

# USING PRODUCT MODELS TO REPRESENT USER REQUIREMENTS

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*ABSTRACT: The Service Life/Asset Management project at the Institute for Research in Construction has identified “enabling” technologies critical to attaining the project objectives of optimizing the service life of building envelope components and systems. The preliminary investigation concentrated on the need for close links between the enabling technology of user requirement modeling and those of service life prediction, life cycle economics, maintenance management, and risk analysis. The integrating tool is an information technology (IT), namely product modeling. The current research focuses on modeling of user requirements.*

*There is a rich history in the field of user requirement (performance concept) modeling in the research literature and existing standards documents. However to date, there is no conceptual model and little vocabulary to represent the concepts described in much of this research literature and standards. In addition, the language even in the applicable ISO standards needs additional refinement and more structure.*

*In addition, to our knowledge, very little research has been done to represent these user requirement models in a digital format (i.e. product model). Although “performance” is identified as an attribute in the Building Construction Core Model, this representation is considered to be preliminary by the authors. However, product models can provide the necessary structure and refinement for representing user requirements models.*

*This paper describes a user requirement modeling vocabulary: a language to describe the necessary entities and their relationships. The paper discusses similar systems developed to date; it identifies uses for a user requirement model, and it describes limitations of the proposed model.*

**KEYWORDS:** *asset management, product modeling, user requirement modeling, performance requirements*

## 1. INTRODUCTION

The Service Life Asset Management (SL/AM) project at the Institute for Research in Construction has identified “enabling” technologies critical to attaining the project objectives of optimizing the service life of building envelope components and systems (Vanier and Lacasse, 1996). The preliminary investigation concentrated on the need for close links between the enabling technology of user requirement modeling and those of service life prediction, life cycle economics, maintenance management, and risk analysis. The integrating tool for this project is an information technology (IT), namely product modeling. This paper addresses the need for digital representations of user requirement models.

### 1.1 User Requirements

There is a rich history in the field of user requirement and performance concept in building in both the research literature and the existing standards documents (CIB W60, 1976,1993; ISO 6240,1980).

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User requirement modeling is closely related to the performance concept modeling described in the CIB as well as the ISO literature; it is the authors' opinion that the performance concept forms an integral portion of user requirement.

Although there is considerable and valuable research in the referenced literature, to date there is neither a digital conceptual model nor a regimented language of the concepts described in much of this work. In addition, the vocabulary even in the applicable ISO standards needs additional refinement and definitely requires more structure. The rationale supporting these assertions is detailed later in the paper.

## **1.2 Product Modeling**

There is now a long history of product modeling research in the construction domain (Luiten, 1993). For those unfamiliar with product modeling, it can be best described as the digital representation of the "totality of data elements that completely define a product for all applications over its expected life" (Reed, 1990). There is now active participation in the STEP initiative from a large number of researchers from around the world (ISO 10303, 1993).

However, to our knowledge, very little research has been done to represent these user requirement models in any digital format (i.e. product model). Although "performance" is identified as an attribute in the Building Construction Core Model (BCCM), this representation is considered to be preliminary by the authors.

## **1.3 Using Product Models to Represent User Requirements**

It is the authors' view that product models can provide the necessary structure and refinement for representing user requirements models. This paper describes such a user requirement modeling language: a language that contains the necessary vocabulary to represent user requirement concepts, as well as a language structure to handle the strong inter-relationships between these concepts.

## **1.4 Summary**

This paper describes the existing research in user requirement and performance concept modeling; it provides a brief overview of product modeling tools; it identifies the vocabulary and structure needed to model user requirements; it demonstrates the applicability of these tools and it presents and discusses research and development possibilities. It must be mentioned that this activity is work in progress and that the authors' ideas are still formulating and evolving.

As mentioned earlier, user requirement modeling is an essential element in the foundation of the SL/AM project. It must be emphasized that it is essential for the entire construction community to recognize the importance of modeling a building product's "performance over time"; therefore a comprehensive, robust and consistent representation of user requirement models is an vital component in every product model.

## **2. REVIEW OF USER REQUIREMENT AND PRODUCT MODELING**

This section outlines the existing research in the domains of user requirement, performance and product modeling; based on this information, a preliminary model is proposed. In fact, the user requirement model proposed in this paper relies heavily on a number of seminal papers and projects from the performance concept domain. The product models proposed in this paper follow STEP standards and protocols currently under discussion in the construction industry (ISO 10303, 1992).

## 2.1 Performance Concept Modeling

It is ironic that some of the first papers describing the potential for the performance concept in buildings originated at Canada's Division of Building Research (Legget and Hutcheon, 1967), the former name for the Institute for Research in Construction and the host organization of the two lead authors. Since that time there has been considerable research in this field throughout the world. Unfortunately, it is not possible in this paper to reference all this research owing to the large number of researchers as well as the heavy contributions of members from numerous ISO, ASTM and CIB working groups and committees. As a consequence, the authors only describe those activities that directly relate to their research requirements.

### 2.1.1 History of events

Although the authors state that there is need for more structure and vocabulary to adequately model user requirements, a proposed structure for the performance concept has been available for more than two decades (Sneck, 1973). Sneck provides the definition: "(t)he performance concept is an organized procedure of framework within which it is possible to state the desired attributes of a material, component or system, in order to fulfil the needs and demands of the intended use without regard to the specific means employed in achieving the result" (p. 26). In his proposed structure, the author describes entities such as "external (environmental) factors", "internal factors", "user technology needs", "performance requirements", and "building elements". These entities appear consistently in other related work (ISO 6240, 1980; CIB W60, 1976). Other publications have also identified preliminary performance requirements such as "structurally stable", "weathertight", "capable of ensuring a habitable environment", "durable", and "readily maintainable" (Atkinson, 1971).

Operation BREAKTHROUGH was a USA initiative to breakthrough barriers in the production of cost-effective and efficient housing (Finger, 1972). One portion of this large, multi-year government project concentrated on the need for performance evaluation and user requirements. Although much of the criteria established in Operation BREAKTHROUGH was more qualitative than quantitative, the project did specify criteria for durability and service life. These criteria related durability to factors such as the nature of the material, compatibility to adjoining material, exposure, climate, use and maintenance.

The CIB Working Commission on the Performance Concept in Building (CIB W60, 1976) provides more depth to the vocabulary and structure described earlier. Its definition of the performance concept "takes as a starting point a recognition of the needs expressed in terms of human and user's requirements" (p. 2). The Working Commission also supplements the earlier work in the field with clear definitions for terms such as "stress", "functional performance requirement", and "performance assessment". The paper also tackles the thorny question of the delegation of responsibility for the performance requirements: "(t)he corresponding functional capability, that is to say the predicted ability of an item to fulfil the identified function(s) together with occupancy factors (conditions of use) determine whether these conditions (functions) are met" (p. 3). This is a clear indication that "items" must be evaluated according to their ability to meet functions, under any conditions of use. The importance of this assertion is described below in Section 2.3.2 of this paper.

The International Organization for Standardization's Technical Committee on Building Construction (TC59), and more specifically its Subcommittee on Functional/User Requirements and Performance in Building Construction (SC3), has developed a number of formats and templates for the development of performance standards (ISO 6241, 1980; ISO 6241, 1984; ISO 6242-1/2/3, 1992;

ISO 7162, 1992), and this work has been applied by a number of other working groups (ISO/DIS 7361, 1986). As a result of these publications, the building industry is now seeing concise descriptions of the performance concept; including some structure for the relationships between concepts in performance modeling. In fact, these ISO documents include clear and concise examples and classifications for components of the performance models.

This ISO series of publications honed the previous research and supplemented it with terms such as “user”, “user requirement”, “agent”, “functional elements”, “uses of buildings” and “criteria” (ISO 6241, 1994). It also provided a bare structure for the relationship of these components. For example, all “agents” have a “nature” (e.g. mechanical, thermal), they possess an “origin” (e.g. external or internal) and they have a “cause” (e.g. occupancy, natural, man-made). The document also provides categories for the various components of their model, along with numerous examples (ISO 6241, 1984, Tables 1 to 4). Of particular importance is the fact that these representations approach the precision needed for digital models.

However, this ISO series unfortunately falls short on minor details and minor terminology consistency: and as we all know “God is in the details” to quote the architect, Mies van der Rohe. It is not the authors’ intention to slight this extensive and thorough work; it can be easily seen later in the paper that the authors have based their work on these ISO and CIB activities. In fact, they have supplemented these ISO activities, and its CIB ancestry, and have attempted to provide the granularity of definition and structure required for the digital processing of user requirement modeling.

Recent activities dealing with the performance concept in North America include systems integration for performance (Rush, 1986). This work clearly identifies the six performance mandates as spatial performance, thermal performance, air quality, acoustical performance, visual performance and building integrity. This publication also references the work of others (Lemer and Moavenzadeh, 1972) to suggest that performance can be measured in terms of the three principle parameters of serviceability, reliability and flexibility. The Rush publication also identifies some performance criteria for physiological, psychological, sociological and economic needs. Related to service life, the authors have coined the expression “time units based on the intent of the building” and have proposed the following classification for service life: temporary, short life, long life, and permanent. The publication also defines the four distinct systems of the building as the structure, interior, envelope and mechanical systems. The publication has an elaborate vocabulary for their five levels of integration between a building’s systems: a clear indication that researchers are starting to think of the detailed structure of the performance concept. These levels are: (1) remote, (2) touching, (3) connected, (4) meshed, and (5) unified. The publication also suggest that systems can have a number of levels of integration. As can be seen, detailed structures and vocabulary are beginning to appear in the literature.

ASTM standardization in the field of Performance of Buildings (Davis and Gross, 1993) has focused on topics such as objective rating scales for the quality and functionality of office and educational facilities, behavioural measures of serviceability, and building rating systems for energy performance. Much of this work is still under development. The ASTM Unifomat II (Bowen *et al*, 1992) initiative provides a structure for the functional elements of a building and the authors of that publication recommend the use of Unifomat II for preparation of performance specifications. A detailed classification system of building components, in our opinion, is essential for any user requirement modeling; Unifomat II appears to satisfy our requirements in this domain.

More recent CIB activities (CIB W60, 1993) are providing more depth and detail for user requirement models. Some authors researching the performance concept (Karlén, 1993) commented on the need for stricter vocabulary and for product models: “(w)e must be aware of the risks of word conflicts because of the differences between the words expressing the concepts related to theories applied in reports from research projects also in an international context, and conceptual scheme as bases for STEP and other means for international co-ordination of EDP and IT standards” (p. 25). Finer definitions of the relationship structure for performance models can only help the definitions of the problems: “(t)he performance criterion is a factor against which a decision can be made during the evaluation process” (Sneck, 1993, p. 207). There is still a lot to be learned in this area and there is still need for research. For example, Sneck (1973) commented on the natural sequence of development for performance issues; these start at performance requirements, and progress logically to performance criteria, performance evaluation techniques, performance specifications, performance standards, and finally to performance codes. Therefore a promising area for the study of the performance concept should include the recently formed CIB TG 11 dealing with performance-based building codes and standards.

As can be seen, a language and structure for performance modeling, or more precisely for user requirement modeling, is evolving in the research and standardization literature. However, there is still more detail required in user requirement modeling to meet the needs of the SL/AM project described earlier, and for any service life project focused on understanding issues related to service life. The authors’ investigation in this interesting area brings us back full circle to the beginning: Sneck (1973, p.1) stated that “(c)urrently no fully developed theoretical or practical rules exist for application of the performance concept”. In a more recent paper (Sneck, 1993) the author references the ISO work described above, indicating to the authors that perhaps a system is now available.

### 2.1.2 Proposed User Requirement Model

"The aim is to define the performance required of whole buildings, parts of buildings and building products in terms of the functional requirements of the users" (ISO 6241, 1984, p. 1). This statement is the starting point for the SL/AM user requirement model.

Five (5) different types of objects have been gleaned from an exhaustive analysis of research literature described above: (1) Functional Requirement, (2) Performance Requirement, (3) Functional Element, (4) Agent (Stress), and (5) Factor (Use). A schematic showing the inter-relationships between objects, along with definitions for each one, are presented in Fig. 1.

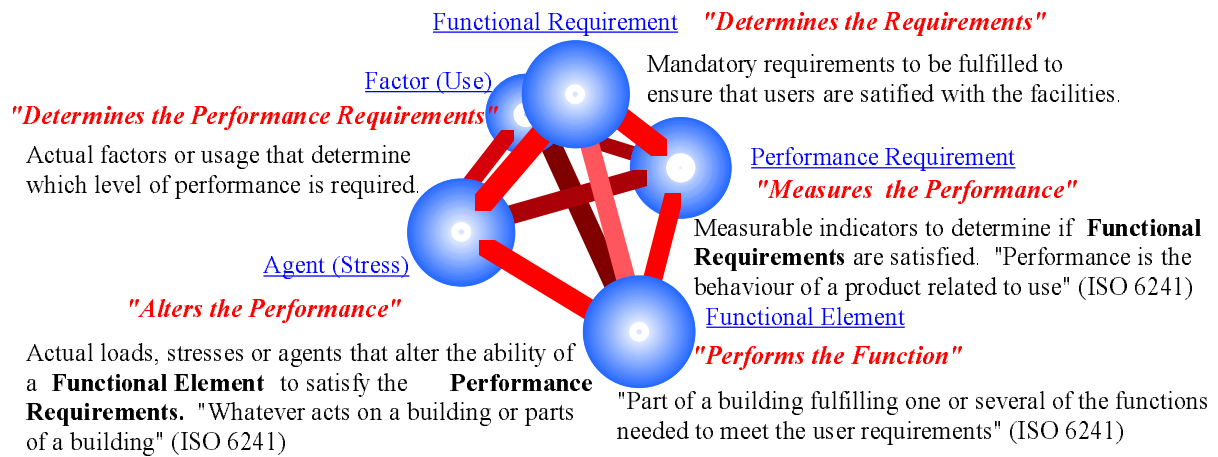


FIG. 1: User Requirement Model.

## 2.2 Product Modeling

ISO 10303 is the international standard for the "computer-interpretable representation and exchange of product data" (ISO 10303, 1993, p. xiv). EXPRESS is the name of a formal information requirements specifications language. EXPRESS provides the language elements for an unambiguous definition of the object and specification for constraints on the objects.

Text-based representations such as EXPRESS are easily understood by computers, but are difficult for humans to follow. Graphical languages such as NIAM (Nijssen and Halpin, 1989) and EXPRESS-G have been used successfully to represent the complex relations typical to construction components and materials (Vanier, 1994). EXPRESS-G was selected in this research project to display the SL/AM user requirement model; this decision was based on the general acceptance of the modeling tool by the BCCM community, and by the fact that EXPRESS-G has the capability to express the authors' ideas, clearly and concisely.

The reader must be familiar with some product modeling terminology and conventions to understand EXPRESS-G; these terms are described in the following two paragraphs. In general, an EXPRESS-G model consists of Definitions, Relationships and Compositions. The Definitions are concepts or things, and they are the core of the model; these are the boxes shown in Fig. 2 and Fig. 3. The Relationships define the relations between Definitions; these are the lines joining the boxes in Fig. 2 and Fig. 3. The heavy lines are used for subtype Relationships; whereas the thin lines are for other relationships. The Composition feature allow the EXPRESS-G models to be displayed on numerous pages: Composition elements are represented by rounded boxes, examples can be found in Fig. 4.

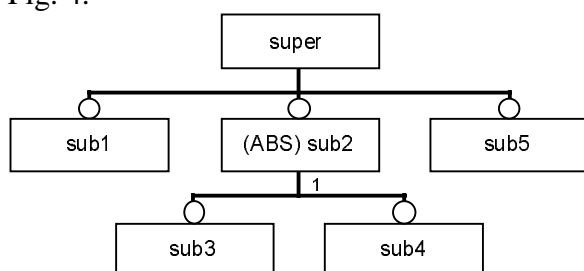


FIG. 2: Supertypes (ISO 10303, 1993).

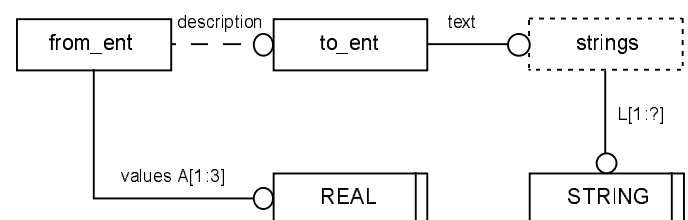


FIG. 3: Definitions/Relationships (ISO 10303, 1993).

The Role of the Relationship between Definitions is placed on the Relationship line, as shown in Fig. 3. The direction of the Role is depicted by the open circle at the end of the Relationship line. Roles have names like “delegated\_to” or “evaluated\_by”; whereas the Definitions have names such as “PerformanceRequirement” or “FunctionalElement”. A dashed line or a dashed box means that the Role or the Definition is optional. The cardinality of the Relationships is denoted by the square brackets. For example, L[1:?] means that the List must have one or more entities, while A[1:3] means that the Array must have one to three entities. If the cardinality is not specified, then it is exactly one for mandatory Relationships and zero for optional ones. The designator “(ABS)” in Fig. 2 means an abstract subtype. The number “1” above “sub3” and “sub4” in Fig. 2 means that “(ABS)sub2” can only have one subtype and it is either “sub3” or “sub4”.

### 3. RESEARCH

Fig. 4 presents an overall view of the proposed SL/AM user requirement model. In this figure only one level of cross-reference is displayed, in order to simplify the relationships for novices to read. The full depth of all cross-references are described later in the paper. The rounded boxes indicate the Compositions element described in Section 2.2; the corresponding figure number are provided in place of the conventional EXPRESS-G notation. The different components and relationships for Fig. 4 are described in the appropriate section below.

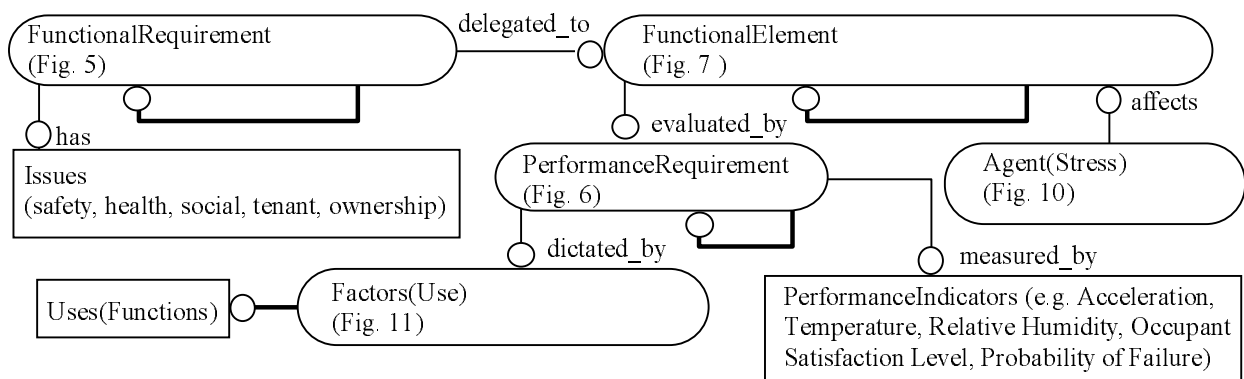


FIG. 4: User Requirement Product Model.

#### 3.1 Functional Requirement

The essence of the user requirement model is the FunctionalRequirement. The authors use the term FunctionalRequirement in place of UserRequirement, which is preferred in ISO 6241, in order to avoid confusion with the authors’ user requirement model. The FunctionalRequirement is a statement of need to be fulfilled by the building (ISO 6241,1984); typically this is in terms of user and facility requirements. For example in Fig. 5, each FunctionalRequirement can have any number of subtypes (as designated by the recursive subtype); it has one issue (e.g. safety, health, social), and the act of satisfying this requirement is delegated to a FunctionalElement. In practical terms this means: the air purity requirements (i.e. FunctionalRequirement) for control of odours (i.e. subtype of FunctionalRequirement) are social issues and are delegated\_to (i.e. Relationship) the heating, ventilating and air-conditioning (HVAC) system (i.e. FunctionalElement).

#### 3.2 Performance Requirement

A PerformanceRequirement is the "user requirement expressed in terms of the performance of a product" (ISO 6241,1984, p. 2). In Fig. 6, the FunctionalElement is evaluated\_by the PerformanceRequirement; that is to say – the building product must meet the

FunctionalRequirement, and the building product is evaluated by its ability to meet a PerformanceRequirement. In addition, the Agents(Stresses) alter the FunctionalElements, and affect how they performs their functions. In practical terms, following the example dealing with air purity (i.e. FunctionalRequirement): the HVAC system (i.e. FunctionalElement) is evaluated\_by a PerformanceRequirement identifying the need for regular air changes. In turn, the acceptable level of air changes (i.e. PerformanceRequirement) depends on the Factor(Use); that is for a given Factor(Use) such as a hospital, more strict requirements for air changes per hour are required than a repair garage (these numbers will have to be established by researchers in the future). Outdoor air impurities are Agents(Stresses) that affect the HVAC’s capacity to supply the correct amount of “pure” air to a particular location.

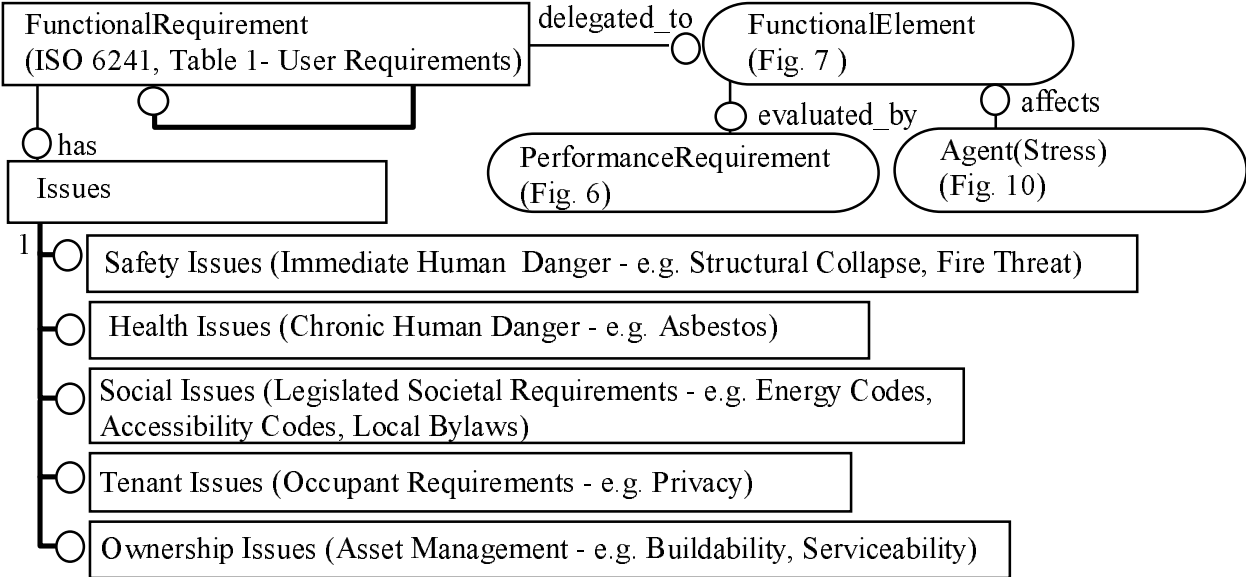


FIG. 5: Functional Requirement Product Model.

The PerformanceRequirement is measured\_by a PerformanceIndicator. The PerformanceIndicator could be the number of air changes per hour, or any quantifiable indicator that could adequately represent that specific PerformanceRequirement, such as air flow through a representative number of diffusers. The Nature and the Criteria are the respective units of measurement and the desired Limit State. The PerformanceIndicators are evaluated\_by Standard(Tests). As a practical example of these relationships we have: a higher level of indoor or outdoor contaminants (i.e. Agents(Stress)) increase the need for more air changes per hour (i.e. PerformanceIndicator) required to meet a specific performance level.

**3.3 Functional Element**

FunctionalElements are the building components, including their strong aggregation and generalization relationships. In the SL/AM user requirement model, the FunctionElements are delegated responsibility by the FunctionalRequirement and they are evaluated\_by the appropriate PerformanceRequirement, as shown in Fig. 7. The FunctionalElements consist of any number of subtypes; which are divided according to their specific building subsystem, for example structure, space, external envelope, spatial divider, etc. The square brackets in the FunctionalElements represent potential subtypes of elements, as per ISO 6241 (1984). Agents(Stresses) affect the way that a FunctionalElement performs. For example, high amounts of contaminants (i.e. Agent(Stress))



affect the HVAC system's (i.e. FunctionalElement) ability to exhaust these pollutants for given air change rates (i.e. PerformanceRequirement).

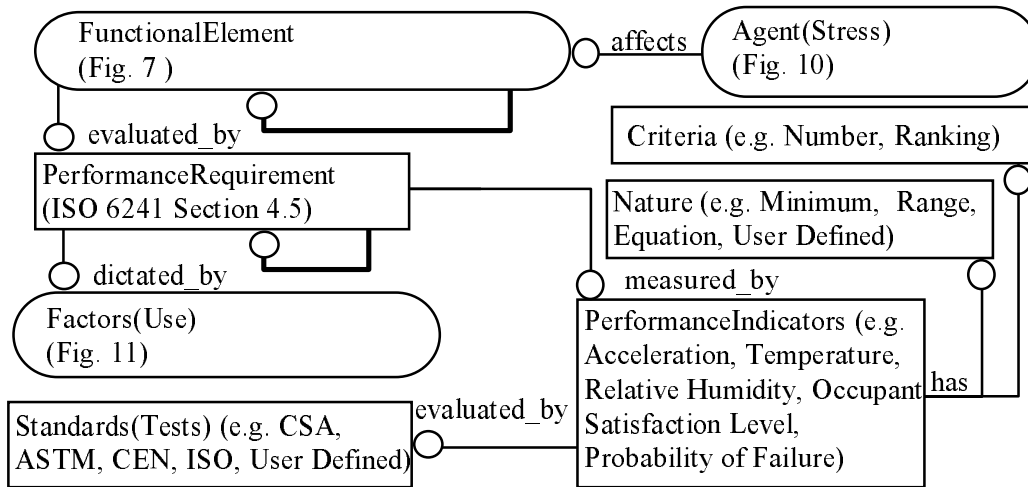


FIG. 6: Performance Requirement Product Model.

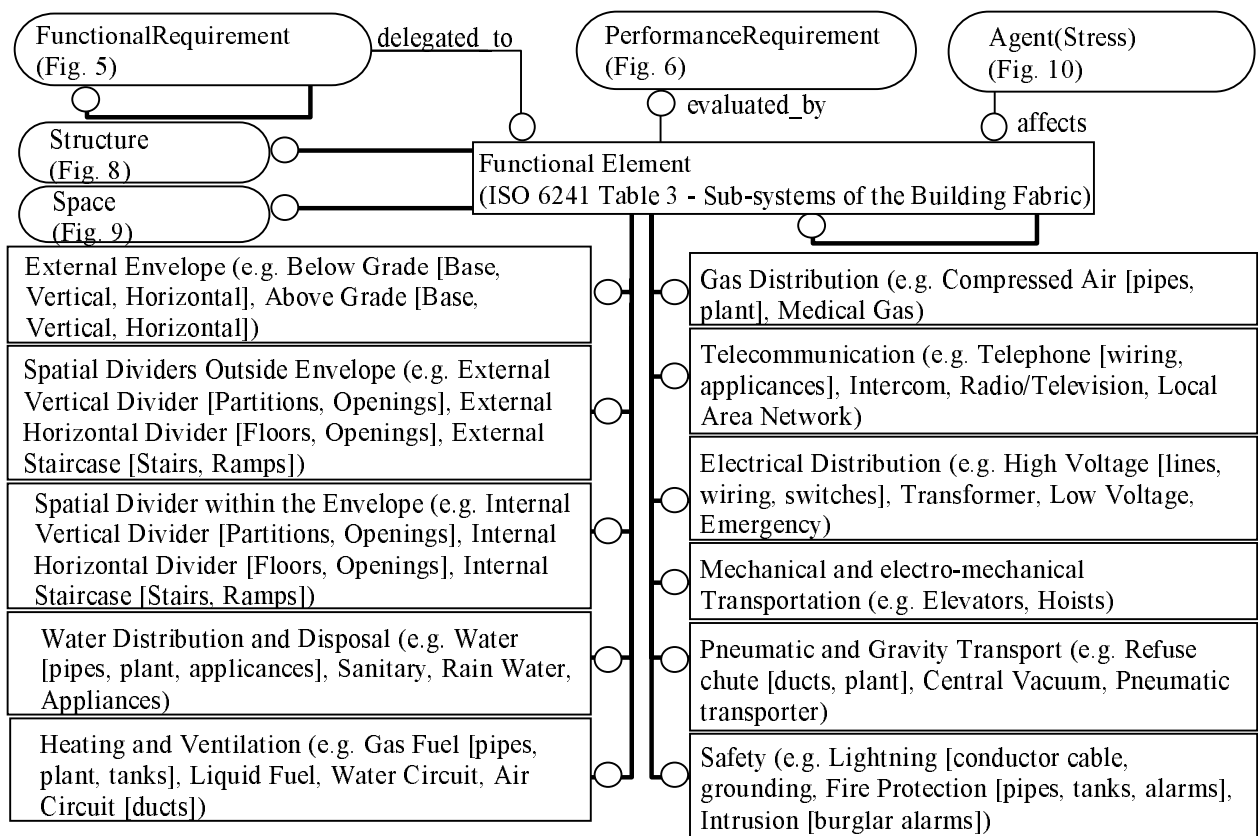


FIG. 7: Functional Element Product Model.

Fig. 8 and Fig. 9 provide some detail into the classification of structures and spaces. Although there is already considerable literature in this area of modeling in the BCCM initiative in STEP; the information provided in these two figures is from ISO 6241 (1984). Unfortunately, there is precious little about the identification of space in ISO 6241; Fig. 8 attempts to fill the gap left by ISO. In the

view of the authors and others in the field (Rush, 1986), it is an unfortunate omission, as space provides the location for users' activities and hence it is an essential part of user requirement models.

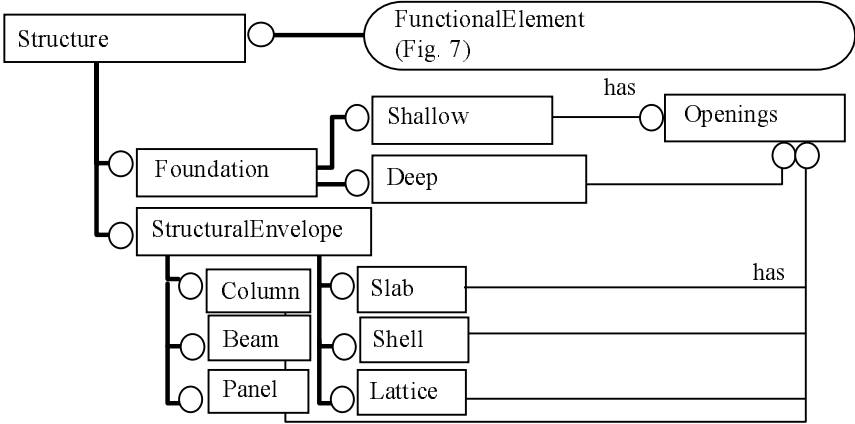


FIG. 8: Structural Functional Element Product Model.

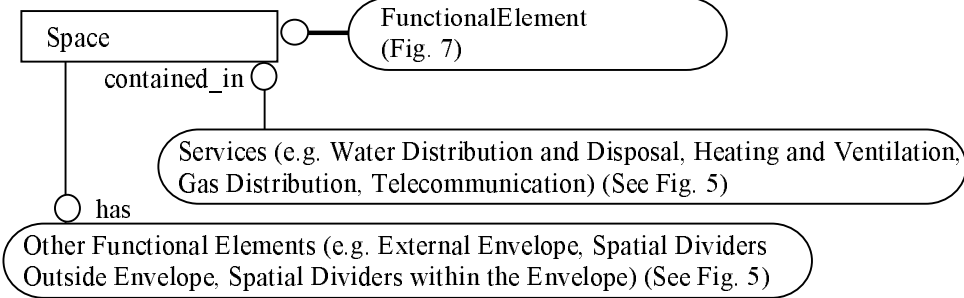


FIG. 9: Space Functional Element Product Model.

3.4 Agent (Stress)

Agents are external stresses, loads or activities that affect how a building behaves. In essence, Agents affect or alter all the same materials in the same fashion (that is, aluminium behaves the same way whether it is roofing flashing or a window mullion) and creep has the same effect on Canadian or Slovenian concrete. Therefore Agents(Stresses) can only affect the FunctionalElements or their composite materials. In addition, each Agent(Stress) has a Nature, and each Nature has an Origin and a Cause. Nature is the type of physical action; Origin is the location of the Agent; and Cause is the reason for the Agent. Examples of all these are provided in Fig. 10.

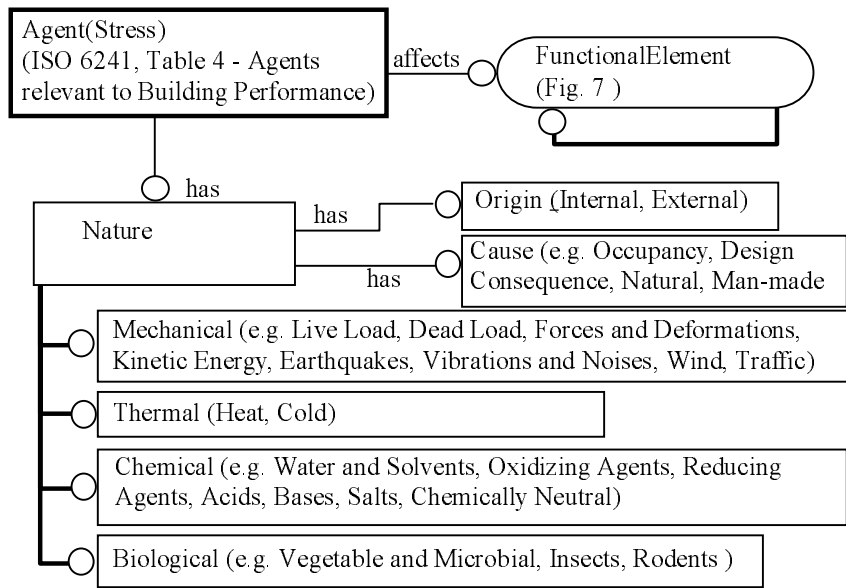


FIG. 10: Agent (Stress) Product Model.

### 3.5 Factor (Use)

The Factor(Use) is closely related to the user occupancy and how the space or facility is used. Factors can be broken down, as shown in Fig. 11, into a number of discrete entities including circulation, catering, hygiene, etc.; these are based primarily on the service provided, along with a subtyping for that service.

## 4. DISCUSSION

This paper presents work in progress; subsequent research contributions (Vanier *et al*) will provide more depth and granularity to the model and will provide a more rigorous validation for the proposed user requirement model.

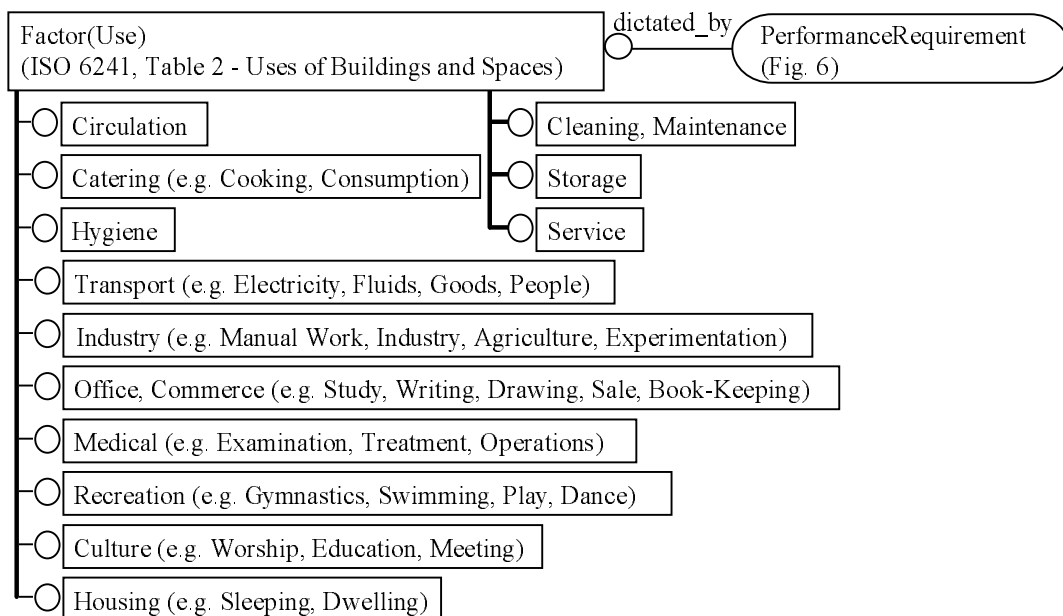


FIG. 11: Factor (Use) Product Model.

As can be seen, the user requirement model proposed in this paper relies heavily on the standardization work from ISO and the preceding CIB research. However, tools such as product modeling permit more precise and thorough representation than possible in the “text-based” definitions or the “table-based” examples provided in the research or standardization literature. The authors feel that they have added value to the existing work and they hope that they, and others, can contribute to the evolution of this methodology.

The readers may be reflecting what this user requirement modeling has to do with the Service Life/Asset Management project described earlier? It is very simple: how can a building professional estimate, or worse yet, specify the service life of a system or a component without knowing what level of service will be required by the user? Or, how can anyone evaluate when a system or component has reached its service life without knowing what is the non-acceptable performance that caused its failure? This was a dilemma faced by the authors in developing the SL/AM project; and the user requirement model is our attempt at a solution. For example, performance indicators such as Road Condition Index (RCI) have been used for years in pavement management systems to establish “triggers” for maintenance, repair, or rehabilitation (Lee and Deighton, 1995); in addition, data collection to measure and record the RCI has been raised to a high level of sophistication, allowing these “asset managers” to assess the current and projected future state of performance of a disparate selection of roads and streets. In addition, the asset manager can also select from a palette of “treatments”, each of which can raise the performance to a higher level. It can be readily seen that the pavement industry is predicting service life and managing their assets efficiently; but they already have established some performance requirements, user requirements and service life parameters.

There is still considerable work required in this important area. For example, the authors will be testing this proposed model as to its application in a number of areas related to building codes, performance specifications, thermal comfort and air purity (Vanier *et al*, 1996). Other research still required relates to controlled vocabulary; – considerable attention has been paid to the “nouns” or entities in the product modeling language, but there has been little control of the “verbs” or relationships (Vanier, 1994). The same controlled vocabulary is needed in user requirement models. More research is required in the application testing of the model in construction practice. One particular area of interest for testing is performance-based codes and performance specifications. Although both these fields have had over two decades for implementation, there are few recipes for practitioners or code writers to follow when developing performance specifications or performance-based codes.

Design/Build is an interesting application area for performance specifications, as well as user requirement models. For those unfamiliar with the term, design/build is a delivery method where the owner specifies general requirements and the Design/Build team provides both the design and the constructed facility. Conversations with professionals in this field have pointed to the need for some form of user requirement models to assist the contract development stage, as well as the product evaluation stage.

## **5. CONCLUSIONS**

User requirement models will help the construction industry be more innovative by specifying the requirements and not the solutions; they will help designers be more creative by expanding the set of possible solutions; they will save money for the owners by allowing both the designer and

constructor to offer alternatives that do not affect the performance of the building; they provide quality control by providing a mechanism for inspectors to evaluate the resulting performance; and finally, they help asset managers by allowing them to record, monitor and predict the performance of their portfolio.

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