Constructing the String Wall

Mapping the Material Process

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The String Wall is the emergent product of a study on technological applications in architecture. Our team attempted to test the limits of the common partition wall construction, challenging the standard notion of the partition screen wall that recedes behind the structures, spaces and objects as a background condition. Such vibrant a partition as the SW becomes the center to the formation of the space it defines. The story of the SW could be described as the organic combination of the bow and the twist. The latent materiality and geometry of the bow and the twist as composite systems that are mined for their structural, tectonic and programmatic potential are tested prior to final construction by 3D printed scaled models. The SW is composed of successive frames that consist of vertical twisted strips of plywood attached to wooden beams. These frames emulate the stud elements of the conventional dry wall partition systems and are manufactured entirely manually. On the other hand, the use of CNC milling machine is employed for the production of the bowed plywood strips that fill in the frame. Three fluctuated curvatures produce strips that are combined rhythmically to produce the striated effect of the SW. The material is manipulated in order to expose its hidden side, the sequence of the multiple layers of the different infilling conditions. The oblique perspective of the SW is achieved through a novel geometric transparency, thus offering constantly changing views to a moving observer. The manipulation of the position of the component bowed and twisted strips explore the application of a see-through condition that escapes the norm and reveals the back to the front in a unique whole. The void of the screen wall becomes ultimately programmatic through the use of light. A sequence of halogen lights situated at the top and bottom of the in-between the wooden strips void create the dumbfounded effect of the SW experience.

Keywords: *Digital construction methods; shape studies; rapid prototyping; 3D printer models.*

Introductory Manifesto

The String Wall project emphasizes on the relationship between form, technique, manufacture, environment and context; it seeks to discern in them underlying principles of organization. New developments in computer-aided design, modeling, visualization techniques and digital methods of construction are incorporated to its design and production process in order to explore their creative formal and manufacturing potential, developing a series of evolving interconnected shape studies. Rather than promote design as a willful self-expression in the tradition of heroic modernism, we seek to engage the design process in the thoughtful investigation of form as socially, politically, technologically and technically determined, in relation to its wider cultural, architectural and aesthetic implications. The String Wall is actually a physical object, a thing in itself; some think it is beautiful, others see past its appearance and design that it aspires to be an experimental study on a digital construction process through rapid prototyping methods. The conceptual process of building the String Wall as a project in its totality will be described and analyzed in the following pages, referring to its methodology and genealogy, its morphological evolution, the technology employed for its conception and realization, the material effect manipulations and finally a broader educational concept that such a project represents for architectural studies.

Figure 1
The String Wall orthographic view

Project Methodology

The String Wall project constitutes a design process that aims at full scale realization right from its start. It was conceived and designed to be produced in a laboratory using the means of an ordinary university lab and bare hands' power. The program of the project was presented for research in the technology seminar at spring term of the academic year 2002-2003 in the Department of Architecture and Urban Design (AUD), School of the Arts and Architecture of the University of California, Los Angeles (UCLA) by the seminar instructor Jason Payne. Our research team worked with the brief of intensive expansion: strategies for the exfoliation of interior surfaces (Payne, 2003) and our case study was an ordinary gypsum partition wall system.

The design process consists of morphological transformations of the rectilinear flat surface employing a series of connected and controlled dynamic flows in order to create a surface level tension of a predetermined character. The project evolves in successive phases: during the preliminary stages of the project formal analyses of selected dynamic flows, the bow and the twist, are tested using both 3D virtual digital prototypes and realized 3D printed models. Then the emergent morph of a combination of forces applied on the surface is tested using again both the 3D virtual digital prototype and the realized 3D printed model while the final refinements and modifications are applied. On the final phase of the design project a full book of all necessary detail drawings is produced in order to construct the object in 1:1 scale. The construction is realized using a repeated procedure.

The entire project methodology employs repetition to create space and meaning for the String Wall. The formation of the wall product is achieved through the serial of potentially endless repetition of self-similar elements within the same conceptual idea. The indexical product of the String Wall project is a model of production in itself, which reflects the contingences of a larger industrial system of production and becomes the optics of a novel customized mechanical reproduction. Just as the Miesian steel frame mimics the anonymous repetition of the assembly line and poses mechanization as another sort of context, while managing to escape the triviality of the social product and salvage the purity of high-art from mass production and mass everyday life culture (Hays, 1996; Somol, 1997), the String Wall method of construction criticizes and enhances the mass production process posing rapid customization as the emerging alternative; it establishes its authorship and authenticity through generic self-similar rapidly customized mechanical object production.

The String Wall Genealogy, Past + Precedents

Let us talk a little bit about the past, the past that the String Wall project refers to: Throughout the twentieth century, architects have broken the Cartesian grid of the rectilinear box of Modern architecture as established by the International Style, pushing the boundaries of what shapes could be built. From Frederick Kiesler in the 1930s to John Lautner in the 1970s, these architects redefined the standard building vocabulary with innovative material use producing fluid shapes and curvaceous smooth forms (Rosa, 2003). Buckminster Fuller, Richard Hamilton and Marvin Goody, Archigram, Metabolism and Superstudio are just some of the individual architects and groups of designers who kept exploring non-Cartesian forms that reinterpreted technology and defied traditional aesthetics of the pre-digital era.

Today's digitally educated designers produce forms that are often described as blobs and folds through computer software that include CAD/CAM systems and surface modelers such as Alias, Maya, Rhinoceros and CATIA amongst others and industrial design technological equipment that include CNC (Computer Numerically Controlled) systems and various types of 3D printers. Although none of these tools and technology was created to facilitate architects with their designs and research, but were originally created to produce airplanes, cartoons, animation and consumer products, they did indeed permit architects to generate and investigate prototypes and typologies such as folds, blobs and digital boxes (Rosa, 2003) of a unique material quality. Architectural research has performed a successful though parasitic behavior in the case of digital experimentation: taking advantage of much more affluent practices, such as industrial design prototyping or the movie industry, that finance novel technologies, has enabled architects to manipulate non-linear surfaces with precise material properties with such methodological control that it was never possible before the digital domain.

Mies van der Rohe + other modernist echoes

Mies was the first architect to foresee and did indeed foretell the power of industrial mass production for architectural structure and adequately adjusted his structural palette and his formal patterns to the dominant Zeitgeist of the modern era. It is our team's utmost belief, that we are at this very moment standing on the hallow of a new turn in the history of mass production when rapid customization can and will transform the rules of mass production process. Mies established his authorship in a micro-scale through generic self-similar object repetition (Evans, 1990). Mass customization procedures can potentially push this generic self-similar mode of repetition to endless extremes, using the process of construction as the means of expressing even non-Euclidian construction forms.

The International style modernist generation of architects created the notion of open plan, with solid walls and contrasting voids. The String Wall project is calling into question these traditional readings of interior space, using means such as translucent, blurred, undulating dividers that are dissolved through embedded light. The precedent is a mundane everyday background condition, an ordinary gypsum partition wall construction, and the prototype produced is a new partition condition that is anything but background. The work is a close connection of head and hand as well as the computer and the machine. The materials used – plywood, computers, metal, light – are not exotic; the technology employed is not extravagant. The result is intended to be experienced and touched, and to explore the space-making potential of often irregular computer-generated volumes and light transforming new materials.

Figure 2.
The String Wall diagonal view

Contemporary digital experimentation + possibilities

The String Wall project refers to contemporary digital experimentations and seeks its genealogy in projects such as the Lattice Archipe_logics installation designed and presented by our tutors SERVO (2002) in Stockholm, Graz and Los Angeles, the Florence Loewy Bookstore cases, produced by Jacob and MacFarlane (2001) and the Dunescape project designed and built by SHoP (2000) in MOMA, P.S. 1, New York. Our team studied these realized projects for their innovative design concept and material use and especially the methods employed in all these different exemplary works, such as the seriality through digital augmentation, the seriality of the grid, and the seriality of self-similar form morphing. All the above mentioned projects use repetitive non-linear systems to produce forms that challenge our perception of constructed environment and provide a new set of rules that act as the antithesis of the autopilot mundane experiences we are continually faced with in our everyday routines (Krasojevic, 2003).

Form + Transformations

The expression of interior architectural surfaces is often muted due to the limitations of common partition wall constructions; in standard practice these walls are meant to fade away, to recede behind the spaces and objects considered more central to the formation of the room they define. The latent geometries and materialities of these composite systems – studs sandwiched between gypsum sheets – are rarely mined for potentials more ambitious than the neutral white background. It is possible however to extract new systemic possibilities from these elements through the development of their intrinsic logic in combination with the incorporation of extrinsic material dynamics. The reinvigoration of the partition wall through geometrical, structural, material and programmatic expansion reasserts its presence and role in the definition of interior space while downplaying its standard structural association and spatial role.

The formal origins of the SW could be described as the organic combination of the bow and the twist. At the preliminary phases of the design process the bow and the twist as composite geometric systems are separately mined for their structural, tectonic and programmatic potential. The layered geometries of the bowed and the twisted wall strips that correlate rhythmically are gradually pulled into three dimensions. Their physics analysis is quite disparate: mere stress and tension to cause the bowed strips and mainly torsion as well as stress and tension to produce the twisted strips. The bow is produced by applying one or more spot forces on the strip perpendicularly, so that just a region around the spot put in tension is being transformed, primarily on the horizontal level. On the other hand, the twist is caused by a circling force applied usually on one short edge of the strip and a stabilizing force on the other end, causing the whole piece to deform primarily on the longitudinal axis. Of course when deforming digitally one can apply the force just on a particular area of the strip.

Technology + Technique

The bowed and twisted effect of the strips constitute surface geometries that were modeled using the Alias Wavefront Maya software. The geometry of the individual strip itself composed of splines and NURBS (non-Uniform Rational Boolean Surfaces). In order to test the model in small scale towards the final production in 1:1 scale, rapid prototyping construction methods were used. Rapid Prototyping (RP) describes the technology for creating a physical model directly from a computer-aided design (CAD) solid model. In order to translate the surfaces and splines from the Maya virtual model to solid models and particularly stereolithography file format (STL) and IGES file format, which are standard interfaces between CAD software and rapid prototyping machines, the intermediate Rhinoceros software was used.

Rapid prototyping (RP)

There are two main methods of rapid prototyping: the additive and the subtractive method. Both were used in the String Wall project according to the production phase. In additive prototyping, RP machines grow models one thin two-dimensional layer at a time from the bottom up. Models are grown on an elevator-like platform, which is lowered one layer-height once that layer is completed. Each layer is a cross section of a solid model created in CAD. The thinner the layer, the smoother the finish on the completed model; however, once the model is complete, most of them, depending on material, may be sanded, plated, painted, or finished in some way (Gould, 2001). It is a WYSIWYG process where the virtual model and the physical model correspond almost identically. The primary advantage to additive construction is its ability to create almost any geometry, excluding trapped negative volumes. One drawback is that these machines make small scale parts, typically within a maximum range of a 20 by 20 by 23,75 inch block. Because of the produced model minor size the additive method is used in the case of the String Wall to test the form and stability of the project before moving on to 1:1 construction using the subtractive method.

The subtractive method is older, less efficient but quite frequent and easy to use. Moreover, subtractive technologies are capable of realizing large scale projects. In this technique the machine starts out with a block of material, such as plastic, foam or wax and uses a delicate cutting tool to carve away material, layer by layer to match the digital object. This is similar to a computer numerical control (CNC) device such as a lathe or a mill. Complex shapes and forms with undercuts are more difficult to accomplish with the subtractive method. Typically these are made in parts and fit together.

Three-Dimensional Printing (3DP)

Three-dimensional printing (3D printing) is a version

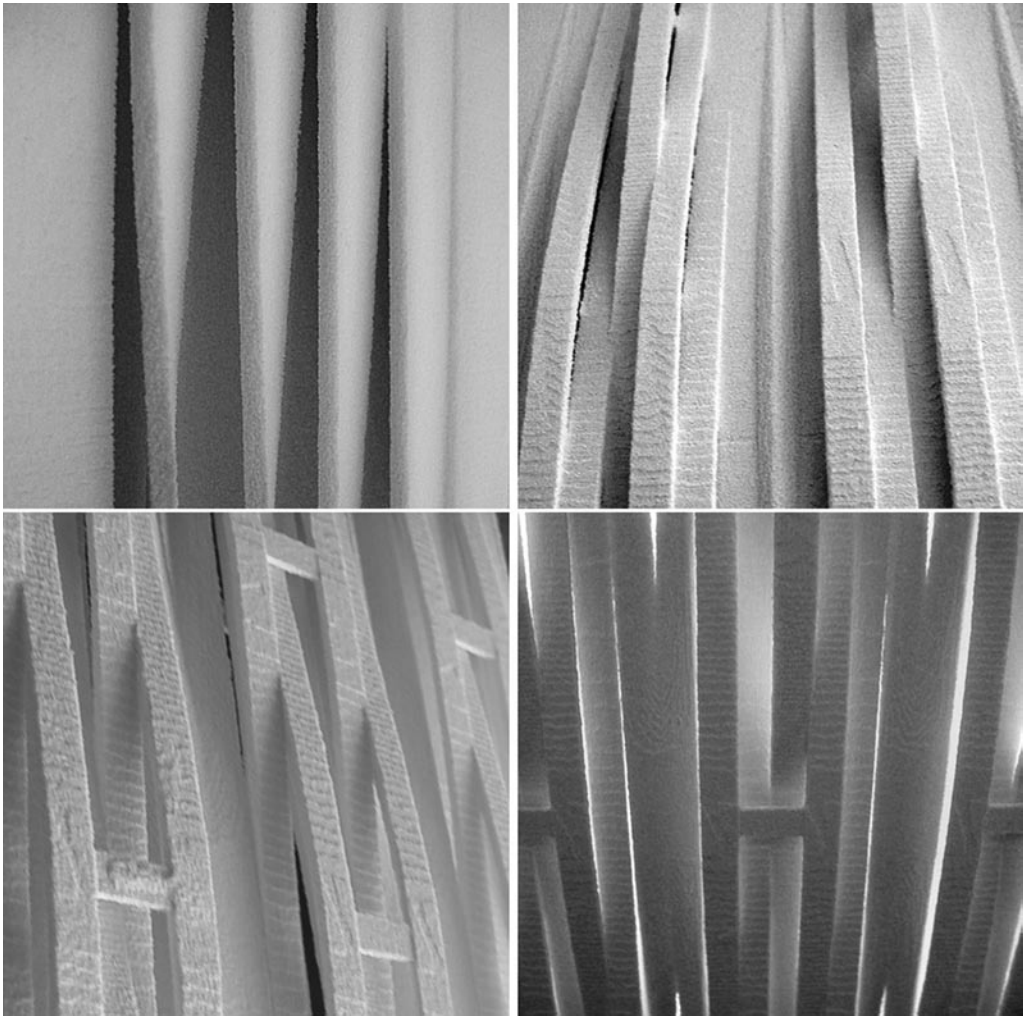

Figure 3.
The 3D printed models

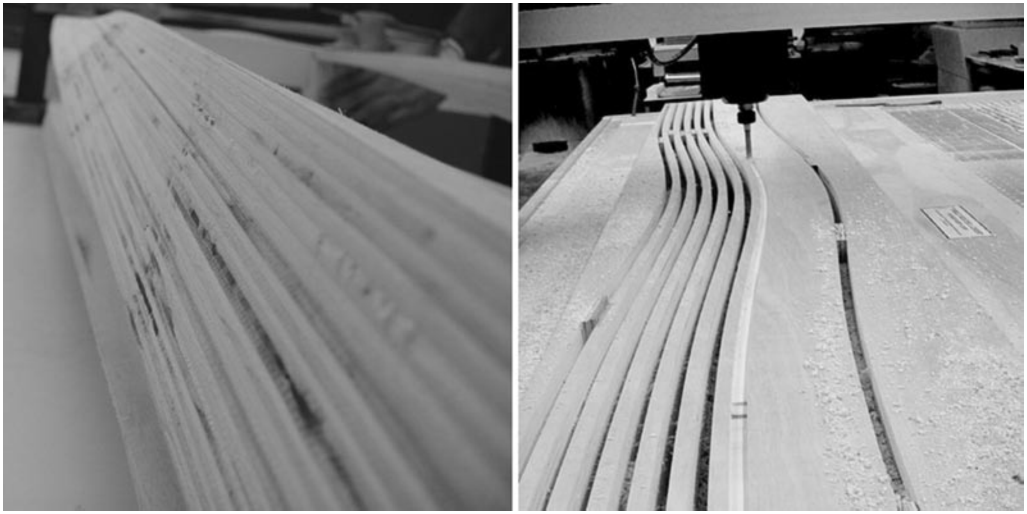

Figure 4
The CNC mill in use

of additive fabrication technology invented at Massachusetts Institute of Technology (Cambridge, MA). The Z-Corp 3D printing machine[1] our team used took virtual designs of the wall from animation modeling software, processed them by transforming them into cross sections at pre-determined intervals, still virtual, and then formed each cross section in physical space, one after the next until the model was finished, using a powder-binder technology to "print" it layer by layer. These cross sections were "printed" on top of each other to rapidly build the prototype model. Models were constructed from starch powder using a water based binder that is sprayed through conventional ink jet head. During construction the model was fully supported by the surrounding powder and when the binder had cured, the model was removed, de-powdered and post processed to suit the customers' end use.

During the thickening material process of the String Wall project various 4 by 8 in. expanses of a typical partition construction are developed through rapid prototyping 3D printer models. The 3D printed prototypes provided the opportunity to test the form, integrity and stability of the preliminary bowed and twisted projects leading to the final String Wall product. Their attributes were analytically described in terms of directionalities, dimensionalities, potentials for transformation, resistance between materialities and material dynamics that become formal organizations.

1 www.zcorp.com: 2006

Computer Numerical Control (CNC)

Computer Numerical Control refers specifically to the computer controller that reads the G-code instructions and drives the machine tool. The introduction of CNC machines, which were developed in the early 1950s by the MIT Servomechanisms Laboratory, radically changed the manufacturing industry. Curves are as easy to cut as straight lines, complex 3D structures are relatively easy to produce, and the number of machining steps that require human action have been dramatically reduced.

Computer Numerically Controlled milling (CNC) that was used to produce the String Wall is the process of machining physical objects from 2d or 3d digital information. The process of CNC milling is a 2-step procedure. The first step is toolpathing, the process of translating a 3D or 2D computer model into a series of paths for the CNC mill bit to follow as it excavates the model from a block raw material. The second step of the procedure is the actual machining, which involves translating the toolpaths into commands to small stepper motors in the milling machine that move the head of mill incrementally in the X, Y and Z directions.

Toolpaths are the information that the milling machine uses to direct the drill bit through the material. They operate as vectors: they can be controlled with properties such as direction, magnitude and position in space, which translate directly into the direction and position of the milling bit in space. Toolpaths come it two types, 2D and 3D. The 2D toolpaths are used for cutting from 2D sheet material and work only in the X and Y direction, while 3D toolpaths are working in all XYZ directions. Machining 2D cuts is a considerably quicker process than machining 3D objects, because there is less information to transmit and less material to remove. The toolpathing operation is critical to machining because it is the point where the real world constraints are applied to the 3D virtual model. When creating a toolpath aspects such as bit size, material type and the limitations of the machine must be taken into consideration[2].

CNC machines today are controlled directly from files created by Computer Aided Machining (CAM) software packages, for example SurfCAM, so that an assembly can go directly from design to manufacturing without the need of producing a drafted paper drawing of the manufactured component. Therefore in the case of the String Wall project the shop drawings produced were mainly addressing the procedures that involved plain hand labor, such as the twist and of course for mere architectural presentation and representational reasons.

The String Wall Technique

The String Wall is composed of successive frames that consist of vertical twisted strips of plywood attached to wooden beams. These frames emulate the stud elements of the conventional dry wall partition systems. The twisted frame is manufactured entirely manually. The structural procedure at this point of construction could be characterized surprisingly low-tech. On the other hand, the use of the CNC milling machine is employed for the production of the bowed plywood strips that fill in the frame.

Three fluctuated curvatures produce 30 strips that are combined rhythmically to produce the striated effect of the SW. The orthographic projection of the SW is materially opaque, the only void space exists between the twisted frames; as a result directional viewing of the SW provides only a faint glimpse to the other side on the top and bottom part. But the side view is a completely different experience: the side is open from one end to the other. The oblique perspective of the SW is achieved not through material transparency, as is the case with many contemporary partition systems, but through geometric transparency, offering constantly changing views to a moving observer. The manipulation of the position of the strips explores the application of a see-through condition that reveals the back to the front in a unique whole.

The tectonic structure of the wall reverses the structural principles of the precedent gypsum partition wall system. Thus the static stud elements are held in place by screws on the top and bottom beam elements standing evidently under continuous tension while the bowed strips though tensioned in appearance are in fact in no tension at all, due to the way they are milled; they are much more rigid than a bowed element could ever be. This tectonic equilibrium constitutes the reversal of the notion that static elements should be under minimum tension while cladding panels should be easily changed or replaced according to functional needs.

Materiality + Effect

The void of the screen wall becomes ultimately programmatic through the use of light; it is flood with light. A sequence of halogen lights situated at the top and bottom of the in-between the wooden strips

2 http://www.arch.columbia.edu/DDL/cad/CNC/fall98/millIntro.html: Fall 1998

Figure 5
A close-up of the Strings

void create the dumbfounded effect of the wall experience. Seen from a distance the String Wall is pure light and shadow. A closer look however exemplifies the intrinsic material conditions of the whole structure. The screen wall reveals the layered materiality of common plywood. The material is manipulated in order to expose its hidden side, the sequence of the multiple layers of the different infilling conditions. The plywood used to manufacture all the strips consists of 11 layers per $^{3}/_{4}$ of an inch. The striated effect of the plies liquefies the material wood. The strips of the wall become strings through this extrinsic material manipulation; they can be interactively moved within the elastic limits of their material. The String Wall project is used to shape a new kind of multi-function live/work space, efficiently and artistically creating permeable boundaries for multiple aspects of daily work and life.

Such vibrant a partition as the String Wall becomes the center to the formation of the space it defines. The effect of the screen ultimately determines the spatial quality of the whole room; the objects in it are reduced to mere coordinates around the center of existence, if one would situate the String Wall in a new position, then probably the whole room would need to be rearranged to its minor details.

Conclusive Educational Implications

The String Wall project is the research outcome of a university based technology seminar in an architecture school. The technology equipment used to model and manufacture it is hardly alien to most universities' laboratories: 3D printers are quite commonly used in biotechnology for medical purposes and CNC milling machines are fairly well known for industrial and mechanical design purposes. Taking the process of form making from the computer screen through technology to production may assist architectural studies of the digital era find another way to create physical objects, surfaces and spatial syntaxes in order to interact with multiple inhabitants, redefining qualities of our live and work environment.

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