DYNAMIC INTERACTION OF SOLIDS
AS A DESIGN TOOL

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ABSTRACT

Architectural form and order can sometimes be described as having dynamic characteristics. To capitalize on this notion, physical qualities (mass, velocity, material elasticity, and friction) are given to objects. The objects are set in motion and allowed to interact at will with each other and their environment. The physical qualities are the rules that govern the outcome of interactions. As a result, interactions can lead to affine transformations (translate, scale, rotate), reformations (topological editing), and/or deformations (geometrical editing) of the objects.

The designer can investigate the effects of interaction between dynamic elements, vary their physical qualities, and evaluate the appropriateness of the outcome as a solution to the design problem.

1. INTRODUCTION

The introduction will acquaint the reader with the architectural premise and goals of the paper. Section 2 presents the influences of previous CAD research on this topic. Dynamic operations, have been experimentally implemented in a system called DICE (Dynamic Interaction of Conceptual Elements). A description of the system interface and features are presented in Section 3. Section 4 presents a case study of an architectural organization and the variations of that order that can be achieved resulting from the use of the system. It offers confirmation that this method can enhance and assist in the exploratory search of form and order at the level of conceptual design.

1.1. Architectural Premise

Many architects exhibit dynamic characteristics in the physical order and/or form of their designs. Formal collision of geometry is a concept in architecture that is frequently employed "to establish hierarchies; to accommodate or accentuate different requirements of interior spaces or exterior forms; to express the functional or symbolic importance of a form or space within its context; to generate a composite form that incorporates contrasting geometries" (F. Ching, 1979).
Skewed or rotated forms, repetition, even subtractive and additive forms, exhibit dynamic characteristics, but notably absent from this is the element of time.

For example, Stirling’s Olivetti Training School (see Figure 1) exhibits a formal collision of geometry. The linear form of the classrooms is disturbed by the penetration of a square form, the communal meeting space. The collision causes a break in and displacement of the linear form and order of the classrooms. As a result, a hierarchy is established, accommodation is made for vertical circulation, and a composite form is created that incorporates differing geometries.

![Figure 1 (F.Ching). Olivetti Training School (1969-72), J. Stirling.](image)

Louis Kahn’s Convent for the Dominican Sister’s, also exhibits formal collision of geometry (see Figure 2). The dormitories form a U-shape plan that defines a precinct. Within the precinct, discrete forms contain community functions. In addition, the forms exhibit dynamic qualities of motion and collision. It could be characterized as having the behavior of colliding solids, sometimes differencing, unioning, or disturbing the geometry of the forms.

![Figure 2 (F.Ching). Convent for the Dominican Sisters (1965-68), L. Kahn.](image)

The curvilinear facade of Alvar Aalto’s "Neue Vahr" Apartment Building (see Figure 3) is a result of dynamic transformations. The order of the apartment party walls forms a ‘sweep’ motion. Radial instances of the wall are modulated in length, but constrained on one end. The final form displays a dynamic curvilinear facade.
Some of these examples reveal some interesting spaces that are generated as a by-product of the dynamic order, almost haphazardly and perhaps beyond the vision or original intent of the designer. But that makes these spaces no less important and it is one factor that this paper attempts to capitalize on.

The goal of this paper is to facilitate the design process through the form/order searching stages of conceptual design. Because the transformations, like the examples described above, are relative to time, it becomes necessary to consider using the computer because of its capabilities to synthesize images which mimic motion.

2. INFLUENCES

Plotting complex motion, in computer animation, where conventional solid modeling was used, was a tedious task. Physically-based modeling was developed to alleviate the work required by simulating the real-world, thus reducing the effort conventional techniques required to make sure that physical laws were maintained. The approach simulated the real-world and allowed animators to efficiently represent the behavior of many types of complex objects (flying a flag), motion (collision and deformation) and materials (steel, clay, gelatin) by assigning physical qualities that determined its behavior.

Hahn (1988) and Moons/Wilhelms (1988), investigated the geometrical and topological algorithms, respectively, of physically-based modeling. Once the objects were in motion, however, animators had limited control in the result. Sometimes many attempts were necessary to get the desired animation to be produced by the modeler.

It is not the goal of this paper to propose another simulator of the physical world. While similar, because it constructs rules of dynamics and insists its rigorous application, it differs by allowing a relaxation or modification of those rules where deemed appropriate by the designer.

A similar approach, based on dynamic transformation, was implemented by Terzides (1989). The system allows the user to transform the topology of one object to the topology of another object, with the ability to freeze the "reformation" at any time. The process is interpolation, where the base and target are known. This paper deviates from the known to the unknown, to a process of extrapolation, where only the base is defined.

The remainder of this paper presents DICE, an experimental implementation that attempts to enhance the exploration of these transformations of form and order. Loosely based on Newtonian principles of dynamics, solids generated by the modeler may be given physical qualities (mass and elasticity) and constraints (velocity and friction), which define it's behavior relative to other objects. The modeler allows the designer to explore interactively, the generation of form and order resulting from interactions of animated solids.
3. DICE, AN EXPERIMENTAL IMPLEMENTATION

3.1. System overview and user interface.

The interactive system, written in C, currently runs on the Apple Macintosh platform. It has been written as an extension to the MacMod shell, provided by The Ohio State University. The shell was selected for its solid modeling data structure.

Shapes of objects and their position in space occur through transformations which affect the two major parts of an object's structure: geometry and topology. Affine transformations and deformation are geometrical operations. They cause an object to translate (see 3.1.3. Motion Initiation), rotate (see Section 3.1.5. Rotate), scale (see Section 3.1.6. Expand/Contract) or deform (see Section 3.1.3). Reformation is a topological transformation. It occurs when a point, edge or face of an object is inserted or deleted. In this system reformation will occur when an object's elasticity is given a flexible or brittle physical quality and it interacts with other objects.

![Figure 4. Screen layout in dynamic mode.](image)

The following are explanations of the system's operations. The interface is icon-menu driven and the symbols next to each section refers to the command icon on the screen (see Figure 4). When a particular command is desired, the appropriate icon is selected and the user will be prompted for further information. The specific information required for each command is provided below.
3.1.1. Physical qualities

The creation of a 3D solid may be a simple extrusion of a 2D polygon, or an object in revolution. After the object is created, the user can assign physical qualities (e.g. mass, velocity, elasticity, and friction) with the use of a dialogue box. To attach physical attributes, the object must be selected. This will cause a dialogue box, particular to that object, to appear. An object’s value for each physical quality is represented not in real numerical terms (e.g. lbs., ft/sec) but relative to other object’s physical qualities (mass of object 1 > mass of object 2). Therefore, each physical quality is a range, represented in the dialogue box by a scroll bar (see Figure 5). The attributes will affect the object’s dynamic motion and, if collision with another object occurs, it’s reaction (geometrical and/or topographical transformation) with that object.

![Figure 5. Physical qualities dialogue box.](image)

Mass, ranging from light to heavy, assigns a weight relative to other objects. Mass affects the momentum of an object (Momentum = Mass x Velocity). The momentum of an object determines how long the object stays in motion (with normal friction depreciation) and, if interaction occurs, whether that object propels or is repelled by the other objects.

Velocity, ranging from slow to fast, can be preset for each object. When the object is set in motion, it can accelerate, decelerate (caused by normal friction), or maintain a constant velocity (no friction) for a determined period of time. Normal Friction causes the loss of an object’s momentum when moving across the XY plane. No friction simulates a very slippery surface with no loss of momentum and an object’s velocity would be constant. A limit in time, or cycles is given, if termination of motion is desired.

Elasticity, ranges from soft to semi-solid, to solid. This physical quality determines the result of an interaction, e.g. affine transformation, deformation or reformation (see Section 3.1.3). An object that’s solid would transfer the energy received by an interaction to translating its position Energy is conserved when both objects are solid. An object that’s semi-solid would deform and some energy would be lost to friction caused by the interaction. An object that’s soft would reform and give little or no resistance to the other object, therefore energy would be conserved.
3.1.2. Direction Vector Attributes

This command defines an object's path or direction. The information is stored until the user puts the object in motion (see Section 3.1.3). An object is motionless unless the user puts it in motion or another object interacts with it, then the resulting reaction is not determined by the direction vector attributes, but the forces of the object it has collided with.

To define an object's path, requires the user to input the desired coordinates of the course that the object is to traverse. By selecting the object graphically, the centroid of the object is calculated and the user drags a vector from the centroid to the first destination point, relative to the current editing plane. The user can continue to input points chronologically to establish a course, or double click to terminate the path.

To give an object direction, requires only a direction vector. By selecting the object graphically, the centroid of the object is automatically calculated. Then, drag a line from the centroid of the object in the direction desired (relative to the active reference plane) and double click. The length of the vector will be automatically redrawn to represent the magnitude of the momentum, which is determined by the velocity and mass attributes.

Objects' direction vector attributes are displayed whenever the dynamics mode is selected. Changing an object's direction, before motion has been initiated, can be done graphically by selecting the direction vector end points, or course points, and dragging it to the desired location.

3.1.3. Motion Initiation and Interaction

With this command, the user can select one or more objects and set them in motion by double-clicking on the screen. If two bodies are in motion and an interaction occurs, the transformations that occur are dependent on the elasticity of both objects. Figure 6 is a matrix of this interaction, and the predicted operations, based on the elasticity of the objects.

![Interaction Matrix](image)

In each category of interaction, geometrical and topological operations occur to affect coordinate displacement and deformation or shape reformation, respectively. In Figures 8 through 12, collisions are illustrated and presented chronologically. Each frame is the state of the objects (a)
before interaction, (b) when interaction is detected and (c) after the appropriate reaction. Below is a diagram calling out the components of the figures (Figure 7)

![Diagram](image)

**Figure 7. Components of Diagrams.**

Geometrical transformations occur, primarily, with solid vs. solid. Figure 8 shows a solid vs. solid collision where the momentum of the cube is completely transferred to the extruded triangle, which was previously not moving. The extruded triangle's resulting velocity is dependent on its mass and the momentum transferred to it from the cube.

![Images](image)

**Figure 8. Geometrical Transformation: Propagate.**

When both objects are in motion, the resulting velocity of each object is the product of the sum of their momentum and its ratio of the total mass. Figure 9 shows the interaction when both objects are in motion and the mass of one is less than the other. The heavier cube pushes, caused by multiple interactions, the lighter extruded triangle.

![Images](image)

**Figure 9. Geometrical Transformation: Push.**

When objects are moving obliquely to each other and an interaction occurs, the reflecting plane is determined and the angle of reflectance is equal to the angle of incidence (see Figure 10).
Reformation occurs when solid and soft, or semi-soft, objects interact. In Figure 11, the interaction is a difference (A-B) of the path of the small cube (operand B) from the large cube (operand A).

Figure 11. Topological Transformation: Solid vs. Soft

When a semi-solid object interacts with a solid, or semi-solid, object, geometrical points of the semi-solid object will be displaced based on the vector forces of the interaction (see Figure 12).

Figure 12. Geometrical Transformation: Semi-Solid vs. Solid.

3.1.4. Instancing

When an object is selected by the user, the system prompts the user for a time interval. When that object is in motion, initiated by the user or by interaction with another object, every time interval that elapses causes a copy of that object, in its current position and form, to be created (see Figure 13).
Instancing allows the user to see where the object has been and what form it may have transformed from. This can be useful for creating repetition in an architectural organization.

![Figure 13. Instancing.](image)

### 3.1.6. Expansion / Contraction

When an object is selected by the user, the system prompts the user for expansion or contraction and X, Y, Z vectors are defined. When in motion, the object dynamically scales and the system determines if any interaction occurs (see Figure 14).

![Figure 14. Expansion.](image)

### 3.1.5. Rotation

The user selects the object, which is highlighted, and then a point that the object is to rotate about is selected on the reference plane. When the object is in motion it will rotate about that point.

![Figure 15. Geometrical Transformation : Rotate.](image)
(Cylinder has an orbital constraint).

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3.1.7. Freeze Face/Segment/Points

Any face, segment, or point of an object can be selected by the user to constrain it from motion. The face (requires two picks), segment, or point is selected graphically, and highlighted by the system. Select that entity again to remove the constraint.

![Figure 16. Geometrical Transformation: Freeze Face. (Face of the large object, opposite the face of interaction, is frozen).](image)

4. CASE STUDY

With DICE, the designer can explore interactively, the generation of form and order resulting from interactions of animated solids. Solid objects can be created by DICE to represent conceptual elements (abstract or literal). For example, in Figure 17a objects were created to represent functions taken from a building program. The bar represents the space requirements of a linear organization of circulation and adjacent classroom spaces. The cube, represents the space requirements for meeting spaces to be shared by the classrooms.

![Figure 17.](image)

To develop a dynamic relationship, the objects are given physical qualities and put in motion (see Figure 17b). The bar is very hard, a slow velocity and has less mass than the cube. The cube also has very hard qualities and is given a mass and velocity with enough momentum to interact with the bar.
The result (see Figure 18a) of the interaction causes a topological transformation of the bar. With the insertion of two faces to the original bar, the one solid now becomes two. Since the interaction has not exhausted the momentum of the cube, it continues to transform the bar. The cube, which does not have enough momentum to cause another topological interaction and because it's heavier, continues on its course and geometrically displaces local coordinate points of the bar, until it comes to rest (see Figure 18b).

For a different interaction, but with the same building program, the physical qualities were changed and the interaction was repeated. This time the bar is given more mass than the cube and has become more soft than before. The cube's physical qualities remain the same. When collision is detected, a topological transformation occurs. The harder cube begins to difference its path from the bar and a segment is inserted on the opposite face from the collision point (see Figure 19a). In addition, forces from the cube caused local geometrical transformations to coordinate points of the bar. Because the mass of the cube is less than the bar, the cube is reflected with the remaining momentum and eventually comes to rest (see Figure 19b).
Whether these interaction results are satisfactory must still be determined by the designer. The building program chosen was not arbitrary, it is the same as Stirling’s Olivetti Training School. The goal was not to simulate the order, although that could be accomplished, but, with same building requirements, to explore the variations of form/order generated by DICE. Certainly, the results exhibit formal collisions of geometry and some of the dynamic characteristics found in the building examples cited above.

5.0 CONCLUSION

Transformation is not a new idea to architecture, but it has taken the development of CAAD systems, which introduced the factor of time to these transformations to be able to visualize it’s power to manipulate form and order. DICE combined it’s rules of dynamics, the assignment of physical attributes to solids, and transformations to suggest a conceptual design tool. Indeed, DICE was able to generate form and order that exhibited formal collisions of geometry. It expanded, by factoring time into transformations, and enhanced, by making it interactive and real-time, the space that the designer could search for form and order.

This paper attempts to explore a unique approach to conceptual design and composition. It is not an attempt to reduce design to a single value. The larger goal is to build a toolbox of design methodologies, that are not, necessarily, related, nor mutually exclusive, and whose use would always be at the discretion of the designer. DICE is not a discrete proposition of what CAD should be, but an integral component of what it could be.

ACKNOWLEDGEMENTS

I would like to thank The Ohio State University, Department of Architecture, Computer-Aided Architectural Design Program, for the use of their MacMod shell. I wish to acknowledge Dr. Chris I. Yessios for his contribution of ideas. And thanks to all my friends for their help.

REFERENCES


