The Relationship between Requirements Subjectivity and Semantics for Healthcare Design Support Systems

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Abstract. Subjectivity exists in requirements described in the healthcare regulatory framework. This is mainly due to the nature of regulatory requirements and the uniqueness of the design process. Past research identified that subjectivity in regulations is a key issue for automated code and rule checking. The aim of this paper is to discuss how requirements subjectivity could be addressed within building models through semantic enrichment, within the context of automated rule and code compliance checking. The paper presents preliminary findings of a research that follows the Design Science Research approach, framed within the UK healthcare design context. Findings suggest that part of the requirements subjectivity exists due to the implicit relationships between the elements of the healthcare built environment, which also include healthcare services. In order to enable automation, implicit relationships from the regulatory framework should be represented in building models – which could potentially be done through semantic enrichment. The paper discusses some complementarity between relationships identified in regulatory requirements and semantic enrichment operators. Moreover, findings indicate that incorporating semantic relationships in building models can be a promising way to deal with requirements subjectivity, rather than eliminating subjective expressions from regulations.

Keywords: Subjectivity; Semantics; Healthcare Regulations; Automated Code/Rule Checking.

1 Introduction

The healthcare regulatory framework includes requirements originating from specific medical needs and technologies, which should represent the needs of all stakeholders involved or influenced by healthcare projects [1]. It is known that healthcare building requirements evolve over time [2], which creates challenges for designers. With the use of digital tools in healthcare design, the iteration between designing solutions and verifying their compliance to the associated regulatory framework can be automated and as such creating opportunities for time and cost savings, in contrast to manual checking approaches. This is influenced by the different typologies and characteristics of regulatory requirements [3], represented by either abstract or concrete information [4], which might be implicit or explicit within requirements definition. Thus, regulatory requirements can, in some cases, be subjective and open to different interpretations [5]. This is because this type of requirement is traditionally created and included into documents and standards to be read, interpreted and used by people, through the use of natural language expressions [5]. This introduces challenges to incorporate information from these requirements into object-oriented and automated interfaces, such as Building Information Modelling (BIM).

The use of automated rule checking for the purpose of addressing building compliance has been extensively explored in research [6,7]. Despite these advancements, there is still a gap regarding its use in practice, related to the subjectivity in regulatory requirements and how these are used across the design process [5,8]. Thus, the aim of this paper is to discuss how healthcare regulatory requirements subjectivity could be addressed within building models through the use of semantic enrichment. The discussion provides insight on how implicit information, mostly emerging from subjective requirements, could be verified in the design process through automated approaches.

2 Information in Regulations and Subjectivity

Regulations are created, interpreted and used by people [5]. The way regulations are developed is pointed as one of the reasons for the difficulties observed while using the documents later in practice [9]. This is because creating regulations can be a cumbersome process, due to many iterations performed by multiple people during long periods of time, as well as changes in requirements [9]. As a result, regulations include an extensive and generally complex set of requirements, consisting fundamentally of interdependent elements [9,10].

Furthermore, there are other factors that contribute to requirements complexity, such as: (i) language structure from requirements; (ii) domain knowledge embedded in the regulations; (iii) logic elements from requirements; and (iv) human knowledge associated to interpreting regulations [9]. In fact, these factors are responsible for an important characteristic of such requirements: they tend to be indeterminate by nature, due to the open-textural elements that are used to define the sentences [11]. This typically implies in vagueness and ambiguity, stemming from the diverse senses information might assume within this context [5]. Indeterminacy also might be increased due to implicit local understandings, relationships and unwritten knowledge by experts involved in the development of regulatory documents [9,10]. Therefore, subjectivity is often embedded within requirements through open-texts, which hardly can be automated because they are context-dependent and require human judgment to determine compliance [11,12]. This process demands a significant level of human abstraction so requirements can be properly identified and considered in design [13].

Challenges related to requirements subjectivity are currently discussed, even though these have been identified long ago by e.g. Fenves et al. (1995) [11]. Recent research has explored structuring and translating regulatory documents for use in computational interpretation [6]. Despite these efforts, the importance of understanding and interpreting regulatory information is still under researched [9]. According to Macit İlal and Günaydın [10], identifying the nature of regulations and the hierarchical information associated to its requirements is fundamental to enable a degree of automation in the design process. Solihin and Eastman [9] also point that the analysis of regulatory requirements still needs be done by humans because at the moment, only they are able to understand the implicit content of regulations. This process could be facilitated by using mechanisms of classification, which enable grouping elements according to different classes, i.e. distinguishing them according to their characteristics, such as a requirements taxonomy [3,14]. Additionally, by classifying the content of regulations it might be also possible to identify different relationships between requirements [10], which can support a better understanding of the degree of embedded subjectivity [3].

3 Semantic Enrichment of Building Models

Semantic enrichment is defined as an automated or semi-automated process which allows incorporating meaningful information to building models, related to its objects and their relationships, through the use of domain-specific rulesets [15,16]. This information, in turn, can potentially enhance the building model by facilitating its use for specific issues, such as code compliance checking [17,18]. Relationships among objects in the semantic enrichment process are incorporated according to three steps, defined as tiers [15]. Tier 1 relates to the definition of inference rule sets by the users; tier 2 relates to libraries of concepts and operators used to compile rules; while tier 3 relates to how operators are implemented by programmers [15].

Enhancing building models through semantic enrichment to facilitate code compliance checking emerged due to the lack of practical solutions which are applicable to different types of requirements [18]. This was mostly due to issues with existing modelling approaches, stemming from the need to include additional information which was originally missing or inaccurate, so building models could be used for multiple types of analysis and iterations[17]. The need for semantic enrichment is also explained due to the need to turn implicit semantics and relationships into explicit information by enhancing data from Industry Foundation Classes (IFC) files [18].

Bloch and Sacks [17] reviewed existing applications focused on building code compliance and identified that one of the main difficulties involved in this process emerges due to the lack of sufficient information embedded within building models. In this context, explicitly defined parameters, topological structures and connections among objects [18] are often missing or inaccurate, which is identified when building models are analysed. Another factor that increases the importance of semantic enrichment is the limitations of current checking tools.

The use of automated approaches for code compliance is often limited to quantitative and objective requirements, i.e. numerical constraints or mathematical equations [3,6,18–20]. The use of semantic enrichment is an opportunity to enhance building models by including other types of relevant information, so they can be used for different purposes and analysis – acknowledging that automated code checking can be one of the main uses of such approach.

4 Research Method

This paper reports preliminary findings of an ongoing research project investigating opportunities for improving the healthcare design by using design support systems. The research adopts the Design Science Research approach (DSR), which is relevant for solving problems that have both practical and theoretical relevance [21]. The outputs of DSR are artefacts aimed to solve practical problems, while their development, implementation and evaluation enable theoretical insights [21,22]. By using DSR, the research problem is typically understood at the same time the artefact is designed [23]. This process is fundamentally done through iterative cycles of analysis, understanding, development and refinement. It is important to highlight that the findings presented in this paper do not include final artefact, but are part of the initial stages of the research, and hence involve mainly a better understanding the research problem.

A literature review was developed to understand subjectivity embedded in regulatory requirements and how it could be addressed in the healthcare design process, focusing on automated code checking. The discussions presented in this paper are also partially informed by empirical data from two studies: (i) one in collaboration with an institution responsible for Primary Healthcare buildings across the UK; and (ii) a retrospective study developed with a University Hospital in Porto Alegre, Brazil. The sources of evidence are: (i) analysis of regulations, which supported understanding and identifying requirements characteristics and subjectivity; and (ii) meetings and interviews with designers and other stakeholders, which provided inputs related to how the regulatory framework is used in practice and how subjectivity affects the development of healthcare projects.

5 Key Findings

From the analysis of the information within healthcare regulations, different types of requirements were identified. One key element responsible for such outcome was identified i.e. the degree of abstraction involved in the requirement. Some requirements are objective while others remain subjective. Within this context, much of the identified subjectivity is due to implicit relationships between elements of the healthcare built environment, which also include health services. Examples of these requirements are presented below, through extracts from both Brazilian (RDC 50) and British (HBN 11-01 and HBN 00-03) healthcare regulations.

In the below, the terms in bold are examples where implicit relationships were identified, e.g. arranged with a direct relationship to. These relationships might often manifest across different sets of regulations within the healthcare design context, since requirements tend to repeat their structure and typology [3]. These relationships cannot be included in building models using traditional modelling approaches.

1. *Specific installation systems (e.g. hot water, medical gases and alarming**) are needed within** the spaces of healthcare facilities, depending on the use of each individual space* (followed by a set of tables). (RDC 50)
2. *The bed-area in the physiotherapy diagnostics and therapy rooms **must be equal or superior to** 2.4m².* (RDC 50)
3. *Consulting/examination suites **should be arranged possibly with an adjacent** suite to enable patients to be referred on from their initial consultation to a specialist consulting/examination suite or treatment suite*. (HBN 11-01)
4. *Generally, community records **should be stored within or adjacent to** the open-plan admin area. GP records and records on loan from the acute sector **should be stored close to** the main reception desk or appropriate control point.* (HBN 11-01)
5. *Consulting/examination suites should be **arranged with a direct relationship to** the main waiting area, and possibly an **adjacent** suite to enable patients to be referred on from their initial consultation to a specialist consulting/examination suite or treatment suite.* (HBN 11-01)
6. *The dental treatment room **will contain** specialist built-in cabinetry, a reclining chair, ceiling mounted lamp, wall-mounted inter-oral periapical X-ray machine and a console **adjacent to** the chair supplying dental gases.* (HBN 11-01)
7. *Seated recovery area **should contain** a separate zone for clinical hand-washing.* (HBN 00-03)
8. *The space required for the en-suite shower room **includes** not only the enclosed area but also the temporary manoeuvring space for assisting a patient on both sides of the WC **which overlaps** the bed space.* (HBN 00-03)

One of the promising possibilities of incorporating implicit information from healthcare regulations to building models is associated to semantic enrichment. Implicit relationships observed in this context occur due to the way information is embedded into regulatory requirements. In order to enhance building models semantically, operators related to concepts, properties, relationships, geometry, spatial orientation, spatial topology and auxiliary information are used [15]. This is a very important step of the semantic enrichment process because by doing so, implicit information can be incorporated as explicit parameters and data within building models, so it can be further utilized for different purposes.

The use of semantic enrichment appears to be a fruitful opportunity to support addressing the issue of automated rule checking for code compliance. Within the scope of healthcare regulations, particular types of information are observed due to the specific characteristics of this context [3]. The *Spatial Topology operators*, which are one of the specific tier-2 elements defined by Belsky et al. [15], appear to be especially relevant in relation to the healthcare regulatory framework. Table 1 is based on the original definition of the Spatial Topology operators [15] and how each of the examples of regulatory requirements described above might be related to them.

Table 1 suggests that by better exploring the spatial topology operators it might be possible to enable an easier automated rule checking approach. This is due to the correlation identified between these operators and specific types of requirements observed in the healthcare regulatory framework. This fact indicates an existing complementarity between the relationships identified in regulatory requirements and semantic enrichment operators.

Table 1. Relationship between spatial topology operators and requirements, focusing on semantic enrichment

Spatial Topology Operators	Description according to Belsky et al. [15]	Example from Regulatory Requirements (highlighted element)
Adjacency	At least two objects which have a common face or are inserted within a given tolerance distant from each other.	[3] *[space]* ***should be arranged possibly with an adjacent*** *[space];* [4] *[space]* ***should be stored within or adjacent to*** *[space];* [5] *[space]* ***adjacent*** *[space];* [6] *[object]* ***adjacent to*** *[object];*
Contact	Adjacent objects that are in contact, meaning their tolerance distance equals to zero.	[4] *[space]* ***should be stored within or adjacent to*** *[space];* [4] *[space]* ***should be stored close to*** *[space];* [5] *[space]* ***arranged with a direct relationship*** *[space];*
Containment	One object is utterly contained within another spatial object.	[1] *[objects]* ***are needed within*** *[space];* [4] *[space]* ***should be stored within or adjacent to*** *[space];* [6] *[space]* ***will contain*** *[object];* [7] *[space]* ***should contain*** *[space] [to service];* *[8] [space]* ***includes*** *[space];*
Overlapping	At least two objects have an overlapping volume	*[8] [space]* ***which overlaps*** *[space];*
Volumetric operators	A relative volume of space that is occupied by one or multiple objects.	[2] *[space]* ***must be equal or superior to*** *[dimension];*

- Requirements related to the operators **adjacency** and **contact** are often identified in the healthcare regulations. These are associated to the spatial configuration of buildings and represent information considered at early design stages, e.g. schedule of accommodation, briefing and basic layout and flow definition.
- The operator **containment** can be associated to a type of requirement frequently observed within the healthcare design context. It is associated to the presence of

specific systems and objects such as furniture and medical equipment within rooms, according to their use.

- The **volumetric** operator is related to requirements that describe needed object spatial boundaries and/or projection spaces, e.g. minimum spaces in front and on the sides of beds. The **overlapping** operator is observed in spatial requirements and can be associated to volumetric operators e.g. bed space.

Typically, dealing with requirements subjectivity within current approaches for automated code checking requires human involvement. Building codes and regulations are typically translated into a coded fashion after arduous efforts from human experts, what might involve individual biases and potential misunderstandings. This generally results in partial interpretations due to the fact that subjective information is converted into objective and quantifiable sentences before rule creation. The issue involved in this inductive reasoning is related to a potential harmful approach to the automated rule checking context. By doing so, individual understandings might be generalised, hindering the more creative and idiosyncratic character of the architectural design process. Such issue becomes especially relevant while considering the context of healthcare design and the importance these facilities have on health outcomes.

6 Final Remarks

This paper explored how semantic enrichment can support addressing subjectivity from regulatory requirements for automated rule and code compliance checking. Key findings are related to identifying that implicit information within the healthcare regulatory framework is one of the main sources of subjectivity.

By analysing eight examples extracted from Brazilian and British healthcare design regulations, important characteristics of requirements have been identified. Moreover, some requirements, in fact, match the definition of some semantic enrichment operators, such as adjacency, contact, containment and volume. Therefore, semantic enrichment could potentially be a suitable way of addressing these implicit relationships in BIM. This could support automated design compliance checking.

Additionally, by exploring the relationship between regulatory requirements and semantic enrichment operators, it was possible to discuss how this approach might support the use of subjective information across healthcare design. By turning implicit relationships into explicit data in building models through semantic enrichment, subjectivity is not completely eliminated from the process, whereas no individual biases are introduced in the checking process. This approach might prove to be beneficial to the healthcare design context and it consists of an important shift. While the beneficial aspect of subjectivity would remain, allowing the creative and idiosyncratic reasoning from human designers, the negative aspect of subjectivity would be eliminated. By using semantic enrichment, subjective requirements would not have to be transformed into objective sentences, what could occur through potential biased processes.

The findings presented in this paper are limited as it is based on an exploratory literature analysis and partially informed by empirical data. There is a need to further test the relationships identified and verify in practice if the assumption presented on Table

1 is valid. Further testing should also explore whether semantic enrichment is, in fact, capable of dealing with subjectivity in a more efficient way, by taking into consideration human inputs through hybrid solutions, instead of eliminating subjective expressions from the regulations. Future research should also explore different types of semantic enrichment operators aiming to identify new relationships between those and different types of requirements. Finally, although semantic enrichment is not novel, it could potentially support the future adoption of automated rule checking in healthcare design by also considering subjective requirements.

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