INFORMATICA, 2003, Vol. 14, No. 3, 375–392

3-D Computer Modeling with Intra-Component, Geometric, Quality and Topological Constraints

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Received: March 2003

Abstract. The study of 3-D indoor accurate scenery modeling is an active research area. The produced model can be used in a number of virtual reality applications, in digital documentation of monuments and sites, and so on. Digital photogrammetry and CAD technology have to play a vital role in this field. Photogrammetry's contribution is mainly on data acquisition from imagery, whilst the necessary image knowledge is derived from geometry and topology of image contents. While the first is traditionally used, the second one only lately is been tackled.

In this paper, a technique is presented for modeling of indoor scenery based on digital images, photo-derived intra-component, geometric and topologic constraints, object-oriented graphic databases containing 3-D parametric models and a rough (generic) CAD model. Optionally, an absolute reference system could be applied, but for VR applications a relative reference system is adequate.

The original contribution with respect to related works in this field is mainly the introduction of *Display File*, *Segment Table*, *Scene Parts Table* and *Constraint Table* structures which deal with the constraints and "drive" a modeling control program called the *Constraint Modeler*. The use of these structures leads in a direct, global, portable, and semi-automated technique for 3-D indoor modeling. Experimental results from simulated images are presented, and the robustness of the technique is discussed.

Key words: photo-derived modeling, intra-component constraints, geometric constraints, quality constraints, topological constraints, computer modeling, virtual reality.

1. Introduction

Usually, accurate 3-D models of scenes and objects can be generated by CAD software and geometric modelers if the design concept is defined and the necessary data are available. However, the process is complicated and the modeling accuracy is low if the necessary data are either not available, or their quality is low or uncertain (due to small image bases, badly defined control points, non-metric uncalibrated equipment, variable f, etc.). This is the case in indoor scenery when amateur surveying procedures are applied (non-metric cameras, video, many close-ups, zooms, etc.). In this case both geometric and topologic constraints could be a remedy. Such constraints (e.g., regarding shapes, geometry, dimensions, proximity, symmetry, continuity, closure, adjacency, etc.) can be imposed either from traditional photogrammetric measurements or from simple photo interpretation. Additionally, a continuously updated object-oriented graphic database, containing 3-D parametric models, could be used for both enhancing the functionality of these constraints and also automating the process to a degree.

Modeling with constraints is a modern approach to reconstruct geometry in general, and 3-D indoor scenery modeling in particular. Engineering knowledge is associated with geometry and topology in the product model. So, in conjunction with the traditional feature-based technique, modeling with geometry and topologic constraints is expected to widely affect the development of the new photo-based CAD and VR systems.

The architecture of these systems will reflect the impact of both, photogrammetry and CAD technologies (El-Hakim, 1985; Gruen, 1992). Today's digital photogrammetry and CAD/Solid modeling systems provide powerful tools for an accurate design of 3-D objects and scenery. In this field, techniques used for solid modeling are: the constructive solid geometry (CSG) or sketching technique, the sweeping to 2-D shapes technique in conjunction with the geometric transformations methods, the skinning technique, and the reconstruction of solids from projections technique (Styliadis *et al.*, 1996; Rongxing, 1993; Leberl *et al.*, 2002).

All of these techniques require accurate data. Even more, the process is complicated if the necessary data are either not available or their quality is low or uncertain (small image bases, resection angles, badly defined control points, non-metric equipment, variable f, etc.). In this case both geometric and topologic constraints could be a remedy.

The traditional CAD systems are based mostly on a feature approach for solids, defining an indoor scenery as a structure of, always, predefined objects called *features*. This feature approach is often based on a combination of both CSG (sketching) and sweeping techniques. Thus, in these techniques, the user (designer) defines the scenery by composing it of solid primitives (e.g., cubes, cylinders, spheres, etc.), positioning them in space using hand-based methods and then by using Boolean modeling operations like union, intersection and difference (Styliadis, 2001).

In addition, a number of sweeping techniques, based on geometric transformations, could be used. Sweeping techniques include translation of a shape along a vector, rotating a shape around an axis or moving a shape along a spatial curve (Anderl *et al.*, 1996). Fig. 1 shows a simple example of a translational sweep.

The proposed technique is based on geometric and topologic constraints (e.g., regarding shapes, geometry, dimensions, proximity, symmetry, continuity, closure, adjacency, etc.) imposed either from traditional photogrammetric measurements or simple photo-interpretation. In particular, the architecture of the proposed technique is based on a rough (generic) CAD model, digital images, a number of structures and tables (display file, segment table, constraint table), a constraint modeler, a graphical user interface (GUI), and a 3-D graphic parametric object-oriented database.

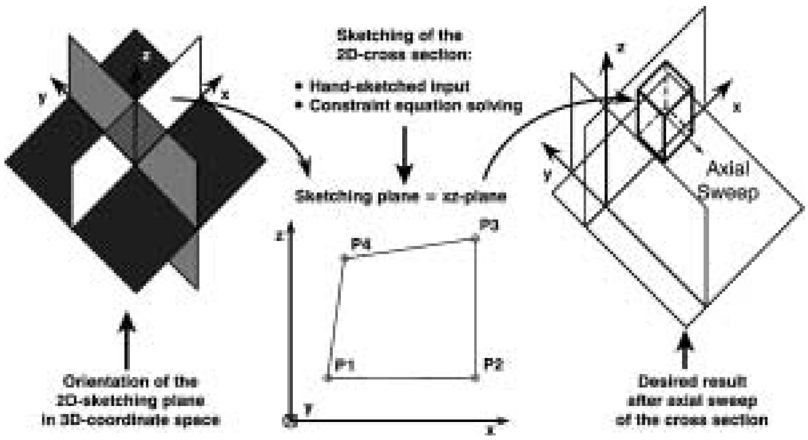

Fig. 1. A simple example of the sweep technique.

The constraint modeler is undoubtedly the key component of the proposed technique, since it evaluates and solves the network of constraints formulated by the rough CAD model and the image data. These constraints are stored as a set of instructions in the constraint table structure.

The flexibility of this technique makes it significantly different from related work. The original contribution with respect to related works in this field is mainly the introduction of a number of data structures which deal with the constraints and "drive" a modeling control program. The use of these structures leads in a direct, global, portable, and semi-automated technique for 3-D indoor modeling. Finally, experimental results from simulated images are presented, and the robustness of the technique is discussed.

2. Related Work

One of the first researchers studying automatic synthesis of general recognition strategies was Goad (1983) and Wu *et al.* (2002). Their work is related with automatic programming for 3-D model-based vision. In particular, Goad was concerned in generating a recognition scheme for matching object's edges based on a ***General Sequential Matching Algorithm***. The algorithm proceed in three steps: i) predict the feature, ii) match the feature, and iii) back-project the feature (i.e., refine the object hypothesis based on previous step ii). These three steps form a template which is used by the automatic programming phase. Also, a **unit sphere** was used to gather the view-angles (camera positions) which represents orientations of the object.

Goad's work differs from that described in this paper in that he obtains 3-D interpretations of the two-dimensional intensity images rather than 3-D co-ordinates and topology information. Also, Goad's system did not consider geometric or topologic constraints. However, this was a major contribution since it was one of the first attempts to automate the generation of object recognition schemes.

Later, Ikeuchi (1987) explored the use of ***Interpretation Trees*** for representation of recognition strategies. His system uses the concept of visible faces to generate generic representative views, called **aspects**. Then, from this set of aspects, an interpretation tree is formed which discriminates among the different aspects. His system uses a variety of object features such as: face shape, face inertia, adjacency information and shape characteristics. Finally, a object-specific interpretation tree is generated using a set of object specific rules selected by hand in a batch procedure.

The work here resembles the Ikeuchi's system as far as the shape characteristics are concerned. However, most of Ikeuchi's features are based on planar faces as opposed to 3-D objects of the proposed technique. Also, the modeling controlling rules were selected by hand rather than generated automatically by a structure-based constraint modeler. Even more, there does not appear to be any algorithmic approach for the application of the rules to discriminate between the aspects. Hence, the branching on the tree seems to be a function of the particular aspects chosen rather than being based on the geometric and topologic information of the object.

Another influential project was the 3DPO system by Bolles and Horaud (1996). This work is the 3-D generalization of the ***Local Feature Focus*** method (Bolles *et al.*, 1982). Their system annotates a CAD model and a so called *extended CAD model* is produced. Then, from this model, feature analysis is performed to determine unique features on which the hypothesis is based. The main focus feature in this system is the **dihedral arc**. Hence, when the recognition system finds a dihedral arc, it looks for nearby features which are used to discriminate between model arcs with similar attributes. From these, an object's pose is hypothesized and subsequently verified.

The work here is similar to the 3DPO system as far as the conceptual design phase is concerned. However, focus features were hand-chosen and keyboard-driven in 3DPO, as well as the local features used for discrimination, as opposed to the semi-automated proposed technique.

A knowledge-based approach for the surface reconstruction of buildings to be used in computer graphics applications is presented by Alvarez *et al.* (2002) and Weik and Grau (1996). Their work is based on a **calibrated stereo camera pair**, whilst **scene depth** is estimated by correspondence analysis. Also, together with the scene description, additional geometric constraints can be selected from a generic knowledge base. Each of these constraints describes a relationship either between parts of the model (e.g., the perpendicularity of two walls) or between the 3-D scene and extracted 2-D image features (e.g., edges or depth information). The work here has a similarity with this system as far as the adjacency information is concerned.

Finaly, Haggren and Mattila discuss **videography** for 3-D indoor modeling (1997). In this case the modeling procedure is based on recorded video sequences and it is operated on a ***modeling first – then measuring*** basis. That is, a functional 3-D model is build first and the measurements for exact geometry are done thereafter.

The proposed technique developed in this paper incorporates ideas from all of the systems described above. However, the technique is designed to treat *3-D objects* rather than *features* and, even more, it is not dependent on a certain class of objects (features) but can rather be extended to include many classes of objects not implemented in the supported graphic database. This extension is feasible since the *Display File* structure holds the photo-derived co-ordinate information which is a space indicator and it is not connected to particular object models.

The introduction of the *Segment Table* structure, which holds the scene partitioning, improves technique's modularity and portability. Also, the incorporation of topologic constraints such as *collinearity*, *parallelism*, *connectivity*, *repetitive patterns*, and *adjacency* enhances technique's functionality (*constraint table*).

3. Modeling with Constraints

In traditional modeling, while applying sketching and sweeping techniques for a design – on the user interface level – a *Boundary Representation* (B-Rep) is created for the internal representation of the features. This B-Rep is also called the *Secondary Structure* of the solid model and represents a solid feature (body) by its faces, edges and vertices.

When defining or editing the shape of features or their positions as well as their interrelations and topology, the so called *constraint modeling* technique is of advantage. In this technique, the designer sketches the topology of a feature's shape by picking points and drawing line segments or arcs on the design session and then applying linear and angular dimensions and dependencies or properties, such as horizontiality or parallelism to the topologic incorrect objects on the design session. This procedure is hand-based, has low accuracy, and it is known as: *constraining the sketch* (Anderl, 1996). In this case the dimensions and dependencies are referred to as the geometric and topologic constraints. Furthermore, the relative or absolute final position and orientation of the objects, in an indoor scenery, can be defined accurately and in a semi-automatic way if a rough initial position is calculated, the topology of the scenery is known and a *Constraint Modeler* or *Constraint Network Solver* (software support) is developed.

Low-cost digital photogrammetry surveys can plays a vital role in this field, since the rough initial positions can be calculated, and the scenery partitioning and topology can be documented. Also, photo-derived information, e.g., "*the computer and the light-spot must be on the desk*" (adjacency), can help to improve the initial scene modeling accuracy.

From the designer's point of view, constraints can be applied to both the feature structure and the B-Rep structure of the solid models using the same operations but internally all the constraints refer to topology and geometry objects, whilst the majority of them is related to vertices and their geometric co-ordinates. Some researchers use the term *parameters* for the geometric constrained co-ordinates.

Constrained-based Scene Description

The main aspects of modeling with constraints are structuring a scenery as a sequence (known as the *history*) of objects, using parametric 3-D models and their geometric co-ordinates, derived from photography, as parameters, and then applying geometric and topologic constraints to these objects (models) to improve accuracy (see Fig. 2).

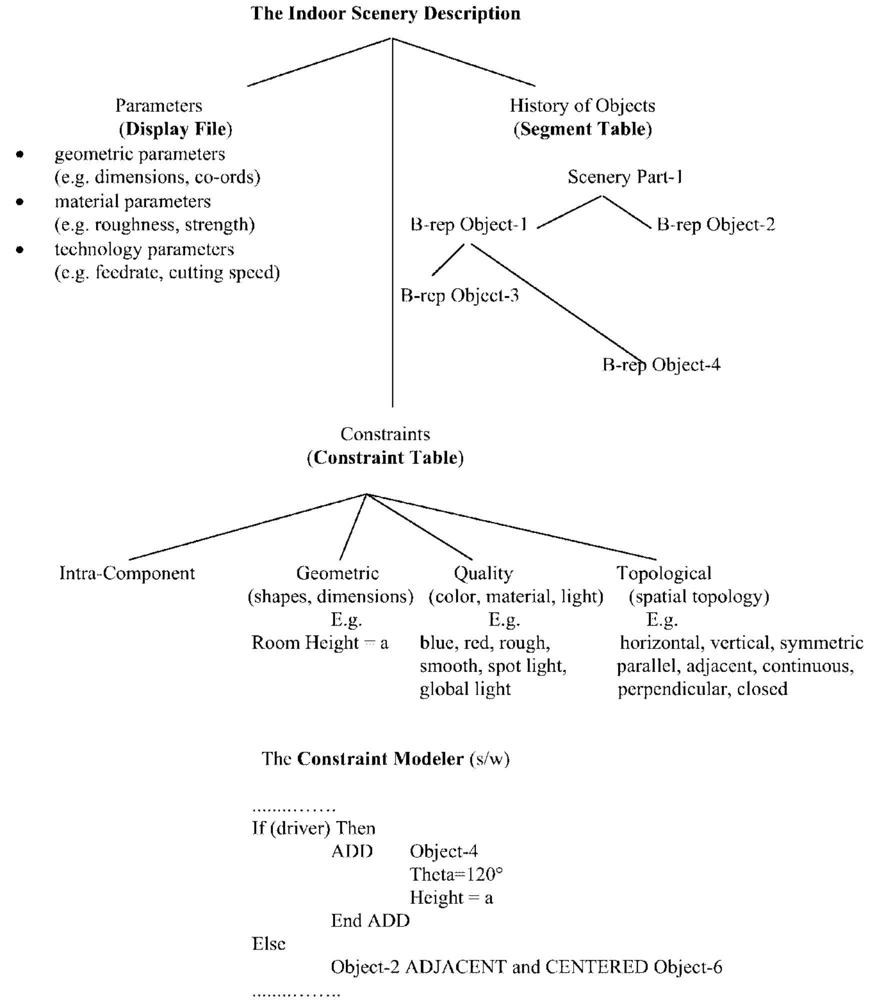

Fig. 2. Modeling with constraints.

In a CAD design session, not only geometry of a scenery or part of it (object) is of importance, but also parameters representing additional quality information, like material properties or even technology and manufacturing properties must be modeled. This, also, affects the constraints, which can be sub-divided into geometric (relating geometry, like dimensions), quality (relating object properties like material), and topological constraints (relating topology).

4. Modeling the Constraints – the Constraint Modeler

This section describes the basic coordinate data structures and the proposed technique that allows for efficient modeling of constrained models and scenery. Based on these structures, the *Constraint Modeler* (i.e., a computer program) calculates the positional calculus of coordinates of the projected model edges and endpoints in the 2-D image plane with respect to model, as well as the intra-component, geometric, quality and topological constraints.

The proposed technique enhances the accuracy of the photo-derived coordinates by taking advances from the intra-component, and the geometric constraints for a single object modeling and the quality and topological constraints for a scenery modeling. In this technique, point and edge information are supplied by the photogrammetry (photo-derived coordinates).

Let consider two single component models, the *box* and the *pyramid*. These models contain intra-component and geometric constraints which are specified when the model component is defined. For example consider a generic BOX. The BOX model contains three parameters for width, length and height. The bounds of these dilational parameters could be first set by calling a function, say *set_variable()*.

```
Set_variable(WIDTH, ... )
Set_variable(LENGTH, ... )
Set_variable(HEIGHT, ... )
```

The actual constrained dilation is then embedded within the declaration of the points of the BOX, as follows.

```
Set_point(1, 0, 0, 0)
Set_point(2, WIDTH, LENGTH)
. . . . . . . . . . . . . . . . . . . . . . . . . . . . . ..
Set_point(8, WIDTH, LENGTH, HEIGHT)
```

It is important to notice that the function *Set_point()* will not evaluate the actual parameters. Rather, accordining to the geometric constraint of the BOX object, the final coordinates of the eight vertices are set accordingly. The 3-D model of the BOX is thus constructed from point to edge to component.

Let now consider a tetrahedron PYRAMID with a variable square base controlled by the dilation parameter LENGTH and the top of the pyramid controlled by the parameter HEIGHT (both parameters are photo-derived). In addition, the pyramid object is constrained (a typical intra-component constraint) as to where the top can appear relative to the bases's LENGTH: "*it will only appear at the centre point of the square base*".

```
Set_point(bottom1, 0, 0, 0)
Set_point(bottom2, LENGTH, 0, 0)
Set_point(bottom3, 0, LENGTH, 0)
Set_point(bottom4, LENGTH, LENGTH, 0)
Set_point(top, 0.5 * LENGTH, 0.5 * HEIGHT, HEIGHT)
```

In the proposed technique the coordinates may include any differentiable function. This allows for a generic point specification. In the case of the BOX this implies dilation in three dimensions. For the PYRAMID, this allows for constraining the top point to the center of the pyramid base (i.e., intra-component constraint). Since these models consist of only one component, the model base are the components themselves.

For a scenery modeling with multiple objects, an object oriented modeling approach would be appropriate so that models may inherit from superclasses of components which will share (or not) the intrinsic model parameters (Keene, 2001). In the proposed technique, the problem is solved by having the variables, and hence the relevant cinstraints, stored locally to a each particular model.

Following is the description of the basic coordinate data structures used in the proposed technique.

- **The Display File Structure**

The indoor photography with non-metric cameras is characterized by a number of restrictions which result in photo-derived co-ordinates with a low accuracy. These restrictions are imposed from the nature of the environment and are: small image bases, resection angles, badly defined control points, images at different zooming distances, etc.

Obviously, such photogrammetrically derived co-ordinates cannot be used for an accurate indoor modelling but can be used for a rough position estimation of objects and scenery. In the proposed technique, this photo-derived co-ordinates are stored in a structure called **Display File** (array of records).

- **Scene Partitioning – Display File Segmentation**

Also, in another structure called **Segment Table**, all the necessary information regarding scene partitioning is saved. In particular, in this structure the scene objects are grouped and named (coded) and their actual position into the current design session is referred by corresponding *Display File* records holding photo-derived co-ordinates.

This kind of organization enhances functionality and automation and permits scene partitioning, or the so-called *display file segmentation*. In particular, the Segment Table is another structure (array of records) which is used to group the display file records in logical units called segments.

- **Modeling the Constraints – The Constraint Table Structure**

The final structure is named **Constraint Table** and it is used to hold the constraint information and the relative objects. This information is derived from the photo interpretation.

A number of reserved words, like ADJACENT, PARALLEL, CENTERED, ORTHOGONAL, etc. is used in this structure, and together with the relative objects, forms the constraint records.

- **The Constraint Modeler**

Each entry in the Constraint Table (object segment) can be manipulated easily in an automated way according to the instructions of a control program, called **Constraint Modeler** and the rough co-ordinates holded into the *Display File* structure. As a result, the modeling accuracy is improved. The constraint parameters are organized and coded as in Fig. 2.

The introduction of these RAM-residence structures – *Display File*, *Segment Table*, *Constraint Table* – permits a number of actions like COPY, DELETE, HIDE, DISPLAY, ADJACENT, COAXIAL, PARALLEL, VERTICAL, HORIZONTAL, TANGENTIAL, PERPEDICULAR, and so on. These actions operate as "verbs" in the technique's graphical user interface. So, the modeling instruction, which improve indoor scenery modeling accuracy, is performed in an semi-automatic way.

Intra-Component Constraints: Detection & Definition

To interpret an object qualitatively is something natural for humans and very difficult for the computers. It is therefore quite straightforward to leave the detection and the definition of the intra-component constraints (if any) of the object to the user of the application.

Geometric Constraints: Detection & Definition

Using traditional photogrammetric measurements a rough model approach of the scenery can be described. Besides, rough geometric descriptions of the scene's objects can be performed. In this way the geometric parameters of scenery description (dimensions and co-ordinates) and the related geometric constraints are defined.

Quality Constraints: Detection & Definition

Using simple interpretation of the available imagery, the designer is able to define color, material and light constraint explicitly. In this way the material parameters of scenery description and the related quality constraints are defined.

This procedure is hand-based and time consuming and therefore not well suited for an automated system (technique). Obviously, automatic detection of quality parameters seems to be the most efficient method of supporting the designer. This procedure, however, is an open issue today.

Topological Constraints: Detection & Definition

Using traditional photogrammetric measurements or even simple interpretation spatial topology parameters can also be detected. Obviously, this procedure is operated manually and is based on the human-knowledge of the designer (e.g., "*the computer must be on the desk*"). Then, the *Constraint Modeler* interprets this detection and defines the topological constraint module. This is done by using a list of *noun/verb* operations like:

"*draw a chair parallel to wall*" (noun – verb – noun),

"*adjacent: the light-spot on desk-table top*" (verb – noun – noun).

In this way the *history of objects* of indoor scenery description and the spatial relations between existing objects are defined (Styliadis, 2002).

5. The Architecture of the Photo-Derived Constraint-Based Technique

The architecture of the proposed photo-based CAD and Modeling technique reflects the concept of modeling with geometric, quality and topologic constraints (see Fig. 3). The user (designer) has the ability of modeling the *geometry*, the *history* and the *topology* of the objects found in imagery (indoor scenery).

In particular, the **Display File** structure (see Table 1) is used to describe the *geometry* of scene's objects (B-reps). This structure holds, in an initial rough accuracy, the photo-derived X, Y, Z co-ordinates and the corresponding Id's (Identification Numbers) of all the critical points (end-points, vertices) found in scenery.

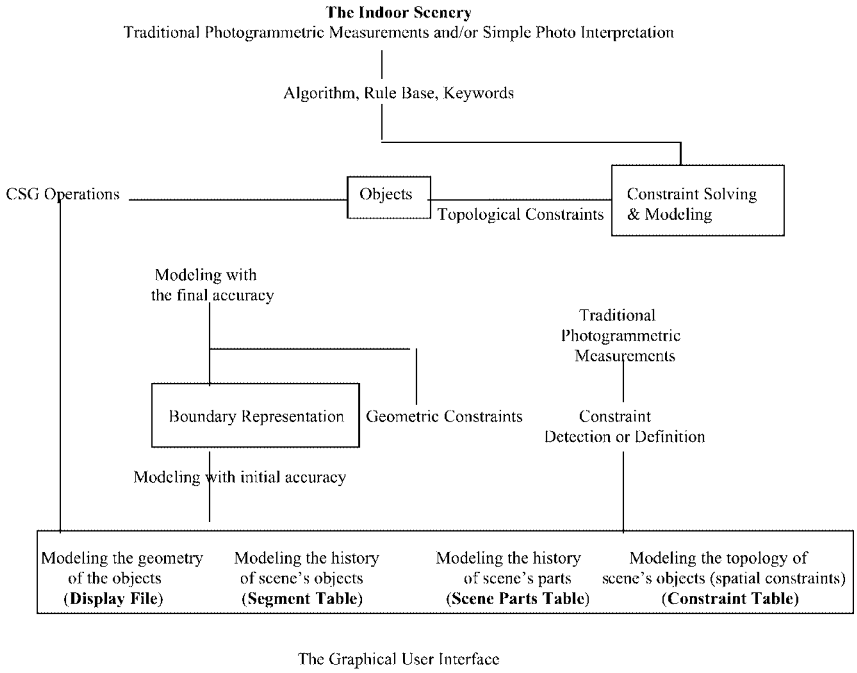

Fig. 3. Photo-based modeling with intra-component, geometric, quality and topological constraints.

The **Segment Table** structure (see Table 2) is used to describe the *history* of scene's objects (scene partitioning). This structure holds, the object codes and the corresponding Id's of all the end-points used in the boundary representation (B-rep) of the object. This structure is actually a Display File segmentation structure holding the relative Id's in a linked list order.

The open architecture of the proposed technique permits the incorporation of another structure, the **Scene Parts Table** structure (see Table 3), which would be used to describe the *history* of logically or/and physically separated scene's parts.

The **Constraint Table** structure (see Table 4) is used to describe the *topology* of scene's objects (spatial objects relationships). This structure holds, the relationship's *topology verbs* (e.g., ADJACENT, PARALLEL, ORTHOGONAL, etc.) and the corresponding object codes of the object members.

Table 1

The Display File structure

Ids	**X**	**Y**	**Z**
15	102.35	108.28	1.09
16	103.87	108.22	1.12
. . .	. . .	. . .	. . .

Table 2

The Segment Table structure

Object Code	**Name**	**Id's**
O101	Desk	15, 16, 22, 73, 74, 90, . . .
O108	Light-Spot	10, 25, 26, 27, 88, . . .
. . .	. . .	. . .

Table 3

The Scene Parts Table structure

Scene's Part Code	**Name**	**Object Codes**
P11	Left Corner	O171, O125, . . .
P25	Desk Place	O101, O108, . . .
. . .	. . .	. . .

Table 4

The Constraint Table structure

Object Code	**Topology Verb**	**Object Code**
O101	ADJACENT	O108
O122	PARALLEL	O106
. . .	. . .	. . .

In the Fig. 3, the *Constructive Solid Geometry* (*CSG) Operations* are used to describe the history of the objects in the form of a binary tree.

All the *geometric* and *topologic* constraints are modeled in a draft 3-D design session (the initial rough CAD model) and this procedure is called the **constraint mode**. In this way the 3-D draft design session becomes a key component of the proposed CAD / Modeling technique. On the other hand, the *quality* constraints, are modeled in an accurate 3-D design session and this procedure is called the **constraint solid mode**. After applying these constraints the final modeling accuracy and consistency is achieved.

The **internal representation** of constraints may be expressed as equations or predicates or keywords. The last case was the choice of the proposed technique. Then, the set of modeled constraints has to be evaluated in order to get a consistent and accurate model of the scenery or part of it. This procedure is called constraint solving and modeling. This leads to the **Constraint Modeler** (Solver). This component may be based on algorithms or a rule base or keywords.

The Graphical User Interface (GUI)

The graphical user interface (GUI) of the proposed technique has been implemented in the MicroStation 95 PC CAD platform (Bentley Systems, Inc., Exton, PA) and it is demonstrated in Figs. 5, 6 and 7. Also, the Constraint Modeler has been written in MDL, the MicroStation Development Language with event-driven functionality.

The 3-D Graphical Parametric Database

A few number of ready-to-use 3-D models usually found in indoor scenery (boxes, pyramids, chair-cases, light-spots, desks, doors, carpets, etc.) has been organized in a graphic database. These parametric models are used in the test application which is followed.

6. A Pilot Application

Modeling with constraints is especially suitable for indoor scenery modeling applications. Here, the definition of geometric shapes, detected in photography, is easily defined and therefore scenery's 3-D model can be roughly reconstructed.

Fig. 4. One of the photos which cover stereo the indoor scenery together with a number of *control points*.

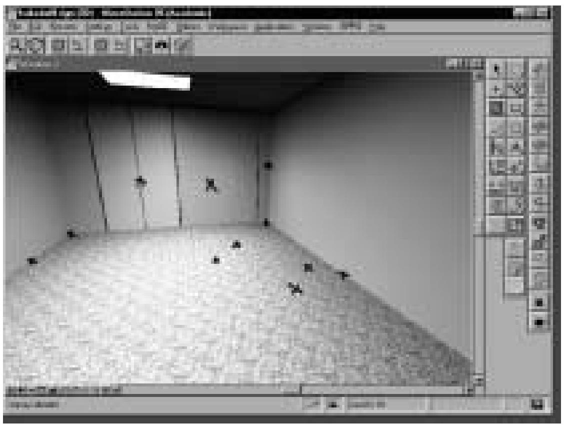

Fig. 5. The rough CAD model (photogrammetrically derived).

Fig. 6. Scene's development phase: The CAD model with a Carpet, a Door, a Light-Spot, a Ceiling, and a Chair-Case (photogrammetrically derived rough low-accuracy coordinates).

Fig. 7. The final CAD model with a Carpet, a Door, a Light-Spot, a Ceiling, a Desk, a Computer, and two Chair-Cases.

In Fig. 4, one of the photos which covered stereo the scene (used also for interpreting geometric and topological constraints) is displayed. In the same photo, also, a number of *control points* derived from photogrammetry can be seen.

The initial photogrammetricaly derived rough CAD model of scenery is displayed in Fig. 5.

In the following figures the simulated development phase of a typical indoor scenery's modeling regarding: a Carpet, a Door, a Light-Spot, a Ceiling, a Desk, a Computer, and a number of Chairs is displayed (see Figs. 6 and 7).

The CAD model of the indoor scenery is based on photogrammetrically derived rough (low-accuracy) co-ordinates. On this model the following constraints are imposed:

- the Light-Spot must be on the Desk;
- the Computer must be on the Desk;

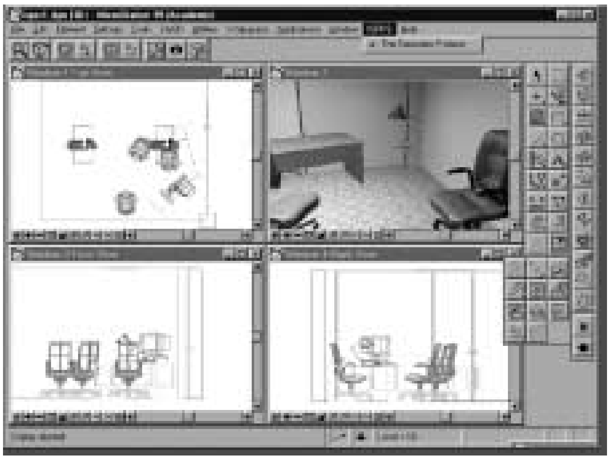

Fig. 8. Due to inaccuracies the second Chair-Case is not parallel to the left Wall and the Desk is not between the Walls' corner and the two Chair-Cases.

Fig. 9. Due to inaccuracies the Light-Spot's position deviates in height from Desk's surfaces.

- the first Chair-Case must be parallel to the right Wall;
- the second Chair-Case must be parallel to the left Wall;
- the Desk must be between the Walls' corner and the two Chair-Cases.

Due to inaccuracies:

(a) The Light-Spot's position deviates in height from Desk's surfaces (see Fig. 9). So, there is a need for Light-Spot and Desk adjacency (topological constraint).

(b) The second Chair-Case is not parallel to the left Wall (see Fig. 8). So, there is a need for Chair-Case and Wall parallelism (topological constraint).

(c) The Desk is not between the Walls' corner and the two Chair-Cases (see Fig. 8). So, there is a need for Desk enclosing (topological constraint).

Fig. 10. The final accurate indoor scenery (CAD modeling).

After the above imposed constraints the final accurate indoor scenery CAD model is reconstructed (see Fig. 10).

7. Modeling with Photo-derived Constraints – Accuracy, Advantages and Risks

Modeling Accuracy

Since the typical environment of the constrained modeling problem assumes little matching information, the first problem encountered is the metric (geometric) accuracy of the photo-derived coordinates and the second is the possible violation of constraints from the initial guess (human topological constraints estimation).

In order to evaluate the proposed technique, the first set of exprериments performed was to demonstrate the proper convergence of linearly constrained models over a wide range of initial offset error. Different sets of matches were obtained for each experiment. First the 3-D model was projected completely into the 2-D images at some arbitrary articulation. Although the calculation involved floating point precision, the resultant endpoint information was stored by truncating each coordinate in fixed point precision. This more accurately simulates the manner that imaging devices obtain images; hence, some error accumulated at each endpoint of the projected image segment.

The first model tested was the generic PYRAMID. This kind of objects has two dilation parameters (LENGTH, HEIGHT). A linear constraint is added to order the relative size of the dilation parameters, such as LENGTH $\leqslant$ HEIGHT.

The second model tested was a generic BOX. This kind of objects has three independent dilation parameters (WIDTH, LENGTH, HEIGHT). This is more complex than the PYRAMID one, since two additional external constraints are needed to confine the relative ordering of the three dilation parameters, such as WIDTH $\leqslant$ LENGTH $\leqslant$ HEIGHT.

Experimental was performed for 20 increasing initial offset errors within a maximum error bound of $|\pi/2\ |$. Since the maximum error bound was set at $\pm\pi/2$, it is not known *a priori* that the correct instantiation of angular parameters was guessed. Thus, there is a possibility that while correcting some of the other parameters, the initial angular values will be worsened. Obviously, as long as the solution converges to less than two pixels distance in the image, the result obtained will appear identical to the one in the image.

The most important advantage of the proposed technique, is that the complex design and modeling process is actually split into five steps. These are namely, *sketching*, *photo-deriving*, *constraining*, *solving*, and *modeling*. While *sketching*, the designer uses *photo-derived* data and does not need to care about exact dimensions. Afterwards, he may feel free to apply the *constraints* and even get support by the technique's graphical user interface. The fourth and fifth steps, the *imposition* of topological constraints and the accurate CAD *modeling*, are completely done by the proposed technique automatically (Styliadis *et al.*, 2003).

The risk is coming from the detection and definition of the constraints or the process of coding (*solving*) the constraints sets. In most cases, the definition of constraints is an easy task (e.g., these walls have *equal* height and their B-reps are *perpendicular*), but there are cases where constraint definition is a complex task and this complexity may result in inaccurate modeling. In this case a number of additional scene descriptions may be necessary.

8. Conclusions, Open Issues and Future Work

In this paper a new technique for 3-D indoor scenery modeling is discussed. The proposed technique is suitable for virtual reality, machine vision and digital documentation applications. The technique is based on data coming by retrieving 3-D geometric and topological properties from a number of perspective images (photo-derived data).

A *rough CAD model* is used as the basis modeling platform, whilst a parametric CAD database, holding 3-D models of every-day objects, is being implemented. The difference between the proposed technique and previous approaches is that it uses intra-component and geometric in conjunction with quality and topological constraints, in order to improve the low input data accuracy.

However, the proposed technique still requires some research and development work. Areas of open issues are: support of automated modeling with constraints in all phases of the product development phases, standardization of constraint categories, re-use of existing design solutions, and support of portability of constrained models in other CAD environments.

In order to achieve an efficient way of photo-derived modeling, the CAD/Modeling technique should not only support the user by solving his design as a constrained problem, but it should also help him to formulate the constraints, which consistently describe the intention of his design. This automatic constraint detection and definition procedure constitutes, today, an open research issue.

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3-D kompiuterinis modeliavimas esant intra-komponentiniams, geometriniams, kokybės ir topologiniams ribojimams

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Nagrinėjamos patalpų vidaus trimačio vaizdavimo ir modeliavimo problemos. Pasiūlytas metodas tinkamas daugeliui virtualios realybes taikymų, pvz. skaitmeniniam monumentų ir miestų dokumentavimui. Pasiūlyta patalpų vidaus užpildymo modeliavimo metodika, grindžiama skaitmeniniais vaizdais, intra-komponenčių nuotraukomis, geometriniais ir topologiniais ribojimais, grafinėmis duomenų bazėmis, saugančiomis 3-D parametrinius modelius ir grubų CAD modelį. èitų struktūrų panaudojimas leidža tiesioginį globalų portabilų bei pusiau automatinį patalpų 3-D modeliavimą. Pateikiami eksperimentiniai rezultatai bei aptartos siūlomos metodikos galimybės.