A Prototype Generative System for Construction Details

Combining FBS Descriptions with Design Grammars

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Keywords: construction, grammar, geometric description, redesign

Abstract: A formal framework for redesign based upon Function-Behaviour-Structure models and design grammars is described. A proposed application domain is for the design and redesign of construction assemblies. GDL object technology is illustrated as a candidate tool for implementation.

1 BACKGROUND

Building upon previous work with function/behaviour/structure grammars (Chase and Liew 2001a), we consider here their application for the generation of construction assemblies. There have been a number of generative systems developed for detail or component based design, usually entailing the use of an expert system or other reasoning mechanism. (Harfmann 1993; Seebohm and Wallace 1998) Another possible paradigm for detail design has been parametric variation; the Topdown system allowed simultaneous top down and bottom up design processes (Liggett, Mitchell and Tan 1992). Design grammars in general have not been utilised for construction detailing, with the possible exception of the EAVE system for roof details (Mitchell and Radford 1987). Function based grammars are becoming commonplace in engineering design domains (Starling and Shea 2002). In our work we utilise a grammar based methodology with a function/behaviour/structure representation as a facilitator of detail redesign by substitution. We describe a prototype implementation using GDL object technology.

2 GENERATIVE FRAMEWORK

Our current work expands upon the original framework, which was based solely upon redesign (Chase and Liew 2001a). In the earlier model, initial design representations were based on geometric features, interpreted from CAD models using feature grammars. The current framework allows the selection of design components from a pre-existing knowledge base. As before, stylistic change, defined by rule modifications, (Knight 1994) serves as the basis for rule replacement in the derivations of the original design with new rules that produce designs conforming to revised requirements.

For redesign, a domain-specific knowledge base is used to create a feature grammar predicated on the functional requirements of the design. This grammar is used to interpret a geometric CAD model through a parsing process to create a design description of geometric features, if one does not already exist. Each rule of this grammar has an associated description that adds functional or behavioural information to that of the geometric features. The Function-Behaviour-Structure (FBS) model of design (Gero 1990) is used to encapsulate this information.

Figure 1 illustrates a panel wall with a possible FBS representation, in which the wall's functional, behavioural and structural (i.e. physical) components and attributes are graphed with their functional dependencies. The Structure box illustrates the physical components of the wall (circles) linked with their associated attributes. The dashed lines indicate physical adjacencies; the arrows, functional dependencies of behaviour to structure and function to behaviour. External effects on behaviour (e.g. climate) can also be incorporated into the model; they are not considered for the panel wall but can be seen in a later example (Figure 7). The same knowledge base can be used to generate rules that define the underlying functional and behavioural requirements for the relevant design domain (Figure 2).

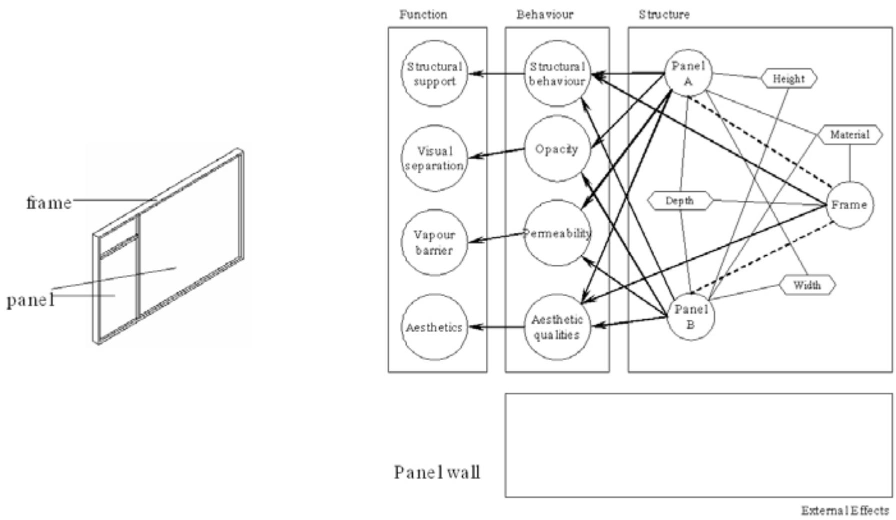

Figure 1 A Panel Wall and its Corresponding FBS Representation

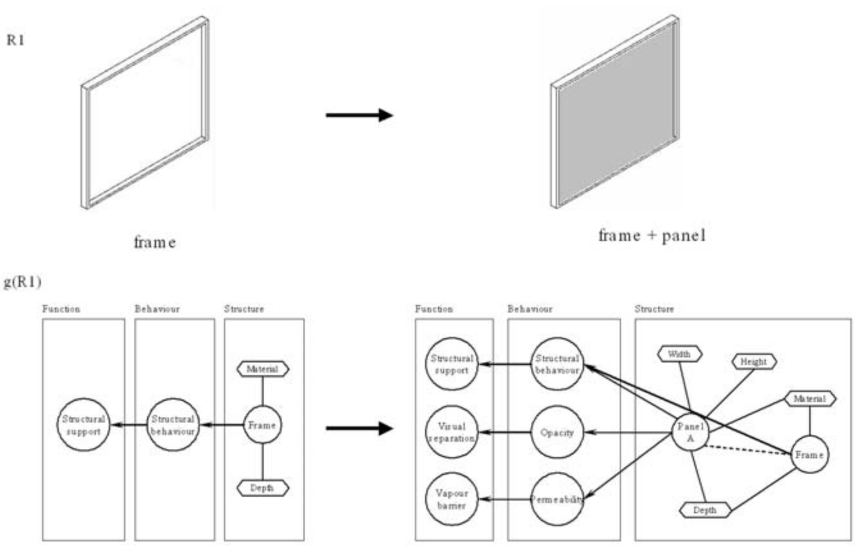

Figure 2 A Rule to Generate a Panel Wall and its FBS Description

The parse of the original design links the set of domain-specific rules to the original rule set. For every original rule used in the parse, its functional or behavioural description is indexed to the new rule set; this allows alternatives to existing design structures to be retrieved. An FBS network defines the search space within which the functional/behavioural indexes operate. By searching the indexed knowledge base of rules, then substituting rules in a derivation with those having similar function-behaviour descriptions, a new grammar is created. This ‘transformed’ grammar generates a new set of designs through the modification of the design state space. The basic steps in the process, listed below, can be seen in Figure 3.

1) Creation of original model without an FBS description
2) Feature recognition
3) Creation of adjacency subgraphs
4) Search of knowledge base for matching subgraphs
5) Extraction of FBS grammar rules from knowledge base
6) (Re)creation of original design with FBS descriptions
7) Possible additional knowledge input from designer
8) Redesign initiation: indexing of FBS nodes in design for knowledge base search
9) Search of knowledge base for alternative rules matching FBS descriptions
10) Replacement of original FBS rules with alternatives; generation of new design

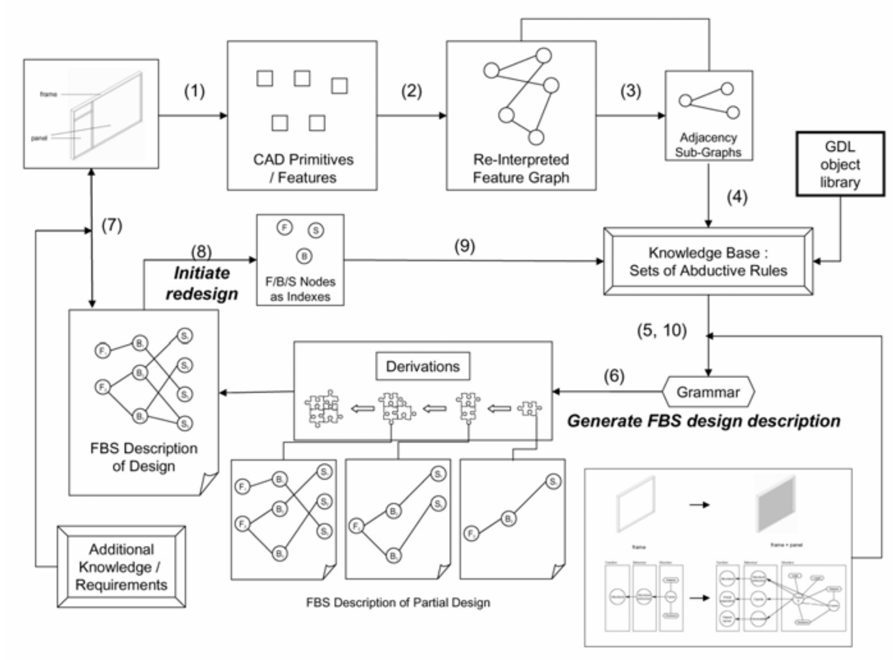

Figure 3 Framework for FBS Description and Redesign

3 GDL IMPLEMENTATION

GDL (Geometric Description Language) (Croser 2001; GDL Technology 2002) is a scriptable language similar to BASIC that facilitates the construction of virtual objects which can be used in a variety of CAD environments. GDL objects can contain both geometric and non geometric attributes such as material, thermal, acoustic properties and cost (Figure 4).

GDL was originally developed by Graphisoft for use in its ArchiCAD™ software, where a model can consist entirely of customisable GDL objects. The technology is currently available as an open standard, thereby facilitating the potential sharing of GDL objects among different CAD systems or viewing through browsers (GDL Technology 2002).

GDL objects can be used to represent building components such as doors, windows, walls, roofs, furniture, plumbing fixtures, HVAC systems, structural elements etc. These components can adapt to changing conditions through a customisable application program interfaces (APIs). GDL objects are typically used in two ways:

- As parametric building elements
- As manufacturer's components (currently a handful of manufacturers

provide downloadable GDL objects from their product catalogues).

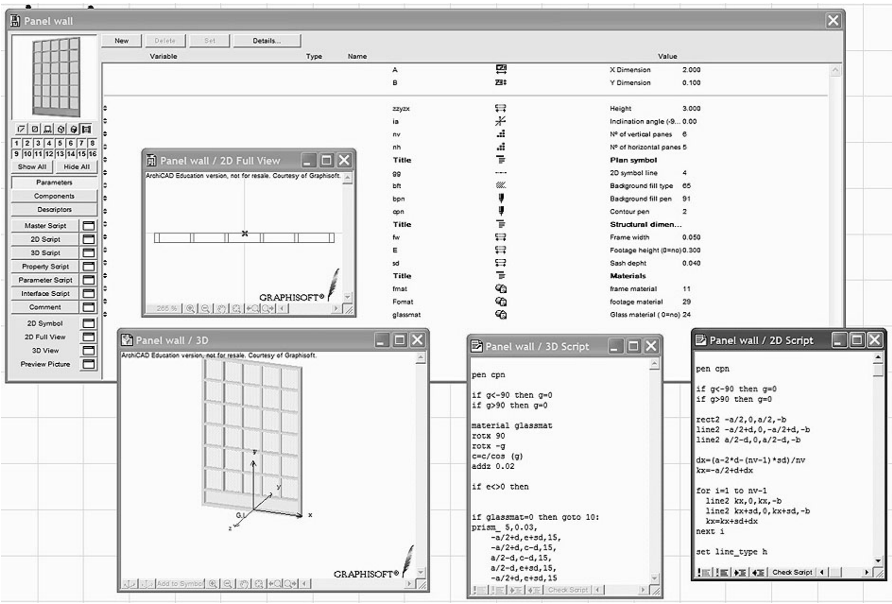

Figure 4 Panel Wall GDL Object

Our implementation uses GDL objects as the CAD database components, with a library and knowledge base of GDL prototypes containing functional, behavioural and structural properties (either explicitly or as derived attributes). An external inference engine will facilitate the retrieval of applicable objects from the knowledge base, construction of grammar rules, and replacement of the associated objects in the existing design. Although we focus here on parametric building elements, the framework could also be used for intelligent selection or replacement of manufacturer’s components, based upon given criteria.

Because GDL objects can incorporate functional, behavioural and structural attributes, they are introduced into the process as objects for inclusion in the knowledge base. This facilitates use of the knowledge base for initiating design with FBS grammars using GDL objects from Step 5 of the process, thus bypassing the feature recognition stages.

4 APPLICATION EXAMPLE

As an example of how the framework could be used for redesign, we describe two different wall types modelled with GDL, and how the GDL object technology can facilitate the replacement of one design with another. Figures 4 and 5 illustrate a GDL representation for a parametric panel wall, with parameters including overall size, inclination angle, configuration of panels (number and size), frame width and materials.

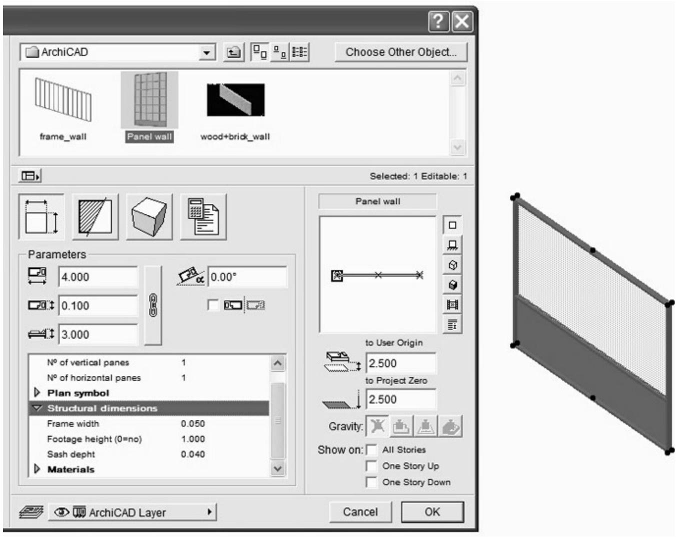

Figure 5 Panel Wall GDL Instance

Now suppose that the wall must now satisfy additional performance criteria, such as thermal and acoustical requirements. In the original design of the panel wall, these criteria were judged not significant and thus the associated behavioural attributes were not included as part of its description.

The redesign process would commence at Step 8, in which the generic wall attributes (e.g. dimensions, structural behaviour) are indexed from the panel wall FBS description. The knowledge base is then searched for generative rules matching the relevant FBS attributes as well as the additional thermal and acoustical ones. In our example, rules that construct a composite wall with these attributes are retrieved and used to regenerate the wall design with its new description and appropriate attribute values.

Figure 6 illustrates the GDL representation for composite wall object. Table 1 lists the wall components in the GDL description, while Table 2 shows additional behavioural attributes (thermal and acoustical), also part of the composite wall description that are not part of the panel wall.

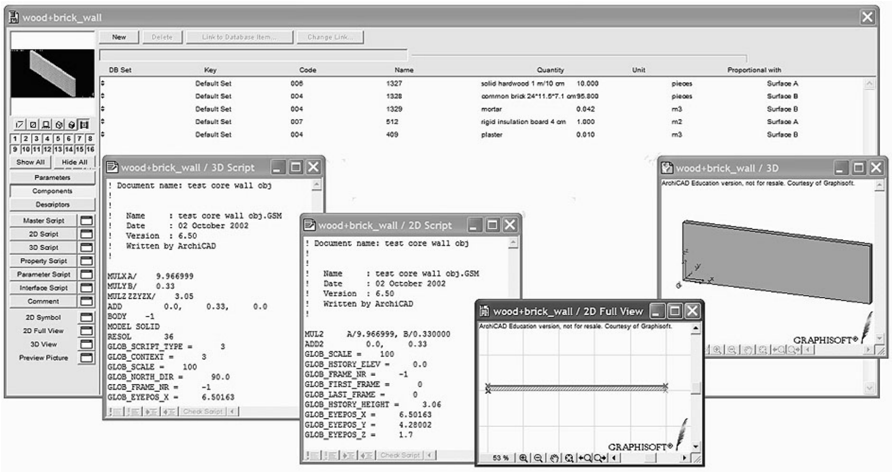

Figure 6 Composite Wall GDL Object

Table 1 Components of the Composite Wall

Key	Code	Name	Quantity	Unit	Proportional width
006-Wood-Plastic	1327	solid hardwood 1 m/10 cm	10.000	pieces	Surface A
004-Masonry	1328	common brick	95.800	pieces	Surface B
004-Masonry	1329	mortar	0.042	m3	Surface B
007-Thermal & moisture protection	512	rigid insulation board 4 cm	1.000	m2	Surface A
004-Masonry	409	Plaster	0.015	m3	Surface B

Table 2 Additional Behavioural Attributes for the Composite Wall

Key	Attribute	Value
009-Finishes	Description	-10 cm wide board siding nailed to 7*4 cm furring furring every 45 cm common brick with raked joints interior face: 2 coat plaster, 15 mm total
007-Thermal	U-value	0.134

& moisture protection		
001-General	Sound transmission class	54

An understanding of the differences in the functional, behavioural and structural aspects of the original panel wall and the new composite wall design can be obtained through a comparison of their FBS descriptions (Figure 7). Note that due to the additional functional requirements for the control of noise and heat loss, and the measured behaviours associated with them, the effect of external variables such as climate becomes relevant.

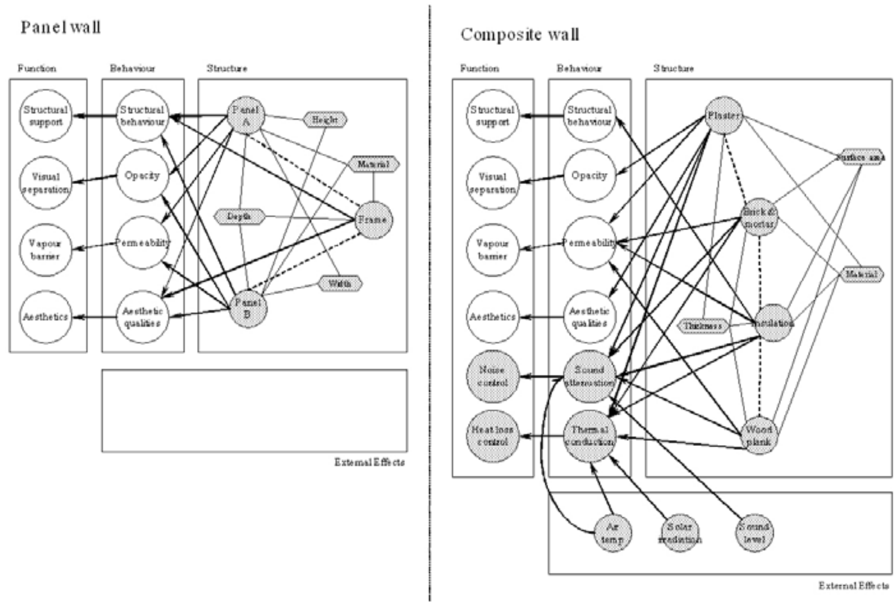

Figure 7 Comparison of the panel and composite wall FBS descriptions. Differences are shaded.

5 DISCUSSION

5.1 Causal Relationships in Redesign

In our example the introduction of new functional requirements (thermal and acoustic) resulted in the complete replacement of the original physical structure. Other possibilities for redesign could result in less drastic modification of the FBS network or a simple modification of the acceptable range for behavioural or structure variables. We also note that the introduction of new functions initiated the redesign process and have also investigated other types of redesign scenarios. For example, in Design for Assembly (DFA), the requirement for fewer parts can lead to a partial modification of structure, but may introduce new behaviours (e.g., the replacement of a nut and bolt fastener with a snap-fit fastener adds the behaviour of elastic distortion (Chase and Liew 2001b)).

In the broadest context, redesign can be considered as the modification of function, behaviour or structure. The relationship between them can be viewed as a causal chain (Gero 1990). In the wall example, adding new functional requirements drives the modification of behaviour, and thereby, structure. In the case of the fastener (DFA), replacement of the structure (nut/bolt) with a different one (snap-fit) affects the behaviour but does not change the functional requirements. There are other ways to drive redesign, and are worthy of investigation in the context of our framework.

5.2 Current and Future Work

Our current work involves the development of GDL object descriptions that can be used in the generative framework described. In order to fully implement the framework described, there are a number of issues that require further investigation:

- Given that a local design modification may cause the need for more global design changes (particularly with construction details), how can one manage these local modifications? What sort of constraint management and propagation is to be implemented?
- How will the interface to the system operate, i.e. how does one control the redesign process? How is choice handled, when there is more than one possibility for a redesign? These issues are discussed by Chase (2002).

The generative design framework described represents a new application for grammar based methodologies—their use for redesign, in combination with FBS models. The use of GDL objects in the framework as an existing and rapidly growing technology facilitates its development, while expanding the potential uses of the paradigm by means of new knowledge bases.

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