A PRODUCT MODEL FOR THE GENERATION AND EVALUATION OF BUILDING ELEMENT ALTERNATIVES

M. Aygun, I. Çetiner, C. Göçer
Istanbul Technical University

ABSTRACT: Thus a comprehensive yet versatile representation of all the entities involved in the building system is required, may these be notional or physical entities. The intention here is to provide a parametric conceptual model for generating and evaluating alternatives of functional building elements for ascertaining the best overall performer. The proposal enshrines three interrelated subsystems. The first two are concerned with constraints and performance requirements respectively as notional entities and the third with physical objects related to buildings. The discrete performance requirements for a descendant are interpreted as functions of ancestors in the context of the physical model. Hence element requirements are designated to discrete components as their functions. Each component contained within an element serves one or more primary functions. Conversely each of the latter is served by one or more components.

KEYWORDS: Performance requirement, Product model, Building element

1. INTRODUCTION

By tradition building elements are labelled with familiar terms associated with accustomed solutions such as floors, walls and roofs. While these perceptions of elements are adequate for describing most conventional buildings and conveying information about their constituent parts they impose restrictions on progressive element development and appraisal. Thus a comprehensive yet versatile representation of all the entities involved in the building system is required, may these be notional or physical entities. The intention here is to provide a parametric conceptual model for generating and evaluating alternatives of functional building elements for ascertaining the best overall performer.

A brief overview of the relevant works is presented as follows. Aygun presents a conceptual model intended for describing functional building elements as applied to glazed curtain walls evaluated in terms of their life cycle performance by means of multiple indicators [Aygun 1999]. Mahdavi describes an object-oriented building representation environment where a class inheritance hierarchy is adopted with which relationships between elements are established [Mahdavi 1996]. Rivard *et al* describe an envelope design process based on functional analysis of principal design requirements [Rivard 1995]. Rivard *et al* elucidate a shared conceptual model for integration in the building envelope design process [Rivard 1999]. Tang applies object technology to simulation model creation in object-oriented environment by means of abstraction and encapsulation of data in building modelling [Tang 1997]. Vanier *et al* propose a product model for representing user requirements as a complete data structure [Vanier 1996].

2. CONCEPTUAL MODEL

The proposal enshrines three interrelated subsystems. The first two are concerned with constraints and performance requirements respectively as notional entities and the third with physical objects related to buildings.

Constraints: These describe the existing conditions with which the existing or prospective building must comply such, e.g. climate, location, surroundings, mandatory regulations.

Performance Requirements: The notional subsystem for representing the performance requirements, synonymous in this context with criteria, comprises transitive entities the order of which is immaterial as far as the information contained within is conserned. Each instance of the preceeding entity relates to all instances of the succeeding entity, i.e. the branching is cross-linked and the links are identical , thus all predecessors pertain to the same successors. The instances of these entities are ordered as arrays, i.e. one dimensional matrices. These entities are listed below.

1. Life cycle phases (manufacture, construction, occupancy including repair and maintenance, refurbishment, demolition and recycle),
2. Participants (investor, designer, contractor, user),
3. Domains (safety, health, comfort, ecology, cost)

Element Model: The subsystem that conveys information on physical objects on the other hand has an hierarchical order and encompasses intransitive entities each preceeding instance of which as a ancestor relates to a different set of succeeding instances as descendants, i.e. the branching is downwards divergent. These entities are

1. Building (e.g. residential, office, hospital),
2. Space (e.g. living, working, sleeping),
3. Elements (e.g. floor, wall, roof),
4. Components (e.g. finish, insulation, waterproofing, core) and
5. Materials (concrete, steel, timber, glass)

The approach espouses to the principles of object-oriented modeling thus adhering to inheritance and encapsulation. Since each ancestor is almost invariably connected to at least one other ancestor of the same or another descendant there will be one or more ancestors shared by descendants. Each instance of any given physical entity is associated either closely or remotely with all the instances all performance entities. The discrete performance requirements for a descendant are interpreted as functions of ancestors in the context of the physical model. Hence element requirements are designated to discrete components as their functions. Each component contained within an element serves one or more primary functions. Conversely each of the latter is served by one or more components.

With reference to the elements as the subject matter of this paper, each of these in turn consists of any number of components. By definition an element must have at least one component which can be connected to another of the same element and also shared by an adjacent element. Consequently this subsystem is partially cross-linked. The branching extends laterally to include all elements in the building system. Components are described herein by one or more attributes that become congenial properties of the respective components. All components of an element share the same idiosyncratic attributes. Hence a physical entity as part of a building is defined as functions of all its descendant instances, i.e. higher-level entities as embedded objects, in an hierarchical order:

$$\text{Element} = f(\text{Components}, \text{Materials})$$

The object hierarchy allows any sub-types (descendants) derived from the main types (ancestors) to inherit the acquired attributes while retaining their embedded attributes. Instances of these objects are obtained when actual values are assigned to these attributes as independent variables of the functional element concept. The synopsis of the model description is presented below:

<u>Element</u>

Location: External (Below -, Above -, Partly above ground), Internal, Semi-enclosed.

Inclination: Horizontal, Vertical, Inclined.

Order of Components (Layers in the context of the building envelope):

- External finish or layer (Surface characteristics)
- Vented Cavity
- Thermal insulator and Vapour barrier
- Waterproofing
- Core and/or Carrier
- Supplementary Layer (e.g. filter or drain sheet)

<u>Component</u>

Geometry (Form, Dimension, Position)

Texture and Colour

Material (Chemical, Physical and Biological description)

Intra- / Inter-component Joints

Structural (Self-supporting, Supporting other component of same element / other element)

Restraint/ Attachment / Fixing

The notation above is self explanatory except the distinction drawn between inter- and intra-component joints. The former refers to those between two different components belonging to the same or different elements. The intra-component joints refer to those within the same component consisting of small units or layers, e.g. tiles or laminates.

Hence by superposition of the performance requirement model on the element model a requirement for any given physical entity, e.g. a building element, can be expressed by the compilation or function of the relevant instance of all three entities of this subsystem in any order. A physical entity may acquire a requirement either directly from a notional entity (or indirectly as inherited from its' higher-level descendant physical entities. In both cases of acquisition the requirements become encapsulated in that entity. Hence all requirements may be listed in sequential order by exhaustive enumeration.

$$\text{Requirement}_{w\,xyz} = f(\text{Physical Entity}_w, \text{Life-cycle}_x, \text{Participant}_y, \text{Domain}_z)$$

3. ALTERNATIVE GENERATION

By means of this model element alternatives may be generated through the combination of component and material alternatives. The process of combination entails these steps:

<u>Components constituting the element</u>: The prospective primary components are identified to which element requirements are allocated as component functions.

<u>Arrangement of components</u>: The components identified in the preceeding step may be arranged as layers in different sequential orders with the exception of outer and inner finishes which retain a constant position.

<u>Material of components:</u> Alternatives are listed for each component material and also its' form to be included in the element.

Consequently element alternatives are obtained by exhaustive enumeration. Incompatible combinations are precluded from further treatment.

4. APPLICATION

The conceptual model is demonstrated by an application on the glazed curtain wall of an hypothetical high-rise office block located in an urban area with a temperate climate. The structure is of reinforced concrete. The assumed element performance requirements as designated to functional components pertain to the life-cycle phase of occupancy, the participant of user and the domains of health, comfort, vision and ecology. The element consists of 1.Transparent double-glazing units with gas-filled cavity, reflective and low-E coatings, 2.Aluminium carrier frame and 3.Mechanically augmented structural sealant joints. On the basis of this overall information the element model is implemented below. Note that for the purpose of this exercise the element in question is not indexed to spaces. By induction the components thus become allocated to one or more requirements.

Component Requirement	Component 1	Component 2	Component 3
R_1.Thermal transmittance	C_1.Gas-filled cavity	C_2.Low-E coating	-
R_2.Solar heat factor	C_3.Reflective coating	-	-
R_3.Water penetration	C_4.Sealant joints	-	-
R_4.Air infiltration	C_4.Sealant joints	-	-
R_5.Light transmittance	C_5.Glass	-	-
R_6.Thermal movement	C_6.Carrier frame	C_4.Selant joints	C_7.Fixings
R_7.Structural safety	C_6.Carrier frame	-	-

Alternatives for this element may be generated by altering the relative position (e.g. glazing in front or behind the carrier frame), configuration (e.g. joints with structural sealant or pressure plates) and material (e.g. coating of type A,B or C) of the functional components mentioned above.

5. CONCLUSIONS

The proposed approach described above provides a viable model primarily intended for the manipulation of information related to functional elements as parts of a building from the viewpoint of life-cycle phases, participants and domains. Alternatives for these elements may be generated and consequently appraised, thus acting as a tool for all concerned involved in the design or selection process of products related to buildings at various scales. Further research is anticipated to be conducted in the field of establishing priorities of performance requirements.

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