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A Systematic Method for Redesign

Using function, behaviour and structure to facilitate grammar transformation

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We present a formal framework for redesign. Stylistic change, defined by grammar rule modifications, serves as the basis for rule replacement with ones that produce designs satisfying revised requirements. Each grammar rule has an associated description that adds functional or behavioural information to the geometric representation of the design using Function-Behaviour-Structure representations. This method provides a formal mechanism for redesign and defines a means to generate and link structures with different behaviour and functions within the FBS model of design. We demonstrate this with an example of redesign of a wall responding to changing functional requirements, and also discuss its usage in other types of redesign problems.

Keywords*: redesign, design grammars, Function-Behaviour-Structure models, feature based design*

Introduction

Design projects are often multidisciplinary. An initial design created in one domain is usually subject to modification by another due to differing requirements. In this context, redesign is considered as the process of modifying an existing design based on additional criteria from another domain. The current workable design is the starting point for the redesign process.

This paper describes a formal framework for redesign. The representational foundation for this framework is based on feature grammars (Brown, McMahon, & Sims Williams, 1995). The concept of stylistic changes as defined by rule modifications (Knight, 1994) is the basis for replacing rules used in the derivations of the original design with ones that produce designs conforming to new requirements. The mechanism that enables this replacement is based on the Function-Behaviour-Structure (FBS) model of design (Gero, Tham, & Lee, 1992). The main concepts for the redesign framework are described below, with an example application involving the redesign of a wall.

Feature grammars and knowledge bases

Original designs are typically produced with a CAD tool. The design process can be carried out with simple geometries or predefined feature sets. The only requirement is that the resulting model be interpretable using feature sets of the required domain. Typically, features are represented as graphs in a solid model data structure to enable graph grammars to be used for automatic feature recognition (Pinilla, Finger, & Prinz, 1989).

A domain-specific knowledge base is used to create a feature grammar based on the functional requirements of the design. This grammar is used to parse the original design, producing a structure based

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on the grammar rule invocations. Each rule of the grammar has associated descriptions containing functional or behavioural information. The parsing process extracts feature information from the initial design model, allowing reconstruction of the initial design with the additional functional or behavioural descriptions. The knowledge base is also used to generate a set of rules (with similar functional or behavioural descriptions) that defines the underlying requirements for that particular domain.

FBS model of design

In the FBS (Function-Behaviour-Structure) framework of design knowledge, function defines what the artefact does, while structure specifies the component parts and their interconnections. Behaviour specifies how the structure of the artefact achieves the required function and acts as a link between function and structure.

This framework of design knowledge explicates the relationships between function, behaviour and structure of an artefact and facilitates explicit reasoning among them (Gero et al., 1992). The incorporation of behaviour breaks the rigid coupling between form (structure) and function, thus providing an opportunity to explore a wider variety design possibilities without prejudice to certain artefacts, thereby facilitating innovative solutions.

The relationships between function, behaviour and structure are described using dependency networks. These networks show explicitly the relational, computational and qualitative knowledge among function, behaviour and structure in a schematic form. Graphs can be used to represent the dependency network (Qian & Gero, 1996). Each node in the network represents either a function; behaviour; structure or their characterising variables and the link across nodes describes the dependency between them. Figure 1 illustrates a sample FBS representation for a panel wall.

Previous work using FBS paradigms has focused on the static representation of FBS descriptions and not on their generation. As we are interested in redesign, we consider dynamic descriptions and use a description function for constructing FBS representations as the geometric representation is generated by the design grammar (Liew & Chase, 2001) (figure 1).

Stylistic change and grammar transformation

Terry Knight (1994) has demonstrated how systematic modification of shape grammars can encapsulate stylistic change. This occurs through addition, deletion

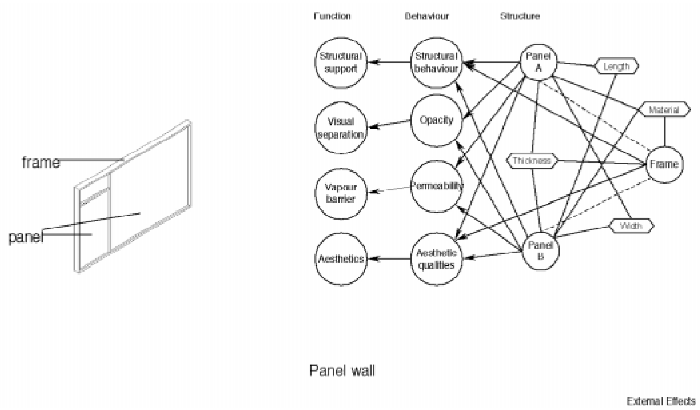

Figure 1. A panel wall and its corresponding FBS representation

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or modification of grammar rules, often by shape replacement or modification of spatial relations. Examples of this include the transformation of Wright's Prairie style to Usonian style, and the evolution of the artist Vantongerloo's painting style. While Knight's description of stylistic change is elegant by its use of grammar rule modifications, there is little mention of the motivation for any modification.

We choose to utilise recognised but informal design principles as the rationale for specific rule substitutions (DFX, e.g. Design For Assembly, design simplification (Boothroyd, Knight, & Dewhurst, 1994)). In this way Knight's model of stylistic change via grammar modification is extended by including transformations based on the modification of functional, behavioural or structural characteristics of designs. This technique also provides a formal method for employing DFX principles.

Redesign framework

Redesign occurs in our model by specific operations upon the functional, behavioural and structural properties of the original design in the context of additional requirements. An FBS description of the original design is generated and later modified. Figure 2 illustrates the process flow, detailed in the following sections (figure 2).

Construction of FBS descriptions

A design is created with a tool such as a solid modeller by using its native geometries or predefined feature sets (1). The resulting model is reinterpreted as graphs of the required features specific to the relevant domain for redesigning (2).

Adjacency subgraphs of this feature graph are extracted (3) and used to search a knowledge base (4) for rules that model part of the designer's knowledge. Each rule R is modelled with a description function g(R) that generates an associated FBS description. The structure part of this description contains adjacency information between physical elements that is matched against the adjacency subgraphs from the original design for the retrieval of relevant rules (Figure 3).

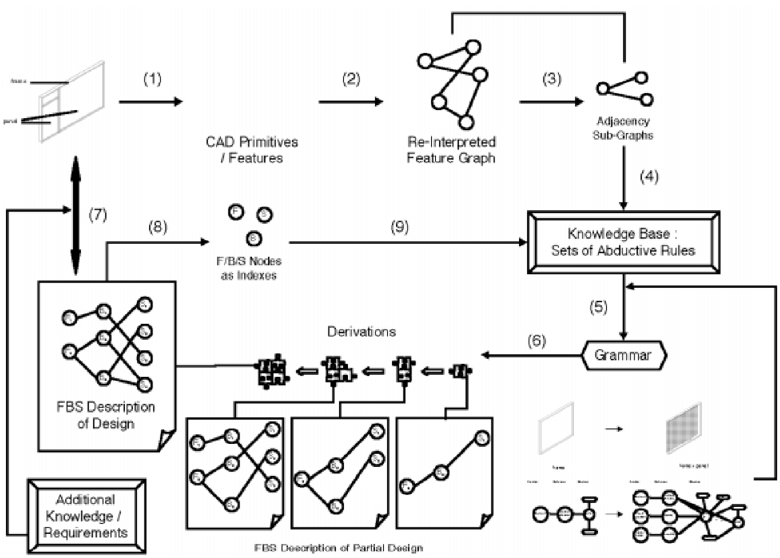

Figure 2. Construction of FBS description and the redesign process

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A grammar is assembled from a set of such rules (5) and then used to generate the original design (6) with an associated FBS description (represented as a graph with the functional, behavioural and structural properties as nodes and their relationships as arcs). Additional input from the designer may be required to form a more complete FBS description, as the derivation only provides a partial description (7). This additional information could be obtained from a functional analysis of the original design (figure 3).

Redesign process

To initiate redesign, the nodes in the FBS description of the original design are used as indexes (8) in the search for alternatives from the library of grammar rules (9). New rules are selected, based on new requirements for the functional, behavioural and structural properties of the original design. The original rules in the grammar are replaced by the new ones, resulting in the transformation or "adaptation" of the original grammar. A new design with its associated FBS description is generated using the transformed grammar. A comparison of the original and modified FBS descriptions highlights potential requirements for elements that were added or modified.

An example: wall redesign

The following example illustrates an application of the framework in the context of redesigning a wall to satisfy additional performance requirements. It is loosely based on the EDM representation of panel and core walls (Eastman, Bond, & Chase, 1991).

We assume that the user utilises features (wall and panel components) to design the wall assembly (Figure 4). The adjacency subgraph for these features can be obtained from the CAD database of the original design. The subgraph is used to search for rules in the knowledge base that have the same adjacency information in their FBS descriptions (e.g., compare the panel-frame subgraph on the right side of g(R1), Figure 3 with a subgraph of the one in Figure 4).

A grammar is assembled from a set of these rules and then used to generate the original wall assembly with an associated FBS description (Figure 1). Note that the panel insertion rule provides only part of the FBS description. The aesthetic properties are obtained from the designer's knowledge base. Other such functions and behaviours could be added through functional analysis, e.g. increased rigidity for structural behaviour (figure 4).

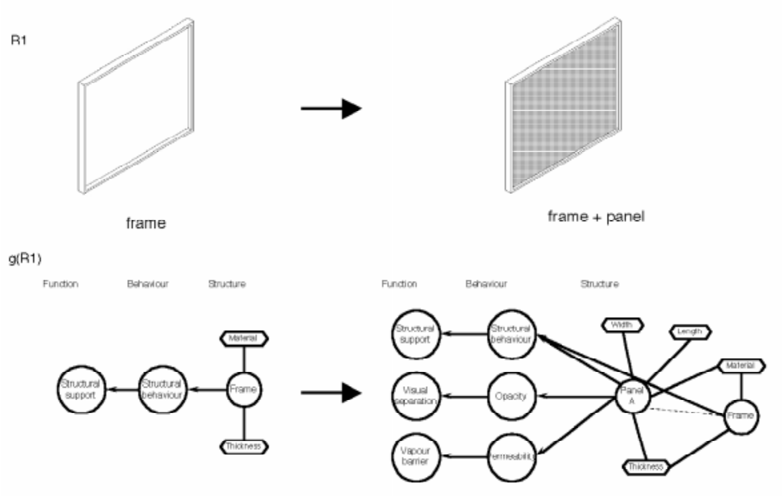

Figure 3. A sample abductive rule R1 with its associated function g(R1) to generate the FBS description of a panel wall

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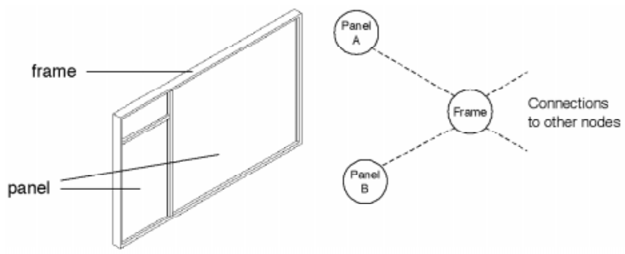

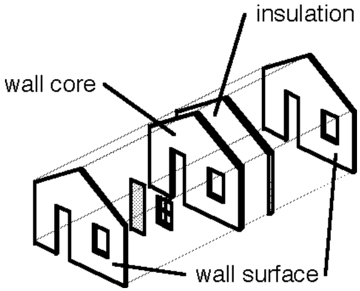

Figure 4 (left and middle). Panel wall and its adjacency graph

Figure 5 (right). Core wall construction

For redesign in the context of this example, we assume that the acoustic and thermal properties of the proposed wall now become relevant, having previously not been considered in the FBS representation for the panel wall. These functional and behavioural requirements (control of noise and heat loss) are added to the FBS description of the proposed wall (8), which currently contains requirements for structural support, vapor barrier, visual separation and aesthetics (Figure 1). The knowledge base is searched for rules that contain these nodes (9). Rules such as those that construct core walls (Figure 5) can be used to transform the grammar by replacing the analogous rules for panel walls. By replacing the rule invocations of R1 in the original derivation (6) with those for generating core walls, a new wall is generated that satisfies the additional requirements, and the original grammar has been adapted (figure 5).

A comparison of the FBS descriptions of the original and modified designs can elucidate the differences in their functional, behavioural and structural aspects (Figure 6). With additional functional requirements and the measured behaviours associated with them, the effect of external variables such as climate is now relevant.

Discussion

In our example the introduction of new functional requirements resulted in the complete replacement of the original structure. Other possibilities for redesign could result in less drastic modification of the FBS network or simply modification of the acceptable range for behaviour or structure variables. We note that the introduction of new functions initiated the redesign process. In other situations, such as Design for Assembly (DFA), a requirement for fewer parts might lead to a partial modification of structure, but could introduce new behaviours. For example, the replacement of a nut and bolt fastener with a snap-fit fastener adds the behaviour of elastic distortion (Chase & Liew, 2001) (figure 6).

We can consider redesign as modification of function, behaviour or structure. The relationship between them can be seen as a causal chain (Gero, 1990, Figure 7). In the wall example, adding new functional requirements drives the modification of behaviour, and thereby, structure (Figure 8a). 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 (Figure 8b). There are other ways to drive redesign. Balázs & Brown (1998) consider design simplification, as occurring by modification of structure, behaviour or function, with an illustration of behavioural simplification.

Summary and conclusions

In this paper we have proposed a framework for redesign by grammar modification through rule replacement. Testing of this framework is yet to be done. Other possible areas of investigation include:

- Use of the framework for more complex examples than that illustrated here. How well will this methodology scale?

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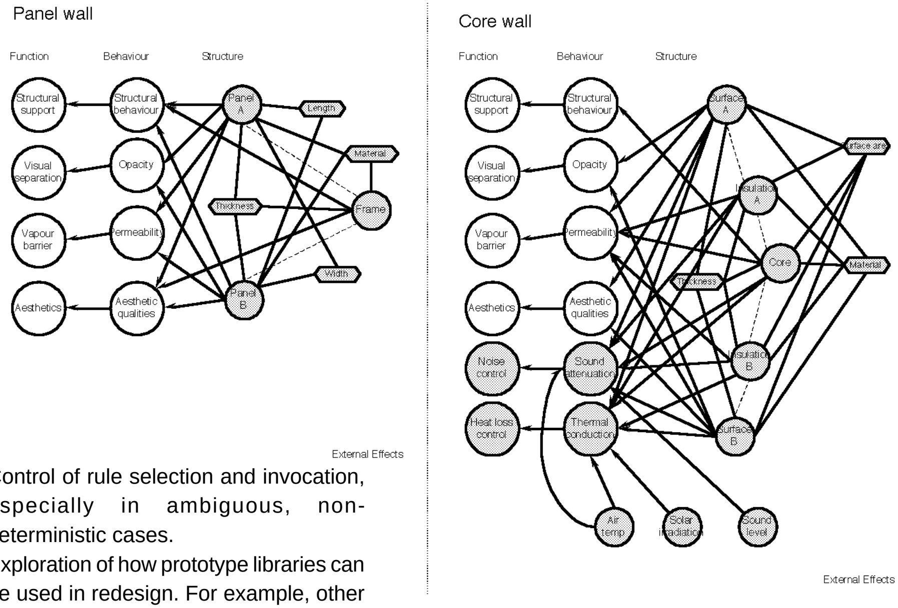

Figure 6. Comparison of the panel and core wall FBS descriptions. Differences are shaded.

- Control of rule selection and invocation, especially in ambiguous, non-deterministic cases.
- Exploration of how prototype libraries can be used in redesign. For example, other possible paradigms used for redesign not examined here include combination, analogy and case-based reasoning.
- Formalisation of design principles (DFX) by graph operations on FBS descriptions.

Our methodology formalises redesign based on functional, behavioural and structure requirements. The generation of FBS descriptions of designs is based on adjacency graphs of their components and knowledge bases of component behaviour. Through rule replacement (grammar transformation), new designs are created to satisfy new requirements. This framework has the potential to support the formalisation of established design principles (figures 7 & 8).

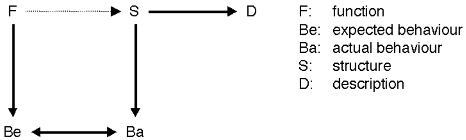

Figure 7 (right). Causal relationships between function, behaviour and structure (Gero, 1990)

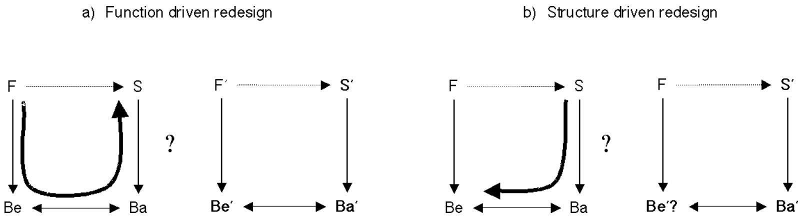

Figure 8 (down). Two different methods for redesign

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