurures and wipable surfaces), controlled access for staff, patients and visitors and a high performance level in terms of specific equipment. Since special air treatment equipment (HVAC) needs to be in place, specific requirements in terms of ceiling height apply. These requirements affect not only on the design of the room itself but also of the functional area and even the building in which it will be located.

Although the semantic labels at space unit's level are developed for rooms, these labels can also have values when applied to functional areas. The philosophy behind the application of semantic labels is identical at both levels. If no independent information regarding properties at the functional areas levels (office, hot floor, industry, hotel

(Netherlands Board for Heathcare Institutions 2007)) is available, the semantic labels for the space units can be used to infer these in the early design stage.

Table 1. Streamer labels.

Streamer labels	Description	Label categories
Hygienic Class	Level of cleanliness of the room e.g. toilet, office, treatment room, operating theatre.	H1 – H5
Access and Security	How the access of the room is controlled e.g. publicly accessible, only accessible for medical staff.	A1 – A5
User Profile	Period of the day the room will be used e.g. mon-Fr from 8:00 – 18:00, 24 * 7	U1 – U4
Equipment	Level of electric power needed e.g. level of an office, Special equipment and requirements regarding safety	EQ1 – EQ6
Comfort Class	Level of comfort in the room e.g. level of a corridor, level of a patient room	CT1 - CT8
Construction	Typology of the construction ea. floor height, floor strength	C1 – C6

Source: FP7 STREAMER project

The label categories specify parameters in three areas: 1) parameters required for the early design configurator, 2) parameters for the selection of a Mechanical, Electrical and Plumbing (MEP) system and 3) parameters for the selection of an Energy efficient Building (EeB) solution.

Table 2. Streamer labels for different layers.

Layer	Description	Streamer label categories
Hot floor	Accommodates the high-tech, capital intensive functions that are specific for hospitals e.g. operating theatres, isolation rooms, emergency	H4, A5, U4, EQ4, CT7, C3
Hotel	Comprises all functions for accommodation of patients e.g. patient rooms, general nursing, day nursing,	H3, A2, U4, EQ3, CT4, C1
Office	Accommodates the office facilities e.g. staff accommodation, accounting and management	H2, A4, U1, EQ2, CT3, C1
Industry	Accommodates all medical supporting and facilitating functions e.g. production pharmacy, laboratories, imaging centre	H5, A5, U3, EQ6, CT6, C4

Source: FP7 STREAMER project

Not all information explicit in the semantic labels and label levels at room (object) level is explicitly stated, but a lot of information can be derived from what is stated explicitly. Design rules, explained below, play an important role in enabling this inferral process to take place.

The structure of the labels itself is flexible. If deemed necessary for the purposes of a specific project, additional label categories can be introduced. Additional performance levels within label categories may also be defined . However, too many label categories and levels are hard to deal with. Designs should use a “minimal required set” approach to ensure manageability of semantic labels. New label categories and label levels should only be introduced if they add specific new (semantic) information to be used in the design process. To justify introduction of new categories and/or levels, this information should also be expected to lead to different choices based on related design rules.

4. Design rules

The purpose of design rules is to formalize the logical thinking employed when organizing rooms in a design proposal. They bring to light and structure tacit knowledge used by designers. Thus, design rules are captured rather than formulated.

The design rules concept used in the STREAMER project has been inspired by the packing approach developed for the early stage design of marine service vessels (Van Oers 2011). In this approach naval engineers created a methodology for the optimal placement of objects which needed to be transported by marine vessels. The descriptions of these objects were data technically enriched with metadata, which is used to support decision making on optimal placement of the objects inside these ships. The methodology allows for the use of metadata like size, weighing loads, and on-board presence periods in algorithms to generate and evaluate proposals for possible placement of these objects.In optimizing the early design of buildings for energy efficiency, the design rules methodology similarly not only creates and evaluates alternatives based on different outer shell layouts, but bases its design proposals also on different groupings of activities taking place in the rooms described in the Program of Requirements (PoR). For this purpose, the PoR is enriched with activity and building labels. On the basis of a PoR enriched in this fashion, design proposals can be generated.

An example: a design rule could be that all rooms with the activity label U1 (opening hours 08:00-17:00, weekdays) should be clustered together. Activity label U1 signifies weekday operating hours form 08:00-17:00 with weekend closure. Energy efficiency in a design following this design rule would profit from the possibility of switching off its energy systems outside operating hours. In terms of quality and safety, the design would profit from improved security and access management.

Other design rules could apply to spatially grouping rooms with similar access restriction profiles and/or placing constraints on the possibilities for spatial contiguity of rooms and areas with different access restriction profiles.

To show that design rules can apply to all three parameter areas, note for instance that high hygienic class levels, will prohibit (or at least strongly discourage) the use of radiators for heating, as these systems are not easily cleaned. To demonstrate that part of the semantic information is implicit, note that rooms with high specified hygienic class levels implicitly require easily cleanable wall and floor coverings even where these are not explicitly specified.

The generic form of a design rule is:

Object X having property A has relation R with Object Y having property B

Based on this template an infinite number of rules can be created based on a limited number of relationship types. The relationship types determine the generic relation between two objects. Examples of relationship types include for instance: clustering, embedding, minimum or maximum distance between one and the other, must be directly above or below another object, must be on the same storey, et cetera The properties in an early design are defined by the different label categories, table 1. The objects the design rules pertain to are the rooms, the outer boundary, the levels and later on the entrance. The properties of the objects that can be referred to are the labels, the name of the Functional Area or the Room Type. By changing the objects or the properties multiple design rules can be created within the same relationship type.

Inclusion of semantic labels in BIM

The room descriptions in the PoR are enriched with activity and building labels. The BIM exchangeable file format IFC also uses room objects. The semantic labels can easily be added to these IFC objects as specific property sets. Standard BIM modeling software can work with the IFC files, and in the STREAMER project a number of tools has been created that work specifically with the labels that are stored in this way within IFC files. The project will start standardization activities to promote the broader use of semantic labels.

The design rules are not hard-wired into the BIM model. They provide information about the compliance or otherwise of a spatial lay-out with the rules, but are not themselves part of that lay-out specification. Hence, the rules are not a part of the semantic model, but a way to store experts' semantic knowledge, and possibly also information on regulations. Semantic technologies, including domain ontologies, may additionally be used to analyse the designs for specific other aspects, but currently this is not yet elaborated.

Relation to MEP systems

The design rules methodology also helps select appropriate MEP solutions. Design rules specifying the constraints on possible MEP systems from certain label values are introduced into the software. Using this design rule, for each room a shortlist of permissible MEP systems is generated from the longlist of all available MEP systems. Currently, research is underway to ascertain whether MEP systems characteristics can also be summarized in a specific 'MEP label' system.

Selection of MEP solutions appropriate to an area, department, level or building wing, or even to a whole building is normally done by a specialist MEP advisor, but here too additional design rules that capture tacit designers' knowledge can be created.

5. Practical applications

Semantic labels and the programme of requirements (PoR)

The development of a PoR will precede any design activity on new build lay-outs and retrofitting solutions. The next step will be the definition of the building-related labels values as defined in the PoR. Once compatibility has been assessed at building level, the next steps are to look up the label values of the new functional areas and rooms proposed and compare these label values to that of the building. This requires that an initial estimate be available of the number of rooms, the functions assigned to each room and the floor area for each room. The semantic labels are assigned to the different rooms and functional areas based on their proposed functions.

An adapted version of the Briefbuilder software tool that allows PoR designers to attach semantic labels is available on the market. The output of this tool can be processed by the Early Design Configurator.

Early Design Configurator (EDC)

The Early Design Configurator (EDC) is a tool that is being developed as part of the STREAMER project. It uses genetic programming methodologies for generating multiple design proposals that progressively satisfy the PoR and design rules. Besides the PoR and design rules, the EDC uses the outer shell layout of the building, and the activity and building labels to generate its design alternatives.

Different design rules may be partially or wholly incompatible or even contradictory. In recognition of this, the EDC methodology is probabilistic: it will apply design rules in such a way as to maximise the likelihood of a layout alternative satisfying a certain rule. This means that solutions generated through the EDC will often not satisfy all rules, and/or satisfy some rules only partially or sub-optimally. Not all rules are equally important, nor do all rules follow the same format. For some, satisfying the rule will be a binary Yes/No assessment, while other rules will employ a gradual scale. To improve user control over design compliance with crucial rules, the EDC allows users to assign relative priorities to different design rules. The higher a priority assigned to a design rule, the more the alternatives generated by the EDC will be geared towards satisfying that particular rule. Different design proposals can be created by changing design rules, or by applying different priority weights to design rules.

During the early design stage, i.e. before proceeding to more detailed definition of technical and functional solutions, an important question to be addressed is whether a proposed or available building (structure) can accommodate certain crucial functional areas. This question is especially relevant when a hospital is considering to retrofit an existing building: in such cases a basic assessment of a building's utility for different healthcare functions is essential.

The relationships that determine the spatial layout are often complex and may be contradictory to each other. For EeB design, the EDC approach is to favour alternatives that include those relationships that, on the basis of the information available in the early design phase, are most likely to improve energy efficiency. The EDC will, for example, favour designs which tend to cluster rooms with the same operational temperature range requirements, as reducing energy flows between rooms reduces overall energy consumption.

Design validation

The EDC output is designed to support manual comparision of alternatives by experts. Its main supportive feature in this respect is conditional colourisation of rooms on the basis of the values in the enriched data linked to the room objects. For example it is possible to show all the 'U' labels to visualize all the rooms with the same U label value. Such a visualization helps in identifying inconsistencies or serious flaws in a design alternative. Multiple labels can be visualized concurrently, using different colour spectra.

Design alternatives may be validated through a design validator. This separate module is under development for this, as the EDC output proper is insufficient for this purpose: although the EDC provides a "satisfaction score" for each layout generated, this is based solely on the placement of rooms, the width/depth ratios of the rooms, floor areas of the rooms and the overall degree of satisfaction of design rules. This does not provide information on which specific design rules are fulfilled or violated in the spatial layout generated. The validation tool will use the same rules as used for input in the EDC, and will allow validation of the fulfillment of each individual design rule.

The manual input from the designer is still required to apply the relations of the PoR, the building regulations and his or her own interpretation. This concept will be "scraped and sanded" into a layout which is more and more in line with the regulations, wishes and budgets, and of course the PoR. Manually updated designs can be validated, evaluated and visualized again.

Design evaluation

When a design has been validated (checked against design rules and Program of Requirements), it needs to be evaluated in terms of KPI scores. The advantage of semantic labels in doing this is that default values for parameters can be derived, which can be used as input for simulation tools modelling KPI performance. The STREAMER project focusses on simulation of energy performance, but other need to be assessed as well; cost KPIs (Life Cycle Costing) and quality KPIs are estimated during design evaluation.

Design process

Figure 1 shows the process of the early design with the Streamer semantic labels methodology.

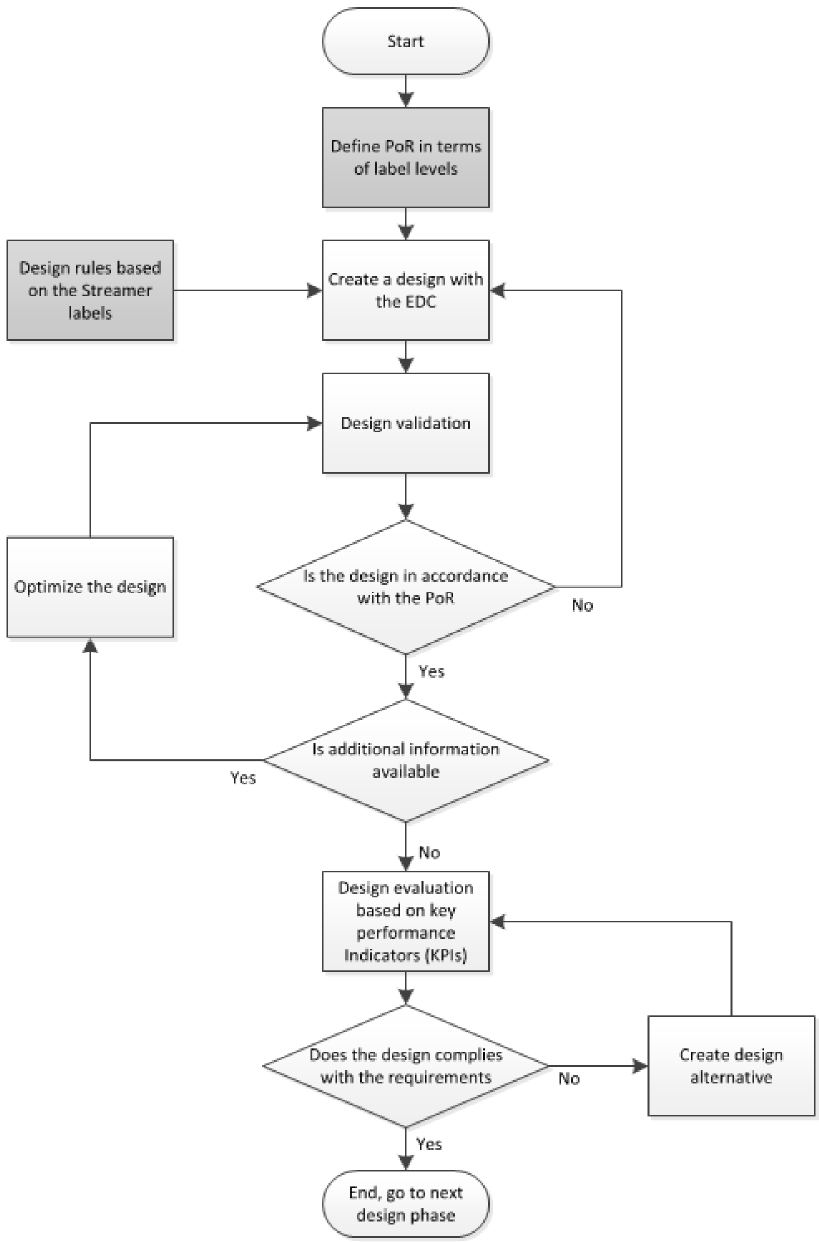

Figure 1. Process scheme of the early design process with the semantic labels.

Assessment of designs by the authorities often takes place at a very late stage in the design process. This may lead to problems, for instance when non-compliance with laws and building regulations comes to light and necessitates major design changes, often leading to substantial cost increases and delays. Use of the tools in development in the STREAMER project addresses this problem both prospectively and retrospectively. Prospectively, our methodologies allow for more accurate early prediction of performance; retrospectivelythey make it easier to go back to previous design stages, to reconsider the other compatible solutions and to find the most convenient way of dealing with the changes requested.

Semantic labels and refurbishment

For a variety of reasons refurbishment approaches are often selected over new build options. The semantic labels approach is very suitable for refurbishmen projects. Naturally, the existing configuration needs to be assessed and the appropriate labels need to be identified for each room. If the labels of a room are known it can be checked if this spatial unit (room) could be used for other functions, provided the requirements for this new function are known as well. This can help designers during the retrofitting of a building or part of a building to find out quickly if spatial elements can be used for other functions as well. Compatibilities and conflicts within the labels (existing ones vs new ones) will define feasibility and costs of the retrofitting interventions.

Testing the approach

Currently the first step (attaching semantic labels to rooms as defined in the Program of Requirements) has been validated in practice. This test has led to some refinements in the label values. It turned out that the labels could be attached to rooms in a consistent way. Also, it appeared that an 80/20 rule applied: the majority of the rooms could be assigned by using a limited combination of label values. The steps following this first one (using the Early Design Configurator, the validation and evaluation) are planned.

6. Conclusions, discussion and future work

Semantic labels have already proven to be a promising approach in early design phases of complex buildings like hospitals. They provide the design team with structured information that can easily be related to the PoR, and that can be extended and revised as the design process continues. The labels enable the capture and application of design rules that formally structure implicit designer knowledge, and allows the creation and evaluation of different design alternatives. Semantic labels play an important role in identifying problems and optimization opportunities. They provide a common language for different groups of stakeholders to communicate abour properties of functional areas and individual rooms in a common and unambiguous way.

In the STREAMER project, the semantic label approach has developed into a central concept for addressing energy efficient building design issues. On the basis of the central concept, a number of tools around the concept is being created to leverage the methodology. These tools have been created and initial tests have been performed, but they are currently at the Proof of Princple stage and need to be elaborated further.

While the semantic labels show promising results in supporting the early design phase for Energy efficient Building design, there is a number of topics that needs to be addressed if the methodology is to be applied more broadly.

Future research should address the problem of how to identify which sets of default values are appropriate when applying the semantic labels in different countries. Climate conditions, regulatory environments and construction practices vary considerably from country to country, and it is extremely unlikely that one single set of default values will be able to capture all this variety.

Another topic for future research is the scope for expansion of application domains for design rules that use the semantic labels as a basis. While it has become apparent that important parts of architects' tacit knowledge can be expressed using design rules, it is still an unresolved question what additional design rules are needed to reflect the state of the art in EeB design. One research direction in this area is the inclusion of MEP design in the approach. In principle this should yield good possibilities for further energy efficiency gains because the selection of MEP systems has a large impact on energy performance. The use of semantic technology may provide additional means to analyse a design in early stages.

References

Abdirad, H., Lin, K.-Y., 2015, Advancing in object-based landscape information modeling: Challenges and future needs, Congress on Computing in Civil Engineering, Proceedings Volume 2015-January, Issue January, 2015, Pages 548-555 http://dx.doi.org/10.1061/9780784479247

Building Differentiation of Hospitals - Layers approach, 2007, Netherlands Board for Healthcare Institutions, ISBN/EAN 978-90-8517-095-2

Dael, O., Keshet, J., Shalev-Shwartz, S., Singer, Y., 2006, Online passive-aggressive algorithms, Journal of Machine Learning Research Volume 7, March 2006, Pages 551-585

De Hoogh, S., Di Giulio, R. Quentin, C., Turillazzi, B., and Sebastian, R. "Hospital Campus Design Related with EeB Challenges", in: eWork and eBusiness in Architecture, Engineering and Construction, ECPPM 2014, Edited by Ardeshir Mahdavi, Bob Martens, and Raimar Scherer, CRC Press 2014, Pages 907–913, Print ISBN: 978-1-138-02710-7, eBook ISBN: 978-1-315-73695-2 http://dx.doi.org/10.1201/b17396-144. dRofus http://www.drofus.no/en/, accessed June 13th 2016

El-Diraby, T.A., Lima, C., Feis, B., 2005, Domain taxonomy for construction concepts: Toward a formal ontology for construction knowledge, Journal of Computing in Civil Engineering Volume 19, Issue 4, October 2005, Pages 394-406 http://dx.doi.org/ 10.1061/(ASCE)0887-3801(2005)19%3A4(394)

Fottler, M.D., Ford, R.C., Roberts, V., Ford, E.W., Creating a healing environment: The importance of the service setting in the new consumer-oriented healthcare system, (2000) Journal of Healthcare Management, 45 (2), pp. 91-107

Guruz, R.; Scherer, R. 2014. Sustainable energy entrepreneurship through architectural design: a key point controlled method, Entrepreneurship and Sustainability Issues 2(2): 60–73. DOI: http://dx.doi.org/10.9770/jesi.2014.2.2(2)

Health Building Note 00-10, Part A: Flooring and for Scotland and Wales the Health Technical Memorandum 61 (2013), Building Component Series Flooring

Knopp-Trendafilova, A., Suomi, J., Tauriainen, M., 2009, Link between a structural model of buildings and classification systems in construction, VTT Symposium (Valtion Teknillinen Tutkimuskeskus) Issue 259, 2009, Pages 285-301

Likhitruangsilp V., Ioannou, P.G., Leeladejkul, S., 2014, Mapping work process and information exchange of construction entities for BIM implementation: Case study of an academic institute, *Computing in Civil and Building Engineering - Proceedings of the 2014 International Conference on Computing in Civil and Building Engineering 2014*, Pages 2224-2231, http://dx.doi.org/10.1061/9780784413616.276

Maradza, E., Whyte, J., Larsen, G.D., 2014, Interactive learning in UK construction practice: Examining the role of BIM process standards, Proceedings 30th Annual Association of Researchers in Construction Management Conference, ARCOM 2014, Pages 613-622

RES Hospitals, http://www.res-hospitals.eu , accessed June 13th 2016

Van Ree, H., Van Meel, J., Lohman, F., 2006, Better briefing for better buildings: An innovative modelling tool for specifications management, COBRA 2006 - Proceedings of the Annual Research Conference of the Royal Institution of Chartered Surveyors 2006, Page 13

Van Oers, B. J. (2011). A packing approach for the early stage design of service vessels. TU Delft, Delft University of Technology. ISBN 978-90-6562-283-9

Razminienė, K.; Tvaronavičienė, M.; Zemlickienė, V. 2016. Evaluation of cluster efficiency tool, Terra Economicus 14(3): 101-111. http://te.sfedu.ru/en/journals/2016/133-no-3/2351-evaluation-of-cluster-efficiency-measurement-tool.html

Rezk, M. A.; Ibrahim, H. H.; Radwan, A.; Sakr, M. M.; Tvaronavičienė, M.; Piccinetti, L. 2016. Innovation magnitude of manufacturing industry in Egypt with particular focus on SMEs, Entrepreneurship and Sustainability Issues 3(4): 306-318. http://dx.doi.org/10.9770/jesi.2016.3.4(1)

Šimelytė, A.; Ševčenko, G.; El Amrani El Idrissi, N.; Monni, S. 2016. Promotion of renewable energy in Morocco, Entrepreneurship and Sustainability Issues 3(4) http://dx.doi.org/10.9770/jesi.2016.3.4(2)

Strielkowski, W.; Lisin, E.; Tvaronavičienė, M. 2016. Towards energy security: sustainable development of electrical energy storage, Journal of Security and Sustainability Issues 6(2): 235-244. http://dx.doi.org/10.9770/jssi.2016.6.2(4)

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