A KNOWLEDGE-BASED REVERSE DESIGN SYSTEM FOR DECLARATIVE SCENE MODELING

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Abstract: Declarative modeling allows the designer to describe a scene without the need to define the geometric properties. The MultiCAD architecture implements the declarative forward design, accepting a declarative description and generating a set of geometric solutions that meet the description. The aim of the presented work is to settle the reverse design process through the RS-MultiCAD component, a knowledge-based system, in order to extend MultiCAD declarative conception cycle to an automated iterative process. The RS-MultiCAD receives a selected geometric solution, which is semantically understood, permits the designer to perform geometric and topological modifications on the scene, and results a declarative description which embodies the designer modifications. That declarative description leads to more promising solutions by reducing the initial solution space.

1 INTRODUCTION

Declarative modeling is an approach (Lucas, 1989) that allows the designer to describe a desired scene without the need to define the geometric properties overcoming CAD applications drawbacks. A set of solutions are generated that meet the initial description. A special approach of the declarative modeling is declarative modeling by hierarchical decomposition (Plemenos, 1991), which gives the user the ability to describe a scene by top-down decomposition at different levels of abstraction. The objective of this method is to remedy the disadvantages of the traditional geometric modeling by allowing the description of a scene by its properties, which can be imprecise and incomplete. More accurately the declarative modeling makes possible to indicate the properties, which verify the desirable scene in several levels of detail allowing thus a top-down design.

MultiCAD architecture (Miaoulis, 1996), (Miaoulis, 1998) is an intelligent multimedia CAD system, liberated of geometrical inflexibility that accepts a declarative description of a scene and produces a set of solutions that meet the description itself.

Our goal is to implement the declarative reverse design by constructing a new declarative description from an initially selected geometric solution which has been modified by the designer in order the design process to become iterative automatically until the system produces the most desirable

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solutions. The new component is placed within the MultiCAD architecture. The introduction of the new component was first discussed in (Golfinopoulos, 2005) and the current work presents the functionality that underlies the RS-MultiCAD prototype component.

1.1 Declarative Conception Cycle

The declarative scene modeling is based on the declarative conception cycle, which consists of three sequential functional phases (Plemenos, 1995). The first is the scene description phase, where the designer describes how he perceives the scene by specifying properties of the scene or leaving them ambiguous. The second is the generation phase, where the generator inputs the declarative model and produces a set of solutions that meet the description of the desired scene. The third is the solution understanding phase, where the scene solutions are visualized through a geometric modeler.

1.2 MultiCAD Architecture

The design environment of MultiCAD features a rich set of modules. These include alternative modules for solution generation using CSP (Plemenos, 1997) or genetic algorithms (Vassilas, 2002), (Makris, 2005) as well as modules responsible for introducing architectural knowledge (Ravani, 2003), representation of architectural styles (Makris, 2003), collaborative design (Golfinopoulos, 2004), and intelligent user profile (Plemenos, 2002), (Bardis, 2005).

MultiCAD incorporates an object-relational database (Miaoulis, 2000), which consists of five logical inter-connected databases. The scene database is supporting information describing the scene models. The multimedia database is containing all types of documents related to the project. The knowledge base is containing all the necessary information about type of objects, their properties along with their relations. The project database is manipulating with data concerning planning, financial and other special aspects of each project and finally the concept database (Ravani, 2004) is storing concepts representations.

The scene database is configured following the Scene Conceptual Modeling Framework (Miaoulis, 2000). The description contains objects defined by their properties, simple or generic ones, as well as group of simple objects with properties in common. Besides, the description contains three types of relations between objects: meronymic ("is part of", "is included in"), spatial organization ("adjacent south", "equal length") and reflective ("higher that large", "wider than deep") relations. Finally, the description also contains properties which describe objects.

1.3 Related Work

It is evident that the forward design in the declarative modeling transforms a declarative description into a set of geometric representations. The reverse design process (Vergeest, 2005), (Wang, 2003) is a workflow of design where, in our case, the declarative description is constructed by the geometric model obtained from the system database or external source.

In the declarative modeling framework, the XMultiFormes project (Sellinger, 1998), is a previous work that integrates the two modelers by using a special interface system to ensure that there is full and complete transfer of information between the declarative and a traditional geometric modeler. This system translates the geometric representation to one that is more suited to interactive modeling. A labeling sub-system is responsible for capturing non-geometric information, which is implied in the declarative description and the geometric-to-declarative conversion process converts a geometric instance to declarative description.

According to (Peng, 2001) one of the application areas of a reverse engineering is the reverse design. The reverse design either creates a new product from an initial model or feeds a recovered result back to an existing product model to compare and update.

In (Fisher, 2004) is presented the contribution of knowledge in reverse engineering problems. The problems considered are how to enforce known relationships when data fitting, how to extract features even in very noisy data, how to get better shape parameter estimates and how to infer data about unseen features. Even if the current work focuses on the reconstruction, it shows that the applicability of domain knowledge, in the general framework of the knowledge-based approach, plays a significant role in the reverse process.

2 EXTENDED MultiCAD DESIGN METHODOLOGY

The declarative conception cycle of MultiCAD architecture can be extended to an iterative process by using a reconstruction phase (Golfinopoulos, 2005) where the scene is understood semantically and refined by adding more detailed descriptions in

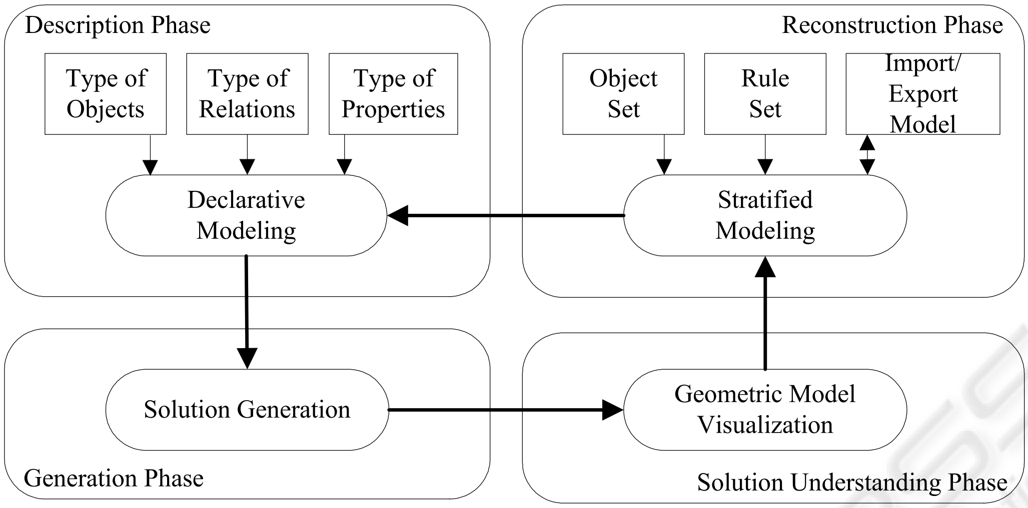

Figure 1: MultiCAD design methodology and modeling levels.

successive rounds of declarative design process. In that case undesirable designs are cut from the set of solutions, the size of solution set after each round of generation can be reduced and after a few iterations the designer gathers all promising solutions. The aim of the reconstruction phase is to receive a geometric model and provide a new declarative description enhanced with geometric constraints to the scene declarative phase. The proposed system is a knowledge-based system that implements the declarative reverse design. Under the reconstruction phase, the designer changes the geometry of the scene by modifying the topological relations and geometric aspects of the objects. These changes are checked semantically and the special representation is updated.

The extended MultiCAD design methodology starts with the description of the desired scene in terms of objects, relations and properties through an interface. A rule set and object set are built representing the designer requirements of the scene.

Initially, the object set consists of all objects of different level of abstraction, and the rule set consists of all relations, properties that the designer has declared during the declarative description phase. Based on that rule set, a set of geometrical solutions is produced by a solution generator. The solutions are visualized through a 3D viewer and the designer selects the most desirable solution, which can be edited. The reconstruction phase is implemented through the RS-MultiCAD component, which receives the selected scene and converts into a stratified representation. The rule set and the object set can be edited by adding, deleting, and changing the objects, relations and properties of the scene. The designer can proclaim his requirements declaratively and geometrically during the reconstruction phase. A new declarative description is constructed, which contains the changes and a new MultiCAD cycle starts resulting to more promising solutions. The iterative process aims to produce scenes, which meet the requirements, after refinement. Figure 1 presents the MultiCAD design methodology and the modeling levels.

3 RS-MultiCAD ARCHITECTURE

The RS-MultiCAD knowledge-based component incorporates architectural domain specific knowledge for constructing buildings. The basic system architecture is modular giving the possibility to further extensions. The component is based on five main modules.

The import/export module is responsible for the communication with the databases supporting the input and output of geometric solution, the output of a new declarative description which comes from designer modifications, and finally the import and export of a geometrical model (eg. *dxf* file format). The latter enhances the interoperability of the system since the designer can either import a design from another CAD system and produce alternative solutions or export the solution to other CAD system and continue the design process.

The extraction module applies all domain specific relation and property types in order to extract all valid relations and properties of the objects from a selected solution. The extraction module is domain independent and facilitates the extension of knowledge and concept database since it parses the available knowledge from the database.

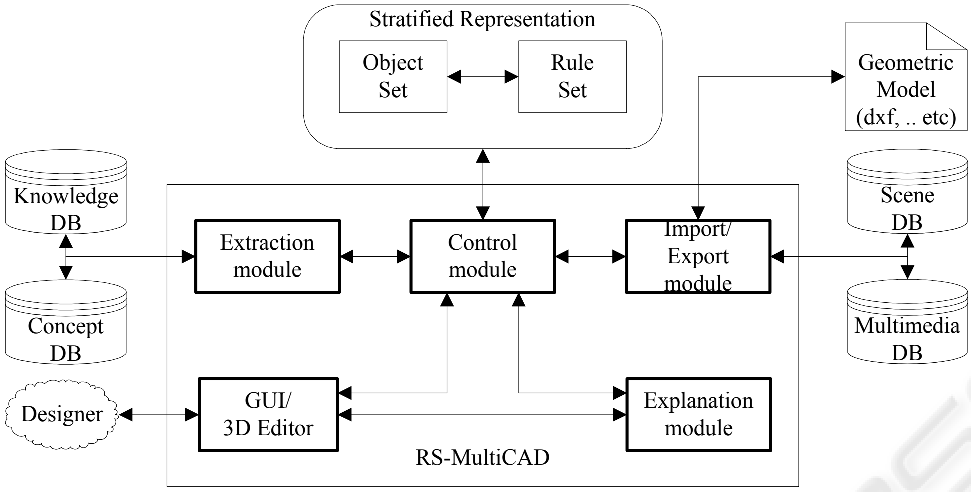

Figure 2: RS-MultiCAD system architecture.

The control module incorporates all necessary mechanisms for building, manipulating and updating the stratified representation. The stratified representation is dynamic and constructed from the designer selected solution with a top-down approach and mainly consists of declarative and geometric information. Declarative information can be summarized into object set and rule set. Geometric information deals with the geometry of each object that constitutes the scene. The control mechanism is event-driven and is responsible for the stratified representation to ensure the correct transition from one state to another. It handles the designer scene modifications examining their semantic correctness and properly updates the stratified representation by propagating the changes in a mixed way.

The explanation module provides valuable information about the system reasoning in cases where a scene modification violates the rule set. Finally, the RS-MultiCAD component incorporates a graphical user interface with a 3D editor in order to visualize the solutions and graphically receive the designer requests. Figure 2 illustrates the RS-MultiCAD system architecture.

3.1 The Stratified Representation

The need of representing geometrical and declarative information leads to an approach of using a stratified representation (Sagerer, 1997). A model in order to become another type of model is gradually transformed into a sequence of different levels of abstraction by a sequence of processing steps.

The stratified representation is an intermediate level model necessary for connecting the declarative with the geometric model, and embodies the two distinct interconnected layers of representation, the declarative layer which represents the scene description with the hierarchical decomposition, and the geometric layer which encapsulates the geometric aspects of the objects.

The geometric layer of the stratified representation is based on the bounding box dimensions of each object which express the object pure geometric properties, along with any extra geometric information that can determine the shape of the object.

RS-MultiCAD inputs a geometric model produced by the solution generator. That geometric model contains the geometric information of all objects and their type as well. The stratified representation is a dynamic semantic net with nodes and directed arrows. Every node corresponds to an object. The arrow label indicates the relations of the nodes. The labels “parent” and “children” connect nodes with same level of abstraction and represent the meronymic relations. The labels “next” and “previous” connect nodes with the same level of abstraction and detail. The label “has-geometry” connects nodes of different layers and represents the geometry of an object. Finally, the label “has-topology” connects nodes of the same level of abstraction indicating the topological relations among concepts and represents the reflective and spatial relations.

The construction of the stratified representation is a top-down process where the hierarchical decomposition is built based on the geometric information coming from the geometric model. For

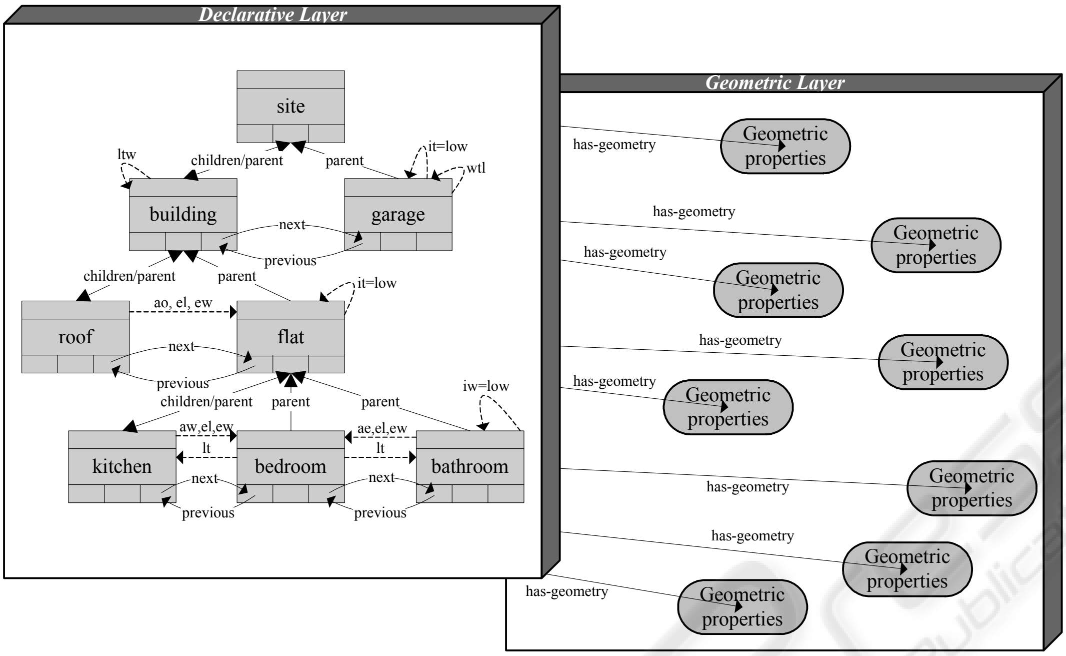

Figure 3: The Stratified Representation.

every object, a node is created on the geometric layer of the stratified representation. As long as all nodes have been created, the pure geometric properties lead to the hierarchical decomposition by creating interconnected nodes on the declarative layer of the representation. In Figure 3 appears a typical stratified representation.

3.2 Scene Manipulation

The dynamic stratified model of RS-MultiCAD allows the designer to perform geometric and topological modifications on the scene. As soon as the designer modifies the scene a special process starts. Every designer modification must be checked according to the rule set for its validity and if so the stratified representation must be properly updated in order to reflect the real state of the scene. RS-MultiCAD provides two inference options according to designer modification which may or may not be activated. The first refers to check the modification according to the rule set. A modification is valid as long as no relation or property of the rule set is violated otherwise the modification is invalid and is canceled. If the designer decides not to check the modifications according to the rule set, the control module performs a set of mandatory conditions ensuring the validity of the scene such as, non overlapping objects of the same level of abstraction, no object exceeding the overall scene limits, etc. The second refers to add pure geometric properties to the rule set that are inferred from the modifications. If the designer moves an object to a new position, pure geometric properties relative to move are adding in the rule set.

The control module properly propagates the modification by updating the geometric layer of the representation and activating the extraction module in order to recalculate all valid relations and properties. If all relations, properties of the rule set are not violated the changes are accepted and the new state of the stratified representation is valid. Otherwise, the explanation module is activated in order to record all violated relations, properties of the rule set and the control mechanism rolls the representation back to the previous state.

Figure 4 illustrates the propagation policy that control module follows. On the left-hand side, if a modification occurs on a leaf node (marked node) then the propagation starts from its brothers and continues to ancestors (shaded area). On the right-hand side, if a modification occurs on an abstract node (marked node) then the propagation starts from its children and brothers and continues to ancestors (shaded area).

The modifications that can occur on the stratified model refer to abstract or leaf node and can be divided into two categories according to the geometrical information that may be supplied by the designer. In particular, the declarative modifications are:

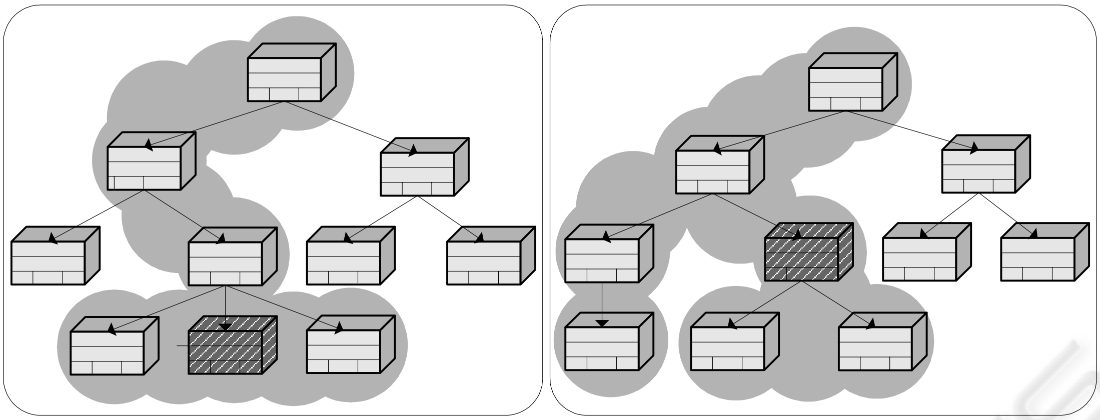

Figure 4: The propagation policy.

- The insertion of an abstract node in the stratified model can be done by specifying firstly an already existing node of the model as its parent and secondly the nodes that become children of the new abstract node. The result of such a change will affect the stratified representation since the object set changes.
- The deletion of an abstract node will eliminate the sub-tree where the abstract node is root. The result of such a change will affect the object set and may affect the rule set as well. The stratified representation must be updated in order to reflect the current state of the scene.
- The designer changes the rule set by adding or deleting a relation or a property of a node.

Moreover, the geometric modifications are:

- Move an object. The designer by providing the new position moves the object. The stratified representation must be updated since the move may affect the position of other objects.
- Scale an object. The designer specifies the scale factor of the object.
- Resize object. The designer resizes the object by providing new values for the dimensions of the object bounding box.
- Insert object. The insertion of a leaf node is carried out by specifying the geometric characteristics of the object.

Alter the extra geometric characteristics of an object. In case where the shape of the object is complex, the designer can alter the extra geometric characteristics that define the shape of the object.

3.3 The Resultant Declarative Description

As soon as the designer has completed all modifications on the scene, RS-MultiCAD results in a new declarative description which includes all modifications required by MultiCAD in order to generate in the next iteration more promising solutions by reducing the initial solution space. RS-MultiCAD provides two optional ways, the manual and automated. In particular, RS-MultiCAD in the manual way results in a new rule set that is based on the initial rule set along with the new relations and properties that have been changed by the designer. In this way, RS-MultiCAD offers the designer the possibility to drive the system to generate a solution space that is nearer to his requirements.

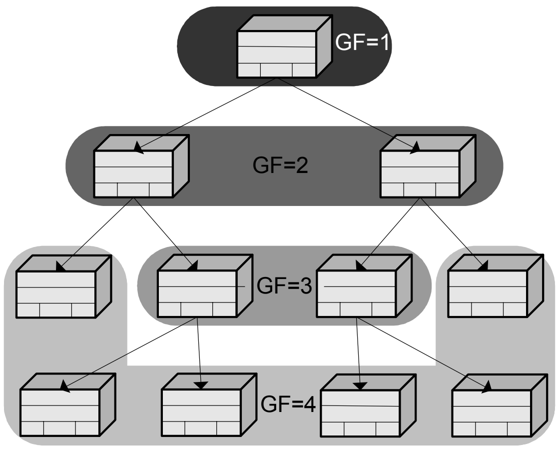

Figure 5: The propagation policy.

Furthermore, the automated way is based on the generalization factor (GF). Every hierarchical decomposed tree is divided in distinct levels of detail. The generalization factor is related to levels of detail, and its values vary from 1 to maximum tree depth. The rule set that results from the automated option, is based on the initial rule set along with all modifications and also all pure geometric properties that are implied from the generalization factor.

Figure 5 schematically shows which pure geometric properties are included in the rule set according to generalization factor. If the generalization factor equals to 1, the pure geometric properties of the root node are included in the rule set. If the generalization factor equals to 3, the nodes that provide their pure geometric properties to the rule set, are the nodes of the three higher levels of detail.

4 RS-MultiCAD IMPLEMENTATION

RS-MultiCAD has been implemented on Microsoft Visual Studio .NET platform using C# programming language and incorporates VectorDraw Viewer component. The working space of the prototype presents, on the left-hand side the declarative layer of the stratified representation, on the right-hand side the geometric layer and in the middle the visualized solution. The relations and properties that belong to the rule set are marked. The current example shows a site with a building and a garage inside. The building is further decomposed into a flat and a roof. The flat consists of a kitchen, bedroom and bathroom. The stratified representation of the example is presented in Figure 3.

Tables 1, 2, and 3 present the spatial relations, reflective relations, and properties that initially constitute the rule set of the example.

Table 1: Spatial relations.

Garage	lower_than	Building
Roof	adjacent_over, equal_length, equal_width	Flat
Kitchen	adjacent_west, equal_length, equal_width	Bedroom
Bathroom	adjacent_east, equal_length, equal_width	Bedroom
Bedroom	longer_than	Kitchen
Bedroom	longer_than	Bathroom

Table 2: Reflective relations.

Building	longer_than_wide
Garage	wider_than_long

Table 3: Properties.

Garage	is_tall	Low
Flat	is_tall	Low
Bathroom	is_wide	Low

In case the designer moves the object “flat” to a new position that causes a possible move of the children of the “flat”, since it is an abstract node. The modification is propagating to ancestors yielding the object “building” with its new position and also to object “roof” since there is a relation “adjacent over” in the rule set. Figure 6 illustrates the result of this move operation.

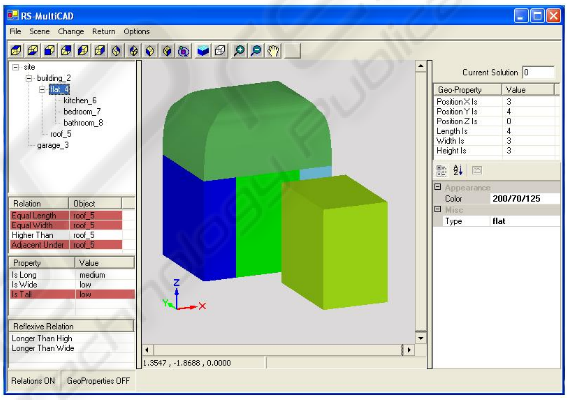

Figure 6: The result of the move operation.

In case the designer resizes the object “garage” to a new length and width value, the system propagates the change to object “building” without affecting it because there is no relation in the rule set that connects the two objects. Figure 7 illustrates the result of the resize operation.

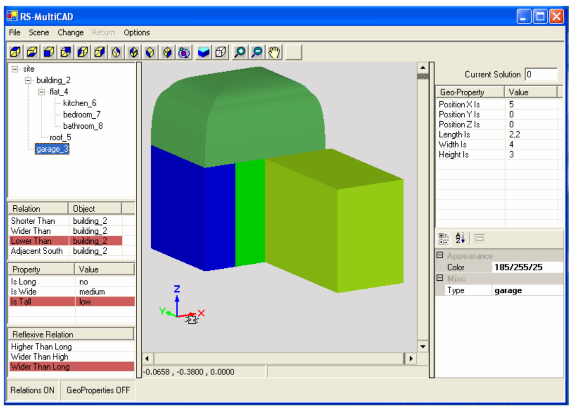

Figure 7: The result of the resize operation.

In case the designer inserts a new object, he has to specify its type and position along with its parent. The insertion of the new object "roof" causes modifications on the stratified representation at both the declarative and the geometric layers. Figure 8 illustrates the result of the insertion. In case the new object is deleted, figure 7 represents the resulting state of the scene.

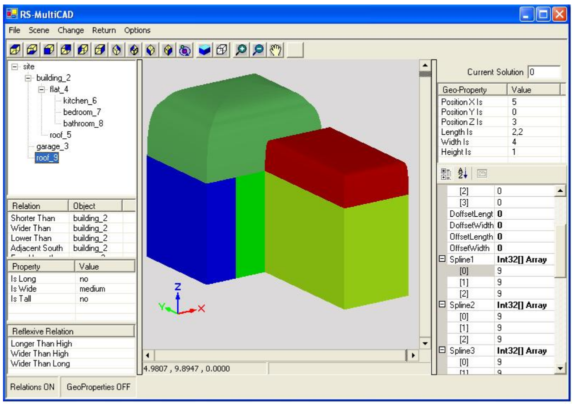

Figure 8: The result of insertion.

In case the designer modifies the extra geometric characteristics of the object "roof", it causes changes inside the bounding box of the object. The roof modeling is based on (Makris, 2005). Figure 9 illustrates the changes.

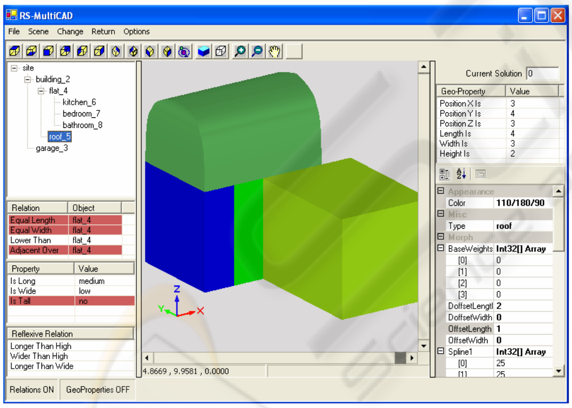

Figure 9: The result of changing extra geometric characteristics.

Table 4 shows some experimental results concerning the manual reduction of the solution space in the next MultiCAD iteration after the production of the new declarative description of RS-MultiCAD. By adding a new relation to the initial set, the solution space is reduced to solutions that also satisfy the new designer requirements. Figure 10 shows some experimental results, in logarithmic scale, concerning the automated production of the new declarative description.

Table 4: Manual reduction of the solution space.

Rule Set	N° Solutions
Initial set	32124
initial set + "building adjacent_west garage"	9270

In each MultiCAD iteration cycle, RS-MultiCAD constructs a declarative description by adding the pure geometric properties of the lower level of detail. MultiCAD in each round generates fewer solutions and when the generalization factor is set to maximum depth of the tree, generates one solution indeed.

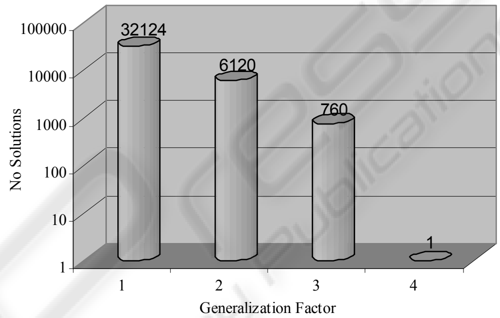

Figure 10: Automated reduction of the solution space.

5 CONCLUSIONS

The RS-MultiCAD is a new component of the MultiCAD architecture, which receives a geometric model and results into a declarative description. The MultiCAD declarative conceptual cycle extends to operate iteratively by the introduction of the reconstruction phase. During this phase, the internal representation of RS-MultiCAD, i.e. the dynamic stratified representation, allows the designer to manually affect the resultant declarative description. This is achieved by modifying the scene topology and the object geometry, in order for MultiCAD, in the next iteration, to generate geometric solutions that are closer to designer requirements. Furthermore, RS-MultiCAD employs two alternative options, the manual and the automated, which conduce to the reduction of the solution space by adding the appropriate pure geometric properties of the objects to the resultant declarative description thus also reducing the solution generation time.

RS-MultiCAD can be compared with XMultiFormes (Sellinger, 1998). The XMultiFormes project approaches the subject by a low-level process and gives special attention on man machine interaction. On the other hand, RS-MultiCAD uses a high-level knowledge-based approach and supports the iterative process of the declarative modeling by an automatic way. The reduction of the solution space proves the quality of the resultant declarative model in every cycle of the iterative process.

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