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AN ONTOLOGICAL APPROACH FOR A RECOMMENDATION SYSTEM OF A REQUIREMENT TOOL: THE CASE OF A NATIONAL STANDARD FRAMEWORK FOR HOSPITAL DESIGN

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Abstract

There is a need to facilitate cross-project learning in hospital projects. To do this, the Swedish national healthcare project frame and database, PTS (Program for Technical Standard), has been created to provide a framework for Swedish regions when conducting hospital projects. However, the fragmented information currently available and overall structure makes it difficult to embed knowledge and requirements for cross-project learning. In this paper we use an ontological framework to review the current structure of PTS and also propose a conceptual information-structure for machine-readable functional and spatial requirements that can be utilized in a recommendation system for hospital room layout.

Introduction

The design process of a hospital contains several technical and organizational challenges. One of the most profound challenges is the limitation to learn, apply, and facilitate knowledge transfer across projects. The current approach relies on temporary organizations in the form of projects, where the same set of stakeholders rarely participate in subsequent projects, preventing best practice from taking place. Thus, information is bound to a project basis and prevents cross project learning from happening.

The goal of The Swedish national healthcare project framework and database, PTS (Program for Technical Standard) has been to address by functioning as a resource with the purpose of knowledge transfer across projects and regions to improve the design process. Although available to all Swedish regions, its use varies greatly among the regions with many regions preferring their own internal processes over using PTS and resorting to study visits in other regions to facilitate cross-project learning. This reliance on the own project process has further added to resource disintegration between PTS and each region's own working process for hospital design Moreover, the fragmented structure of the data available in PTS has meant that the information chain among project stakeholders is reestablished from near scratch with each new hospital project.

By not leveraging on previous project experiences and thereby facilitate knowledge-transfer when starting a new project, the efficiency by which spatial requirements are reviewed and validated is also greatly affected. As a result of PTS being intended to be used for validation of spatial requirements in early phases of the design process, there is a requirement on the user's part to thoroughly understand, interpret and review requirements for the respective rooms intended to be design reviewed. However, the lack of understanding for how to integrate PTS in the design process has hindered users from using PTS for design reviewing properly and therefor hindered the standard from being widely used. Thus, information integration and mitigating complexity emerging among stakeholders becomes key factors when aiming for establishing shared knowledge (Gruber, 1993; Sun *et al.*, 2012) and enabling users to gain a semantic understanding, something required when handling complex analyses during different engineering and planning applications (Stadler & Kolbe, 2007; Kolbe *et al.*, 2005). In this context, unclear and ill-defined semantics of systems can be handled by using ontologies to address these issues (Gruber, 1993; Guarino, 1998). One of the more common semantic languages used for ontologies is a logic-based one called Ontology Web Language (OWL) (Pauwels et al., 2017).

Many studies (Mekawy, El et al., 2010; Kedir, Firehiwot et al., 2021; Le, Zhang et al., 2014; Rasmussen, M. H. et al., 2021) have been exploring ontologies using OWL within the domain of AEC industry (Architecture, Engineering and Construction) and specifically within hospital projects (Garcia *et al.*, 2004). However, far less has been explored in terms of presenting an ontological framework for how incorporating a design requirement standard into the design process can help users validate spatial requirements for hospital rooms more accurately but also how to include typically not involved healthcare staff (i.e., not project and facility managers) more clearly in the design process.

Therefore, in this paper we will aim to create a conceptual and ontological based framework for interoperability between a design requirement standard such as PTS and hospitals' own internal design processes for requirement specification. Moreover, we will also present a conceptual information-structure for machine-readable functional and spatial requirements that can be utilized in a recommendation system for hospital room layout. By having such an algorithm within the PTS framework, knowledge transfer across project could be facilitated without the need to reset the information structure.

This will be achieved in 4 steps: first, showing the current state of PTS and challenges users face by showing the interface with the different standard hospital rooms. Secondly, an ontology of the general PTS information structure system will be presented, with its subclasses. Thirdly, an ontology about a specific subclass connected to the preceding ontology will be described. Lastly, an ontology will be presented oriented around a prototype for an algorithm within the PTS framework.

Related work

Ontologies are used as a key tool to convert disintegrated information to well defined and clear semantics of systems (Gruber, T., 1993; Guarino, N., 1998). Moreover, they can help facilitate communication between humans or computers as well as give stakeholders a common knowledge representation framework. Thus, based on observation, ontologies can provide a framework enabling users a number of things:

- Capture semantics of specific stakeholders and translate these into knowledge understandable and available to all involved stakeholders.
- Improving design and interface of software systems.
- Achieve interoperability between different domains helping users infer new knowledge about existing systems.

Within the AEC domain, ontologies have been used mainly to construct and describe semantic mapping of interoperability between industry related systems (Mekawy, El et al., 2010). More precisely, ontologies used in these studies have largely revolved around presenting the meta-data and its semantics found in spatial objects and how it relates to objects within the same or different domains. An example of this is the analyzation and usage of generic building project ontologies such as the Industry Foundation Classes (IFC) (ISO, 2018) and how interoperability can be achieved between IFC and other classification systems. These ontologies are based on the logical theories presented by Copi (1979) which as its name suggests, designed after logical axioms and definitions that are defined for expressing the relationships between entities and classes. The logical-based languages available (e.g., OWL) then enables new knowledge from the semantic model to be inferred, thereby creating a more distributed approach to knowledge and information structure among involved stakeholders.

How these information structures are manifested in studies related to hospital projects is lacking, with available studies focusing on either conceptual information integration (Garcia et al., 2004; Jiang et al., 2010) and developing ontologies revolved around the operations of healthcare facilities (Yang, H & Li. W., 2009; Anand, S. & Verma, A., 2010).

Although there is a lack of ontologies oriented around the design process of hospital construction, and more specifically maintaining the information structure throughout the design process, there are other studies that highlight the complexity and challenges commonly emerging in hospital projects (Holst, 2015; Zhao, 2012). The complexity mainly lies in how good design decisions lead to better building outcomes, consequently affecting the facility functionality (Holst, 2015). This is also supported by the studies presented by Zhang (2012), describing how good design in healthcare facilities have proven to increase healthcare staffs' productivity and affecting their safety and wellbeing directly. Furthermore, As presented by both Holst (2015) and Zhao (2012), the time frame in which these key design decisions can be made, is commonly tied to the early phases of the design process.

In an effort to create a common framework for how these design decisions are done on a larger scale rather than limiting the knowledge and experience gained to a project basis, and centralizing this disintegrated knowledge, healthcare facility standards in various countries have appeared. These have been crafted with the aim of providing a guideline for hospital construction projects and assist design teams to plan and design more accurately, by adhering to these provided guidelines. An example of this is the Australasian Health Facility Guidelines (AusHFG). As stated on AusHFG's website (Healthfacilityguidelines, 2022), the purpose of these guidelines is to provide a standardized framework for conducting hospital projects. Moreover, this work process helps design teams more specifically by basing the process on a best-practice approach to healthcare facility planning as well as offering access to standard spatial components (e.g., 3D spatial components of 272 various, standard hospital rooms).

The Swedish equivalent to AusHFG, PTS, has a similar set of guidelines and goals of making knowledge and experience derived from best-practice available to Swedish regions. Much like AusHFG, PTS also enables design teams the opportunity to validate set spatial requirements via documents listing classification systems related to the spatial components of the listed standard rooms. This validation process of standard healthcare facilities can be argued to facilitate key design decisions made in early design phases, thus help address issues related to facility functionality.

Thus, this paper will aim to create a structured, ontological understanding to better analyze and document the PTS information structure. This will be done to investigate the possibilities of implementing a machine learning, shape grammar algorithm within the PTS framework. The algorithm would then form the basis for an automated computer procedure, capable of generating rooms and furniture placement from previous projects in PTS. This would essentially support facilitate knowledge transfer across projects without the need to reset the information structure, as well as help set the groundwork for a PTS based recommendation system.

This will be achieved in four steps:

1) Analyze the current interface of PTS with the classification system related to spatial components.
2) Present an ontology illustrating the general process when design team validate design requirements for standardized healthcare facilities
3) Present an ontology illustrating the specific subclass "Item" with related spatial components typically found in a PTS standard room. This

graph will be connected to the ontology presented in step 2 via the Item subclass.

4) Presenting an PTS infrastructure with related syntax of how an algorithm can work within a PTS framework.

Lastly, the presented ontologies will incorporate data gathered from 6 Swedish regions based on 6 semi-structured interviews with 13 facility mangers and project managers involved in hospital design processes.

A. PTS interface

The spatial components can be retrieved from the PTS object library consisting of multiple 3D Revit families that can be downloaded to a user's 3D model. Currently there is a limited access for the design team in terms of not having sign-in-access to PTS database. This leads to a lack of spatial components available for project members to download, something that was emphasized by facility managers during the semi-structured interviews. As for the classification of the various spatial components, the Revit-families are named PTS-codes (see figure 1), a numeric code that describes what object group each spatial component belongs to. For example, a peg-rack is named as *381-3* (see figure 1) in *Type Name* and *381* refers to the category of equipment and *1* specifically referring to a specific type e.g., the peg-rack being a model used with a lifting harness.

The three-digit numerical code ranges from 300 to 600 with each 100- numerical category containing a certain type of spatial component. For example, all spatial components starting off with 300 numerical combination is a type of facility fixed component (e.g., peg racks or light installation) whereas 400 is a reference to spatial components classified as furnishment. 500 and 600 entails components in heating and sanitation respective electricity.

Each standard room also has a specific PTS-code consisting of a type name for the room and a three digits number. These range from 1-221 with copying room for example having number combination 28 and an on-call room having PTS code 41.

In regard to how the facility and project managers working with PTS in projects, experienced the interface, many emphasized the difficulties in finding relevant components. Specifically, it was found that the more niched standard rooms (e.g., surgical room and ICU unit) were either outdated or simply not available. Furthermore, with the spatial components being outdated, many facility and project managers highlighted how this often leads to increased workload due to the components being insufficient quality wise and need to be tailored to suit the design needs of the region. The outdated models and issues related to accessibility to the PTS database as well as overall lack of understanding how to integrate PTS into the design process. Thishas led to many regions using PTS in a context where their own internal processes are deemed insufficient during early phases of the design process.

Furthermore, an issue appearing and being highlighted during the interviews, was the lack of understanding among non-design team members. Due to the difficulties in navigating and having an intuitive understanding for the PTS-library, healthcare staff who are not involved in the design process, tend to rely on the facility and project managers for addressing questions related to reviewing and validating spatial requirements using PTS. This could be argued to hinder an efficient feedback loop between healthcare staff typically not involved in the design process and managers. This viewpoint is also supported by previous studies exploring how end-users who often lack technical experience are involved in the design process and the importance of them understanding spatial conditions and connection to layout (Dunston et al, 2010).

Inredning/utrustning		
Fastighet		
301-7	Tvättplatsutrustning	1 st
382-2	Hållare för soppåsar	1 st
382-4	Hållare för bägarautomat	1 st
382-8	Hållare för flytande tvål	1 st
382-12	Hållare för torkpapper, stor	1 st
382-13	Hållare för handdesinfektion	1 st
385-6	Spegel B=450 H=600 (mm)	1 st
381-1	Kroklist 1 krok *Till lyftsele*	1 st
381-3	Kroklist 2x2 krokar	1 st
382-10	Hållare för ytdesinfektion	1 st
382-22	Hållare för munskydd	1 st
382-47	Hållare för visir	1 st
382-51	Hållare för engångshandskar/förkläden 5 paket	1 st
384-23	EU-skena B=600 (mm) *800 och 1200 mm ög.*	2 st
387-7	Dörrhandtag bygelhandtag "elefantöra"	1 st
387-18	Dörrtillslutare	1 st
480-5	Persienn	Ospec
521-4	Tvättställ stort utan bräddavlopp B=600 D=450	1 st
523-5	Tvättställsblandare bänkmonterad, förlängd spak	1 st
540-1	Andningsluftuttag för medicinskt bruk *Placeras i 444-9*	1 st
541-1	Andningsoxygenuttag för medicinskt bruk *Placeras i 444-9*	1 st
611-2	Elkanal väggkanalsystem, vertikalt placerad vid dörr	1 st

Figure 1: Example of categories with pertaining spatial components from the object library for a care-room for 1 patient (Program for Technical Standard, n.d.).

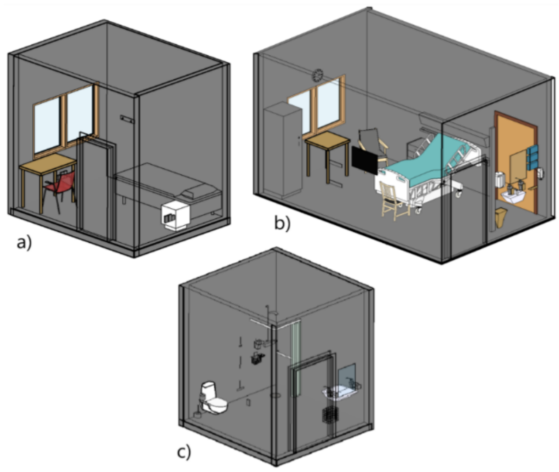

Figure 2: A) On-call room, b) care-room for 1 patient, c) RWC Shower

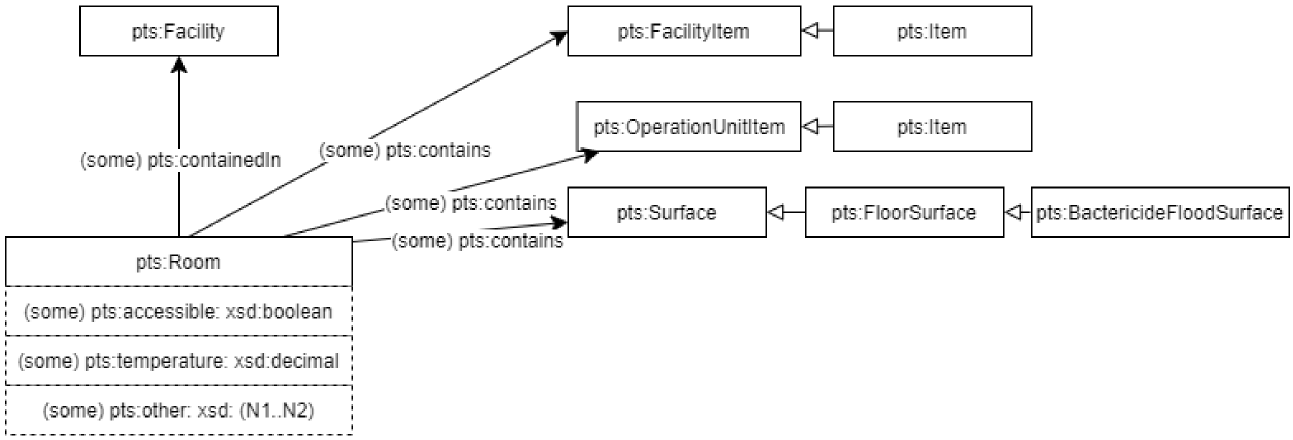

Figure 3: Illustration of the general ontology of PTS information structure with related requirements that each PTS standard room consists of.

B. General ontology for PTS information structure

To better analyze and document the PTS information structure, an ontology illustrating the standard specifications consisting of the different classification systems that each PTS standard facility is made up of (see figure 3) will be presented.

The ontology language used will be OWL 2, which was completed in 2009 and recommended by W3C for the Semantic Web and can be subdivided into two parts: syntax and semantics. The semantics is the meaning of the ontologies (W3C, 2009). The conceptualization was done via the Chowlk visual notation, a set of recommendation for ontology diagrams representation, providing visual blocks that represent each element from the OWL specification (Chowlk, 2021).

The overall ontology has been divided in two separate figures (Figure 3 and 4) and as such, the ontology will be introduced step-by-step.

To conceptualize this information structure, one can consider the system a hierarchy consisting of multiple classes, each with their respective subclasses and instances. Each of these subclasses represent the classification system that together make up the requirements the various standard rooms consist of and is documented in the PTS documents (figure 1).

By observing, one can see that the information structure can be illustrated by first having started with the class Facility. This is due to the importance of distance between rooms. Some standard rooms have requirement to be placed adjacent to other standard rooms. This can be validated by checking the distance between different standard PTS rooms. For example, a care-room for 1 patient should be placed adjacent to a RWC shower. Furthermore, this operation should be checked at the initial phase of the information structure so that localization of PTS can be achieved.

Specifically, this rule can check that PTS room 1 (care-room for 1 patient) is directly connected to PTS room 20 (RWC shower). Another example is that the on-call room should have RWC shower close by and that this can be checked and validated to see that every on-call room has an RWC-shower within a certain distance.

Next, the property restriction "some" is used to restrict the range of the property when applied to the source class, to at least some of the target class. The arrows without label have a white arrowhead, following the notation they are interpreted as "subClassOf". Rectangles are classes, the arrows are properties.

Moreover, the requirements are divided into FacilityItem and OperationUnitItem. This is done to show how depending on what the purpose of the utilization is. Whether it is a part of the room related to those working with facility (e.g., installations) or design layout (e.g., placement of furnishment and medical equipment), it is important to distinguish the two classes.

The data property, as seen in terms of accessibility, temperature and other, is also included in the ontology due to these requirements recurring in various standard rooms (e.g., surgical room, 1-patient care room).

The subclass Item is then shown, which is later connected to the different subclasses Item contains, which is presented further in figure 4.

C. Ontology for Item in a standard room

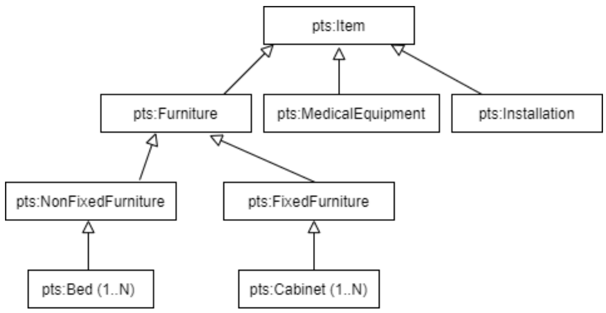

Figure 4: Illustration of the Item ontology of PTS information structure with related subclasses.

As presented in the previous section, Item is a subclass of FacilityItem and OperationUnitItem. This item can then be further partioned into three different subclasses: Furniture, MedicalEquipment and Installation. As illustrated, the subclasses Furniture and MedicalEquipment also have subclasses. The annotation N1 and N2 seen after the property name state the cardianility, which for the sake of illustrating the PTS information structure on simple terms, is expressed as the PTS standard room containin N amount of Beds. By the same token, the FixedFurniture class follows the same ideá, showing with an example class of Cabinet, how there could be multiple cabinets in the PTS standard room.

Related to what has been mentioned earlier, with the purpose of an Item, presenting the classes in this way was motivated by having an ontology that could be conceptual idea of PTS whilst being structured in such way that would make it compatible with a semantic reasoner. Therefor, the ontologies presented in figure 3 and 4 have been crafted on these basises: reflecting the current PTS interface (figure 1) and considering who the target group is. Related to the last point, this could be facility managers whose interest mainly lies in spatial layout or those working with requirements related to spatial layout that does not affect the operations of those working in the standard room (e.g., healthcare staff). As a result, the subclass Installation has been created to represent this above-mentioned distinction.

The spatial components have for the sake of simplicity not all been included and as such only the objects deemed as spatially associated (i.e., not temperature or light related objects) that have been included. This is mainly due to the fact that the algorithm capable of generating rooms and furniture placement (figure 5), visualizes spatial components.

Lastlly, it can be observed how the classes Items, Furniture, MedicalEquipment and Installation are either floor based, wall based or ceiling based. This could then be connected to the algorithm-figure presented in the subsequent section (figure 5). Examples of what can be categorized as Installation would be lighting fixtures and electrical outlets.

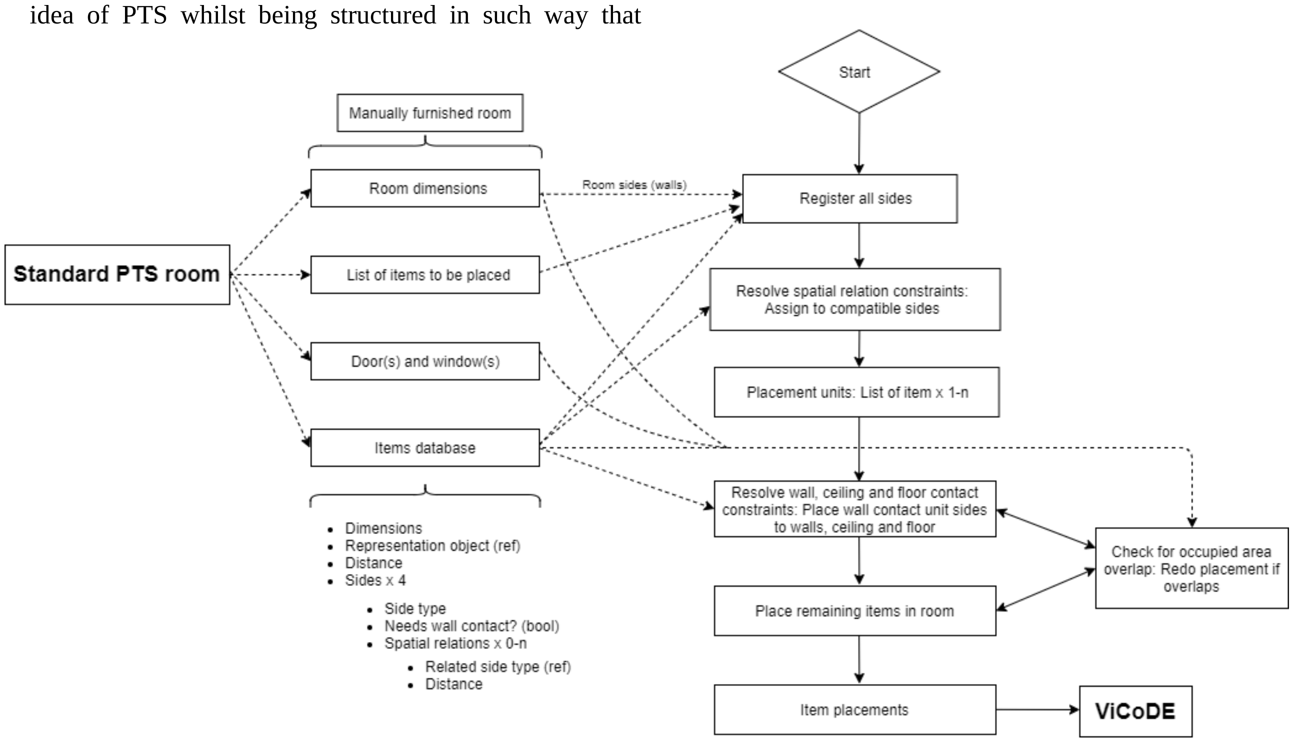

Figure 5: Illustration of the PTS infrastructure with related syntax of how an algorithm can work within a PTS framework.

D. Algorithm for PTS information structure

From the method of creating ontologies and analyzes of them, a connection to machine learning interpretation and algorithm capable of generating rooms and furniture placement, visualizes spatial components can be possible. By breaking down the PTS Standard room down to functional requirements and furniture/medical equipment connected to the classification system, it is possible to create design requirements for analyzing and automatic computer-generated role-based design of the rooms.

In this context the room dimensions, list of furniture/medical equipment to be placed, and doors and windows requirements could be analyzed and be an input to the automatic computer-generated room design algorithm. By creating a role-based sematic database with all the standard furniture/medical equipment (BIM-objects) and its connected required clearance area/space and spatial relation an automatic computer-generated PTS room design could be created as illustrated in Figure 5.

Consequently, this computer-generated PTS room design could further be used in Co-design processes and Co-design systems such as ViCoDE which has shown to support and facilitate cross-discipline collaboration, independent of prior experience to design review session (Roupé, M. et al., 2020). This could potentially provide an opportunity for healthcare staff beyond those typically involved (i.e., project and facility managers) to participate and contribute to the feedback loop that takes place in early phases of the design process between design team and end-users.
The result is that it is possible to creating a role-based design of rooms and its furniture/medical equipment for floor layouts which could late be validated by end-user in using ViCoDE and VR in 1:1 scale.

Discussion and conclusion

This paper has reviewed existing information structures for the Swedish hospital standard PTS and then analyzed the ontology of these structures as a method to see possibilities with connecting it with a machine-readable functional and spatial requirements that can be utilized in a recommendation system for hospital room layout. This rule based design interface could then be connected to the Co-design system to provide the users a number of of recommendations regarding room layouts and the included equipment and furnitures.

By integrating the information structure via ontologies, we have provided a theoretical framework for how to make guidelines and information provided by a hospital standard, accessible and available for all stakeholders. By making information related to hospital standards more accessible, one can argue that this contributes to bridging the gap of involvement in design review sessions typically emerging between those with prior experience (e.g. regular healthcare staff with no knowledge in reviewing and providing feedback on design proposals) and those typically involved (e.g. facility and project managers). Furthermore, this involvement of end-users lacking prior experience could be further facilitated, as described in the last section via a recommendation system. The ontology presented, thanks to the semantics described in the preceding sections, opens up the discussion for not only facilitating an enhanced knowledge and information structure among all involved stakeholders within a project but also how this presented framework can potentially facilitate cross-project learning. By enabling more users to be involved in the design process whilst adhering to a national standard framework for hospital design in a more accurate way, the quality as well as well as the quantity of feedback gained can be translated to better and more accurate design outcomes. The more integrated PTS framework can then form the basis for a more accurate and established knowledge to be spread among different hospital projects.

For future research, it is of interest to further investigate the PTS infrastructure from a more practical framework, i.e., what criterias would have to be met to enable its implementation in real-life project.

Lastly, it would be of interest to explore more in detail how the basis of a recommendation system via an ontology can be created. Specifically, a recommendation system for PTS would be rule-based (i.e., property restrictions), with PTS-classification embedded in IFC-models of the hospital projects. The IFC-files would then be uploaded to the PTS portal once the hospital project is finished. The computer and a machine-learning algorithm would then be applied to analyze the IFC-database connected to PTS.

As the structure showed in the ontologies, it is possible to compare how PTS standard rooms and layout has been utilized. This means that once PTS has gained traction in terms of usage, enough data can be gained for the recommendation system to become more accurate over time. As a result, cross-project learning would realistically be more doable.

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