CONCEPTUAL PERFORMANCE AND PRODUCT MODELS FOR BUILDINGS AND THEIR ELEMENTS

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ABSTRACT

A conceptual model is presented for building elements to enable performance simulation. 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, e.g. elements. The notional subsystem for representing the performance requirements comprises transitive entities. These are listed as Life cycle phases, Participants, Domains. The subsystem that conveys information on physical objects on the other hand has an hierarchical order and encompasses intransitive entities, namely Building, Space, Element, Components. Thus 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 as indexed to the relevant instance of all three entities of this subsystem in any order.

INTRODUCTION

Elements greatly affect the overall performance of buildings. They are either based on previous examples or designed by collective experience or intuition. They are referred to with conventional terms, e.g. floors, walls and roofs. These labels remain to be sufficient as far as conveying information on familiar solutions are concerned. Beyond that scope an effective model is essential for accurate performance simulation. Hence 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 such a tool for generating alternatives of building elements for performance simulation.

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). Aygun suggests a method for comparative appraisal of design alternatives by means of multiple performance criteria (Aygun 2000a). Aygun et al. describe a parametric product model for the generation and evaluation of building element alternatives (Aygun 2000b). 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 modeling (Tang 1997). Vanier et al propose a product model for representing user requirements as a complete data structure (Vanier 1996).

MODEL

The proposal consists of 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 conditions of the environment in which the building will situated. They are considered as external or internal factors. Most constraints relate to the site, climate, surrounds and 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 concerned. Each instance of the preceding 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, legislation, community),
3. Domains (safety, health, comfort, utility, ecology, cost)

Element Model: The subsystem that conveys information on physical objects on the other hand has an hierarchical order and contains intransitive entities each preceding 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
   3.1. Functional building elements (e.g. floors, walls, roofs),
   3.2. Structural system (e.g. steel, timber, reinforced concrete),
   3.3. Service systems (e.g. HVAC, electrical, mechanical)
4. Components (e.g. finish, insulation, waterproofing, core) and
5. Materials (concrete, steel, timber, glass).

The approach follows the main principles of object-oriented modeling, i.e. 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:

Element= f(Components),
Components= f(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:

Element
    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)

Component
    Geometry (Form, Dimension, Position)
    Texture and Colour
    Material (Chemical, Physical and Biological description)
    Joints (Unifying/Separating, Intra-/Inter component)
    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.

Thus 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 are contained in that entity. Hence all requirements may be indexed to each entity in sequential order.

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

APPLICATION

The prescribed method is illustrated by means of an application at the element level of the conceptual model. The hypothetical element under investigation is the paved flat roof of a sports hall in a suburban area with a temperate climate. The building structure is a single span steel frame with trussed roof girders. The consecutive steps followed are elucidated below.

1. Requirements and Components: The interaction between performance requirements and components are established in conjunction with the associated life cycle phase (occupancy), participants (user) and domains (safety, comfort, ecology, cost) in Table 1. An example of this requirement notation is given below:

Thermal transmittance= f ((Thermal insulator, Core), Occupancy, User, (Ecology, Comfort, Cost))

2. Element alternatives: Generic alternatives for the roof element are obtained by the combinatorial process of changing the arrangement (i.e. the relative position of components), material and also form of components, thus yielding 768 ($=4!x2^4$) number of roof alternatives . Table 2 displays the first 4 of 24 combinatorial alternatives of component arrangements among which Arrangement 1 is chosen to be the most suitable. Two alternatives are provided for the material and form of each component (Table 3). Hence the number of alternatives is reduced to 16 (=4!). The heat transmittance coefficient of all the roof alternatives is maintained as a constant value, i.e. 0.4 W/m^2 ^oC. Note that for the purpose of this exercise the element in question is not indexed to spaces.

CONCLUSIONS

The proposed approach described above provides a viable model primarily intended for performance simulation of functional building elements from the viewpoint of life-cycle phases, participants and domains . Benefits that may be derived from the implementation of this parametric representation include generation of configurations for plausible alternatives and their comparative appraisal in terms of performance criteria. Further benefits are envisaged to be efficient exchange and repository of information for the purposes of performance specification and product development. Thus streamlined retrieval and dissemination of notional and factual information related to buildings and their parts are facilitated acting as a tool for all concerned involved in the design or selection process of products related to buildings at various scales. Some examples of application are provided below at various scales of design for the purpose of performance simulation: Life-cycle analysis of buildings or elements in terms of environmental impact, energy, resource, cost and activity, Shape and size of building blocks and elements, Floor shapes and areas of internal or external spaces, Modules of the structural grid, Shape and size of structural members, Modules of façade and floor elements, Combinations of layers within elements and their thicknesses, Transparency ratio and aperture sizes in the external envelope, Roof form and pitch, Composition of materials.

At present research is in progress on quantifying performance requirements. Further research is anticipated to be conducted in establishing priorities of performance requirements pertaining to the built environment.

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Table 1: Interaction between Requirements and Components

Requirements	Components
q_1 Thermal transmittance	c_1 External finish
q_2 Thermal capacity	c_2 Air gap
q_3 Solar heat factor	c_3 Thermal insulator
q_4 Water penetration	c_4 Waterproofer
q_5 Sound reduction index	c_5 Core
q_6 Structural safety	
q_7 Thermal movement	
q_8 Fire resistance	

Interactions

	q_1	q_2	q_3	q_4	q_5	q_6	q_7	q_8
c_1			✍				✍	
c_2			✍				✍	
c_3	✍				✍		✍	✍
c_4				✍				✍
c_5		✍			✍	✍	✍	✍

Table 2: The first 4 of 24 combinatorial alternatives of component arrangements

Arrangement 1	Arrangement 2	Arrangement 3	Arrangement 4
c_1 External finish	c_1 External finish	c_1 External finish	c_1 External finish
c_2 Air gap	c_2 Air gap	c_2 Air gap	c_2 Air gap
c_3 Thermal insulator	c_3 Thermal insulator	c_4 Waterproofer	c_4 Waterproofer
c_4 Waterproofer	c_5 Core	c_3 Thermal insulator	c_5 Core
c_5 Core	c_4 Waterproofer	c_5 Core	c_3 Thermal insulator

Arrangement 1

	c_1	c_2	c_3	c_4
c_2	✍			
c_3		✍		
c_4			✍	
c_5				✍

Arrangement 2

	c_1	c_2	c_3	c_4
c_2	✍			
c_3		✍		
c_4				
c_5			✍	✍

Arrangement 3

	c_1	c_2	c_3	c_4
c_2	✍			
c_3				
c_4		✍	✍	
c_5			✍	

Arrangement 4

	c_1	c_2	c_3	c_4
c_2	✍			
c_3				
c_4		✍		
c_5			✍	✍

Table 3: Material and form alternatives for components

Component	Alternative 1	Alternative 2
External finish	Concrete slabs on pads	Ceramic tiles on screed
Insulation	Extruded polystyrene board	Polyurethane board
Waterproofer	Bitumen sheet	PVC sheet
Core	Profiled steel sheet	Hallow concrete panels