File to Factory and Real-Time Behavior in ONL-Architecture

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Abstract

ONL (Oosterhuis and Lénárd) architecture is based on digital design and fabrication, whereas the design merges into fabrication in a process of direct transfer of data from a 3D modeling software to a CNC (Computer Numerically Controlled) machine. This paper describes ONL design and fabrication processes referring to three main aspects: (1) Form-Finding, (2) File to Factory, and (3) Real-Time Behavior.

Form-Finding Process

The ONL form-finding process is a hybrid process. It relies on diverse concepts and techniques incorporating digital and non-digital media: splines and hand-drawn curves, 3D computer models and physical models are complementarily used in the creative process, whereas digital design and reverse engineering constitute integral parts of the process.

While digital design refers to computer-generated design, reverse engineering represents the inverse of this process. It implies a process of translation from physical to digital. The 3D scanning of the physical model is followed by a software conversion process, which allows for regeneration of the scanned model as a digital 3D model.

The complementary use of these techniques is reflected, for instance, in the design process of the project Web of North-Holland (2002). This process starts with a free-formed digital model. Its concomitant CNC milling allows for further formal experimentation such as adjustment of the shape by means of conventional techniques, while the subsequent translation of the physical model into a digital model by means of reverse engineering enables digital manipulation. In this process, an icosahedron is mapped on the NURBS surface in order to define a generic structure. After being twisted and deformed according to spatial and formal requirements, the warped icosahedron represents an initial structural model. It establishes a spatial matrix for further generation of CNC data for digital fabrication.

File to Factory

File to Factory refers to the seamless merging of the design process into fabrication. It involves direct transfer of data from a 3D modeling software to a CNC (Computer Numerically Controlled) machine. It employs digital design and fabrication strategies based on computational concepts.

1. Digital Design

ONL projects rely mainly on four computational concepts. The first concept implies the geometry of continuous curves and surfaces mathematically described as NURBS, Non-Uniform Rational BSplines. The second is based on parametric design, the third implies scripting and programming, and the fourth computational concept relies on motion kinematics and dynamics.

1.1 BSplines

Freehand drawn curves resemble BSplines because of their free-formed complex shape. The ability to control effortlessly their shape by manipulating control points allows for formal experimentation. For instance, BSplines establish the geometry of the building in the project Acoustic Barrier (2004). They follow the trajectory of the highway, defining a bulge within the sequence of a relative smooth curve: the Cockpit.

The Cockpit as an integral part of the Acoustic Barrier is generated by expanding the virtual volume between the lines in such a way that the length of the Cockpit is 10 times bigger than the width, in order to keep the smooth appearance when passed at a speed of 120 km/h.

In addition to NURBS-geometry, Acoustic Barrier and Cockpit also imply parametric design and scripting as computational concepts.

1.2 Parametric Design

Parametric Design refers to parametric definitions, such as 1 = x2/a2 + y2/b2, for instance, to describe a 2D curve. Each time a parameter changes, the model regenerates to reflect the new value. The parametric model represents the setup of a metadesign allowing for a reconfigurable design.

In order to establish a parametric model the NURBS surface of the Acoustic Barrier, for instance, is intersected with a generic structural model generating a point-cloud (see section 2.3.2). The point-cloud represents a parametric setup: it describes the volume by points and establishes spatial relationships between them. Between these points structure and skin are generated by means of scripting.

1.3 Scripting and programming

Scripting and programming refer to the process of writing a simple program in an utility language to orchestrate behavior. It consists of a set of coded instructions that enables the computer to perform a desired sequence of operations. In the case of Acoustic Barrier the geometry is based on several MAX-Script routines.

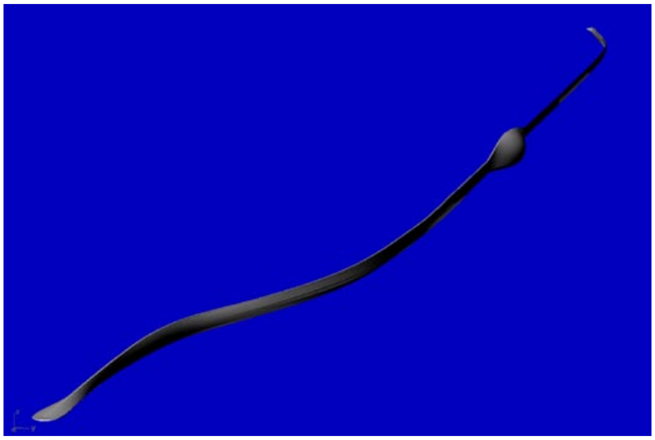

Figure 1. Acoustic Barrier: NURBS Model

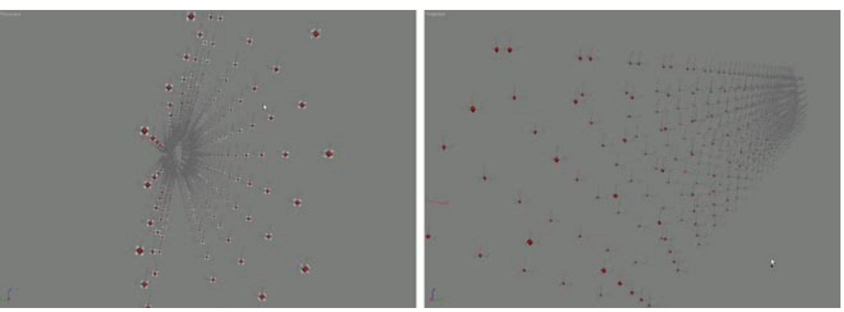

Figure 2. Acoustic Barrier: Point Clouds

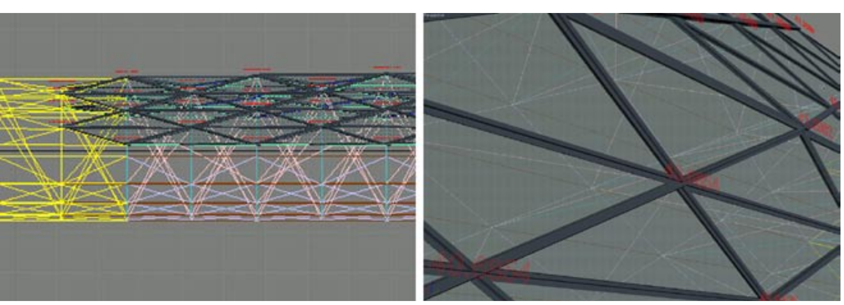

Figure 3. Acoustic Barrier: Steel-Glass Structure

(1) The first script loads the (DWG) files containing the point clouds. It builds the axis of the steel profiles that form the structure and projects the planar surfaces generated between the points, defining shape and position of the glass panels.

(2) The second script generates a detailed 3D model of the steel-glass structure (Fig. 3).

(3) The third script is in development: it verifies the 3D model resulting from the previous two scripts, applies constraints such as maximum tolerance and effectively replaces deficient parts such as not well-formed or displaced parts. Finally, the data generated by scripting is directly transferred to the steel and the glass manufacturer for further digital processing such as laser cutting.

2. Digital Fabrication

Digital Fabrication refers to CNC (Computer Numerically Controlled) technologies implying data transfer from a 3D modeling program to a CNC machine and fabrication by means of formative, subtractive, and additive techniques. These allow production of small-scale models and full-scale building components directly from 3D digital models.

In order to produce small-scale models, ONL uses additive and subtractive techniques, such as 3D printing and CNC milling, respectively. While subtractive techniques refer to material removal processes, as for example multi-axis milling, whereas the machine is exclusively computer-controlled, additive techniques involve processes of layer-by-layer addition of material. 3D Printing, as one of these techniques, uses ceramic powder and glue, where the physical model is generated in a process of selective addition of glue layers. Finally, the loose powder is separated from the model.

Beyond generating small-scale models by means of Rapid Prototyping techniques, ONL projects, as mentioned before, make use of CNC technologies such as laser cutting. Not only does ONL establish direct communication and data transfer with the manufacturers by accessing data from a common database on the Internet, but also the digital data from the 3D model controls the CNC machine. The geometry is converted into instructions to control movement of the machine, tool changes, and material supply. Intermediate stages such as the production of 2D drawings, for instance, are eliminated.

Digital fabrication allows for variable, non-repetitive design. It implies the concept of mass-customization enabling development of non-standardized building systems through digitally controlled variation and serial differentiation (Kolarevic 2003).

The concept of mass-customization is reflected in the project Variomatic (2004), which is a web-based housing project (Fig. 4). It proposes, within certain constraints, individual designs, whereas volume, shape, material, and openings are variable. The website www.variomatic.nl offers an interactive interface for its clients. While changes in the geometry take place in real-time, the customers become an active part of the design process. The final design is converted into data for industrial production, whereas the participants in the collaborative production process are accessing data from a common database on the Internet.

While digital fabrication allows for serial production based on local variation and differentiation, collaborative design and collaborative construction via the Internet enable participants to communicate and collaborate in developing individual designs and produce cus-tomized buildings. The processes of collaborative design and collaborative construction prove to be effective because of the direct link established between client, architect, and manufacturer. It skips several iterations, such as generation of 2D drawings (construction documents) for the industrial production, which prove to be unnecessary.

ONL creates a platform for collaborative design and collaborative production processes. In the design process, it not only makes use of NURBS-geometry and parametric design but introduces scripting and programming in the design process of complex shapes such as double curved surfaces. This allows not only for automated 3D modeling of building components according to the script, but also allows for automated generation of quantitative and qualitative data to control the CNC fabrication of the components.

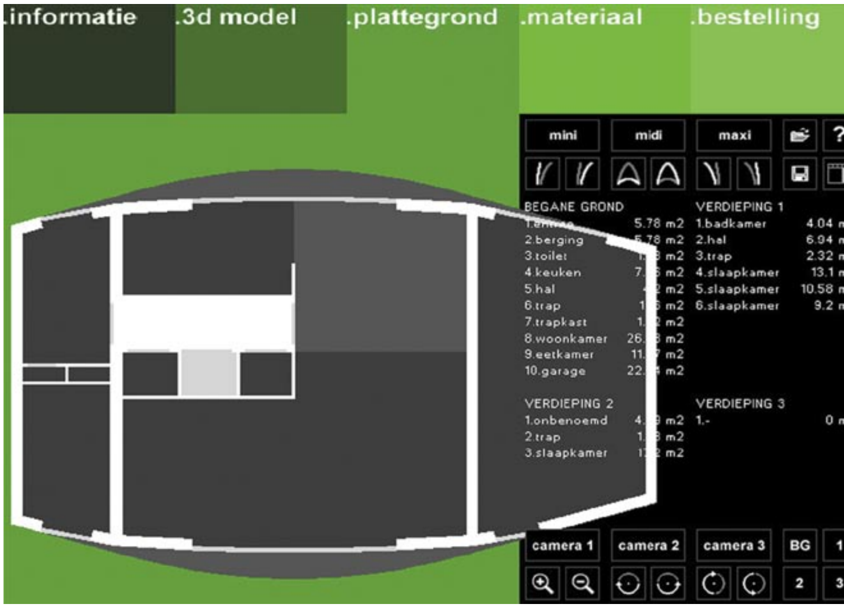

Figure 4. Variomatic: Web Page

3. Construction Strategies

In response to requirements of the double curved surface, ONL employs specific con-struction strategies and concepts such as Structural Skin, Polygonal Tessellation, Generic Detail, and Composite Material.

3.1 Structural Skin

As a construction concept, Structural Skin implies skin geometries, such as double curved surfaces capable to serve as structure, therefore capable of self-support. The constructive concept of structural skin opposes the modernist concept of separation of skin and struc-ture.

3.2 Polygonal Tessellation

This refers to the transformation of the surface from curved to faceted enabling subse-quent extraction of 2D, planar surfaces from double curved surfaces. Generally, the trans-formation of a NURBS surface into a faceted surface refers to automated tessellation processes based on surface subdivision algorithms, providing several computer generated tessellation alternatives. ONL developed a different strategy to transform NURBS sur-faces into polygonal structures: it intersects, in a first step, the NURBS surface with

Figure 5. Web: Structure and Skin

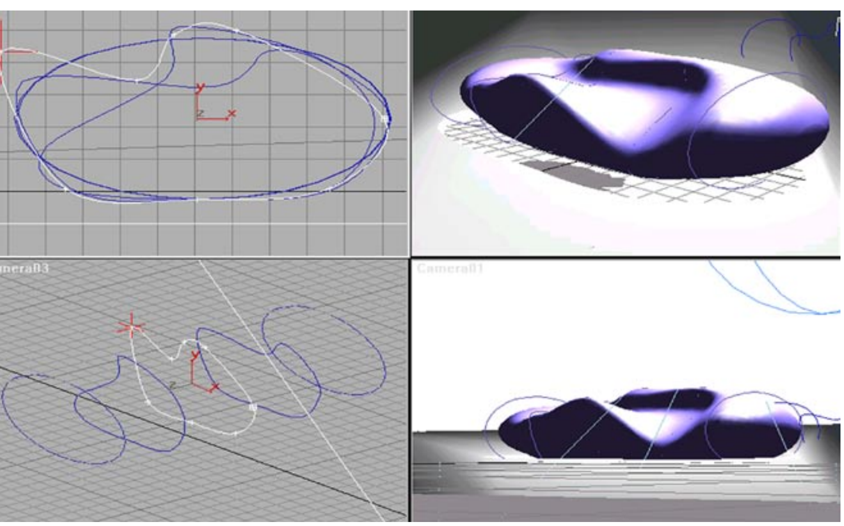

Figure 6. Trans-ports: Motion Kinematics

a generic structure in order to create point clouds. These points resulting from the intersection between the equidistant lines – defining a pattern of identical triangles – and the NURBS surface establish a spatial matrix. From these points the structure and the envelope are developed by means of scripting, whereas the point clouds establish general conditions for the development of a generic detail.

3.3 Generic Detail

The constructive concept of the Generic Detail is based on the premise that there is no separation between building components such as vertical and horizontal elements – walls and floors – as known in traditional architecture. From the generic detail developed according to the requirements of the whole, specialized details are developed according to local rules. For instance, the triangulation of the skin of the WEB (of North-Holland) corresponds to the concept of generic detail, implying that every single panel, although triangular, has an individual size and shape. Even though the elements are the same, since they are all (generic) triangles, they are all different and therefore specialized. "*One building - one detail,*" as stated by Oosterhuis (2003), refers to this principle of development of specialized building components from generic components.

3.4 Composite Material

Produced by combining different constituent materials, the composite displays properties of the different components representing an improvement in performance. For instance, the 2mm thick hylite aluminum panels employed in the project WEB of North-Holland are composed of a polypropylene core between two ultra-thin layers of aluminum. By fastening the triangle at the midpoints of three sides and subsequently fastening the edges of the triangle with omega shaped fasteners, the panels are able to follow the geometry of the curved surface.

4 Conclusion

NURBS rely on non-Euclidean geometries, which are based on axioms different from Euclid's, in which everything takes place on a flat plane or in space. Non-Euclidean geometries study the properties of lines and points on a concave or a convex curved surface, whereas Euclidean planar surfaces expose a special condition of zero curvature. New spatial concepts are challenging the historical concept of "*axiality, symmetry and formal hi-erarchy*" (Kolarevic 2003) in architecture based on Cartesian principles. The paradigm change from mechanical to digital challenges the concept of repetitive, modular systems of organization of modern architecture. It introduces the concept of non-repetitive variable designs developed, designed, and constructed by means of digital technologies.

ONL implements new spatial concepts based on non-Euclidean geometries by means of digital design and fabrication, while it develops its own (design) tools impropriating computer programs designed for the movie, automotive, or airplane industry. Since these computer programs are not specifically designed for architects, they are appropriated by means of programming. ONL develops its own tools; it customizes its design tools by programming with the ultimate objective to develop a computer model containing all qualitative and quantitative data necessary for designing and producing a building. While the single source of information is the digital model, ONL establishes a platform of collaborative production with numerous parties in the building process via Internet (see 3.2.2). ONL also develops prototypes for programmable interactive architecture engaging in future-oriented research with the Hyperbody Research Group at the University of Technology in Delft.

Real-Time Behavior

Real-Time computing implies applications and systems, which operate to an input-output latency of seconds, enabling response to stimuli within milli- or microseconds.

Trans-ports (2001), for instance, is a programmable building. It changes shape and content in real-time according to data-input from the Trans-ports website. Hydraulic computer-controlled cylinders are connected to spherical joints and form an active space frame. The movements of the frame are controlled by a computer program that calculates in real-time the changes in form and sends corresponding instructions to the pneumatic cylinders.

Basically, interactive architecture is based on the concept of hyper-architecture. Like hypertext (html), hyper-architecture establishes connections in real-time; while hypertext connects users all over the world via Internet, hyper-architecture establishes connections between the building and its user. It responds to specific requests, reconfiguring itself in real-time based on the premise that interaction can take place only between two active parts, where one active part is the user and the other one is the building.

The building is not only active but also proactive, anticipating developments and acting in advance, while being connected to the world through the Internet and to the users through the users' interface. Hyper-architecture processes information continuously, re-configuring itself in real-time. Hyper-architecture exposes Real-Time Behavior.

1. Computational Concepts

Real-Time Behavior implies an additional computational concept: motion kinematics and dynamics, which are motion-based modeling techniques, such as forward and inverse kinematics and dynamics.

Basically, kinematics studies motion without consideration of mass or external forces, whereas dynamics takes into consideration physical properties such as mass and elasticity, and physical forces such as gravity, or inertia. Generating design in such environments offers the possibility to, for instance, simulate the movement of people in order to develop architectural devices responding to this movement. Interactive spatial reorganization and re-configuration are typical features of responsive architectures.

2. Computational Processes

Protospace (PS), developed within the Hyperbody Research Group at the University of Technology in Delft, is a web-based multi-user environment relying on computational processes based on: (1) Virtual Reality; (2) Collaborative Systems (Group Decision Systems); (3) 3D Game Programming.

Figure 7. VOR: Responsive Geometry

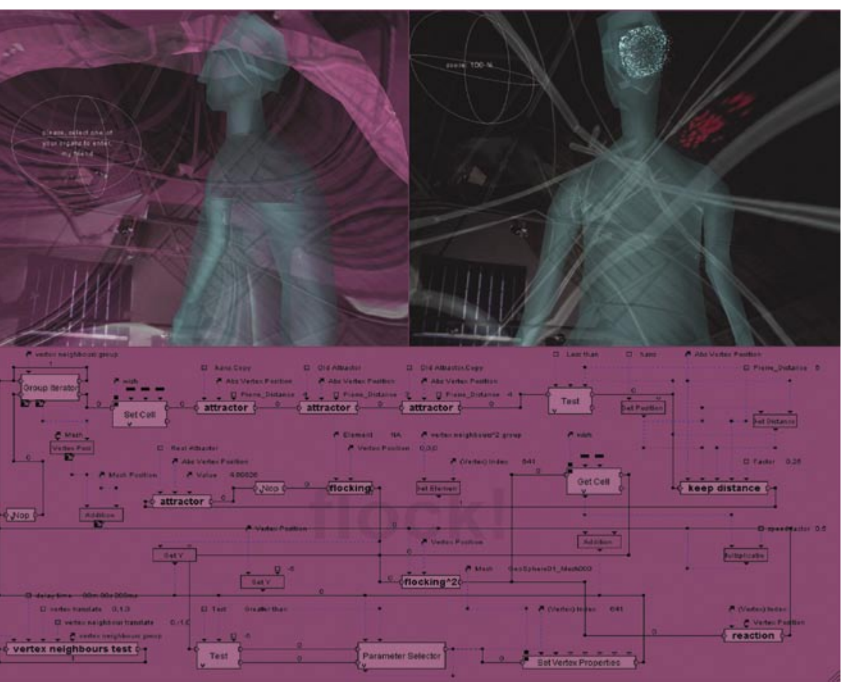

Figure 8. VOR: Initiation World

2.1 VR (Virtual Reality)

VR describes an environment that is simulated by a computer. VR environments are primarily visual experiences, displayed either on a computer screen or projected on surfaces in space. Users can interactively manipulate a VR environment, either through standard input devices like a keyboard, or through specially designed devices such as interactive interfaces. The simulated environment can be similar to the real world – for example, in simulations for pilot training – or it can differ significantly from reality, as in VR games.

PS is an immersive system: It employs sensor and effector technologies based on multi-modal and multisensory devices incorporating human-machine interfaces. These inter-faces process human input by employing gesture, speech recognition, gaze, and head tracking, and generate in turn visual, audio, or haptic feedback.

2.2 Collaborative Systems

Collaborative Systems rely on the concept of shared virtual space, wherein collaborating participants work synchronously or asynchronously on the same project. Intelligent engines, which reside in this shared space, support the activities of the participants by providing automated services, such as detecting design changes and automatically notifying the participants of changes.

Underlying the shared space is a series of databases, which contain information related to the project. Databases include: (1) 3D models of the evolving building, (2) a document management system containing and managing correspondence, contracts, and lists, (3) a discussion platform, and (4) a shared software database that provides software applications to the parties.

PS operates as a research facility providing not only the means of design representation (such as walkthrough, flythrough) but also means of design development (such as 3D modeling, performance analysis, and simulation). PS is a spatial medium enabling Com-puter-Supported Cooperative Work (CSCW), whereas Group Decision Systems (GDS) intervene only when a coordinated decision-making effort between the communicating individuals who possess specialized (and unspecialized) knowledge takes place. PS proposes four specialists – designer, engineer, ecologist, and economist – implying that their views, while being different, reflect particular aspects of the same project.

2.3 (3D) Game Programming

This programming is based on Virtools, which is a platform for creating interactive 3D applications. It is employed for creating multi-user applications, establishing database connectivity, and ensuring accessibility of custom components. Virtools generates behaviors that obey the fundamental laws of physics, employing the digital concept of motion kinematics and dynamics. This allows for precise definition and programming of complex behaviors. VOR (Virtual Operation Room), as a subproject within PS, explores ways to develop an adaptive system, which responds to commands from outside (weather) and from inside (user) the system, and acts as space for transaction and negotiation between participants.

In order to develop its own dynamic and reorganize itself in real-time, VOR (2002) relies on the self-organizing principles of swarms. In analogy to swarm behavior, elements of the structure interact with each other in response to environmental changes.

"Swarm architecture is based on the idea that all building elements operate like intelligent agents" (Oosterhuis 2003), whereas the self-organizing aspect of a swarm is of special interest; it goes back to Reynolds' (1986) studies regarding swarm behavior. He created a computer program which simulates the flocking behavior of birds. The rules according to which the birds are moving are simple: maintain a minimum distance to vicinity, match velocity with neighbors, and move towards the center of the swarm. These rules are local, establishing the behavior of one member in relationship to its next vicinity. While hierarchically the formation of flocks is from the bottom up, organizationally, flocks tend toward similar configurations (Allen 1999).

Similar to Reynolds' flocking rules, VOR establishes rules regarding the movement of its vertices. The initiation world of VOR has a WEB-like internal structure, namely, the structure of an icosahedron.

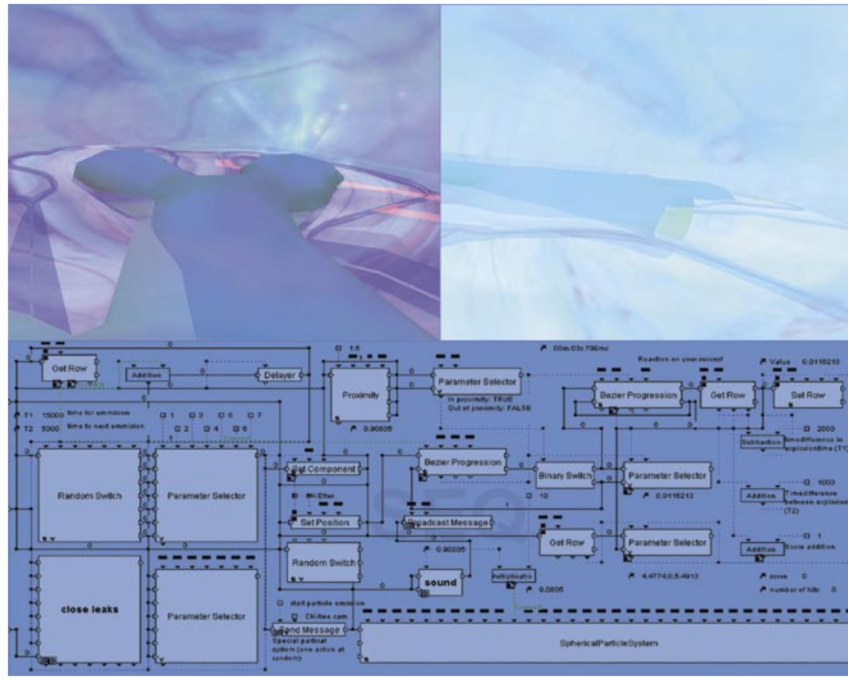

Figure 9. VOR: Purification System

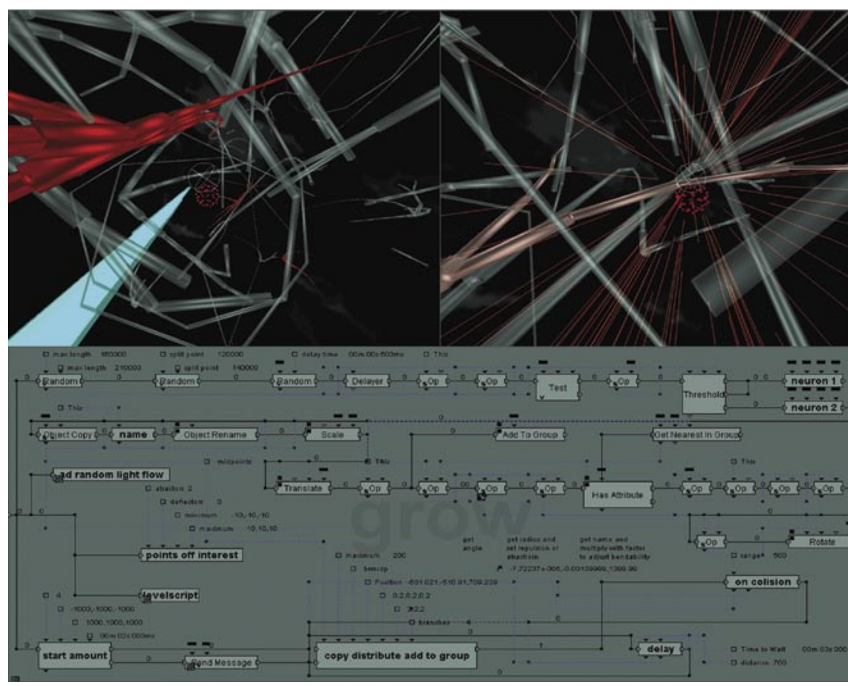

Figure 10. VOR: Brain World

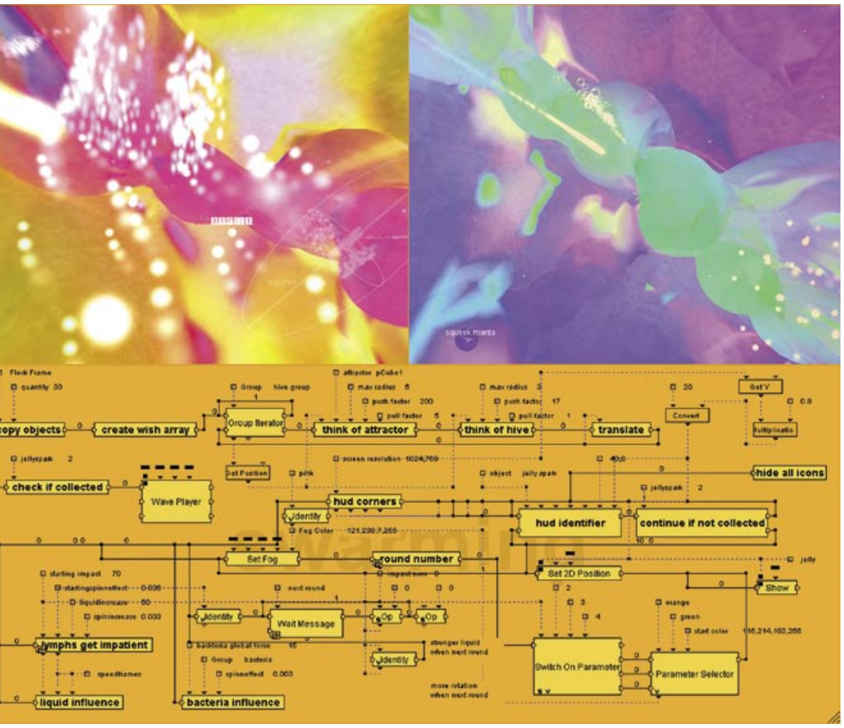

Figure 11. VOR: Lymphatic System

The movements of its vertices are controlled by the following rules: (1) Try to be at a certain distance from your neighbors (vertices); move there faster if you are further away. (2) Try to be at a certain distance from your neighbors' neighbors; move there faster if you are further away. These rules aim to establish a desired state of equilibrium, implying that VOR aims to organize itself as an icosahedron. Under exterior influences VOR executes geometrical-spatial transformations according to rule 3.

(3) Try to maintain a certain distance to the avatar, when the avatar is an embodiment (icon) representing a user in a multi-user virtual reality. VOR, as a multi-user virtual reality, is a computer simulation of an imaginary system (game) that enables users to perform operations on the simulated system and shows the effects in real-time. VOR, for instance, features a responsive geometry. The geometry responds in real-time to the actions of the players of the game, whereas avatars embody the players.

Basically, VOR consists of three bodily systems: lymphatic system, purification (kidney) system, and brain. In each of these responsive systems the player interacts by pointing, shooting and killing cells, while the input device, a joystick, allows for intuitive maneuvering and navigation. The score reflects the total number of points made by each player based on the effectivity of the player in catching bacteria, for instance, while navigating through the lymphatic system. In the end, successful players are congratulated for having healed themselves.

Figure 12. MUSCLE: Prototype

The changes in geometry (in the Brain) rely on GAs (Genetic Algorithms), which are, in fact, search tools. They have been used for problem-solving in science and engineering. Once the objective is encoded in a structure called a genome, the genetic algorithm creates a population of genomes, then applies crossover and mutation to the individuals in the population to generate new individuals. These techniques are applied in this case to develop multiple designs according to rules such as *"adjust amount and size of structural parts according to its future use"* (Oosterhuis 2003).

Beyond changes in geometry, VOR exposes interactive behavior patterns developed in 3D game software. Basically, VOR employs a self-diagnosis and self-treatment game concept: its goal is to heal the patient embodied in the avatar. The game begins with in-formation regarding the patient's state of health based on 3D computer tomography, for instance. In accordance with the diagnosis – in this case cancer – the treatment involves destruction of cancerous growth, the ultimate goal being complete healing.

3D Game Programming involving Virtools is employed not only in VOR but also in the project the MUSCLE (2003), which is the built prototype for a programmable structure. It changes shape in real-time, driven by the Virtools software connected to 72 programmable muscles wrapped around the inflated volume. The pressure inside the inflatable and the tension in the (pressurized) tensile muscles change according to the programmed behavior, exposing three degrees of activity: (1) bored – low activity, (2) happy – high ac-tivity, (3) nervous – hyper-activity. The degree of activity the MUSCLE exposes is corre-lated to the input coming from people in its next proximity.

In regard to technology and components, the pneumatic muscles are contractile hoses which by means of air pressure – are able to generate tractive forces up to 6 KN corresponding to 600 kg. The air pressure is controlled by programmable switches, whereby single, or strings, of muscles can be activated. Working together, muscle groups perform complex movements such as twisting, hopping, or crawling.

The MUSCLE's movements are, in fact, responses to external inputs coming from people moving around and interacting with the MUSCLE. Motion and proximity infrared sensors detect people's movements in the surrounding area, prompting the MUSCLE to react slightly, while touch sensors induce a stronger reaction.

3. Conclusion

The Hyperbody Research Group not only develops software (VOR) but also physical-prototypes (MUSCLE) for programmable interactive architectures. The ultimate goal is to develop an architecture which responds to requests of its users, reconfiguring itself in real-time, while being connected to the world through the Internet and to the users through the users' interface. It not only responds to the requests of its users, but proactively engages in the communication and reconfiguration process. It introduces the concept of intelligent building, where intelligent refers to anticipatory and adaptive strategies involving continuous learning from the building occupants in order to adapt the building proactively to their demands.

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