Algorithms and Design Descriptions for Relational Modeling

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Abstract. Current fabrication processes are limited to rationalizing form to be digitally fabricated as panels for cladding buildings. There is limited or no information that informs about the connection details used in the construction process. The geometry that is extracted from the design is 2D panel information that lacks the intelligence of how the units are fitted and constructed. The exploration conducted in this research entailed finding a method for creating construction information using joinery assemblies for fabrication as the connection mechanics for construction.

Introduction

The research exploration raises interesting questions about the future of construction, detailing, and fabrication technologies. The method explained throughout this paper provides intelligent geometrical relationship between the local and global assembly systems which allows each joint component to reflect the unique condition inherent in the global characteristics of the selected topological surfaces. This provides architects/designers a series of discrete fabrication information for every single joint based on the assumption of constructability of each joint with various different parts (Heisserman, 2000). This approach is aimed at using 2D fabrication technologies such as Computer Numerical Controlled (CNC) devices for creating 3D joint systems. As seen in projects done by Gehry Partners with the use of customized panels, it is quite possible to customize each joint with different sizes and geometries with the aid of the technologies discussed in this paper.

Background

Design Software

Ways of using current software in design processes provoke an array of design solutions, but is stagnant to progress to fabrication of information for constructing intelligent mockups of the design for evaluation. Two wildly used relational modeling software packages in the design process are Generative Components, Bentley Systems and CATIA (Digital Project), Dassault Systems. Although these software packages offer the user a window for manipulating parameters, the manipulation is limited to give variation in form that is used as visual stimuli. There is no direct mapping to the feasibility of fabrication down to the joint level, but is at the abstract level of paneling. This creates a problem of relating the information to the engineer who has to rebuild the information and solve the problem of joinery which leaves models at the representation level rather than documenting how the proposed design needs to be built. The aim of this research is to investigate methods that aid in refining the fabrication problem to the desktop model level for producing information that imply the construction of the solution.

Desktop tools for digital fabrication

Desktop tools are becoming common practice in the design fabrication process. The tools emulate life-size processes (Botha, Sass, 2006) that can be used to evaluate design constructability. The aim is to instigate more digital mockup procedures in order for architects/designers to fully investigate their designs for feasibility of construction before the stages of implementation. The main device used in this research for fabricating the joints was the Waterjet cutter (figure 1.0) that cuts on a 2D axis grid.

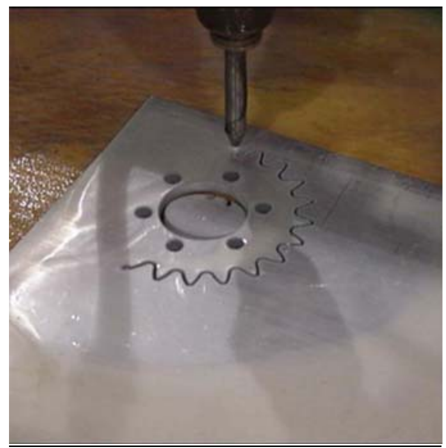

Figure 1.0 *Waterjet cutter*

Design Exploration

Design and exploration done by current architects (figure 2.0) construct complex information that creates difficulty in the stages of construction and fabrication. Past solutions made for such exploration are in methods of rationalizing the surfaces to be constructed using flat panel cladding (Shelden, 2002) (figure 3.0) that still provokes human intervention in the construction stage for negotiating the built project for joinery.

Image removed for copyright purposes.

Figure 2.0 *Design Exploration with material and form*
PROJECT: Eden Project
LOCATION: St Austell, Cornwall
ARCHITECT: Grimshaw Architects

Despite the steps taken to provide information for fabrication, it is still limited to the skinning of the design rather than rationalizing the connection mechanism and the intelligence that constructs the system.

This research introduces a method of looking at joints within a building that can be assessed to solve construction through mockup experiments. The information uses the process of 2D fabrication techniques such as water jet and other forms of Computer Numerical Controlled devices.

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Figure 3.0 *Cladding of building*

PROJECT: Peter B. Lewis Building
LOCATION: Cleveland, Ohio
ARCHITECT: Gehry Partners

Knowledge-based assembly automation

Construction of information for the manufacturing and assembly phases within design without automation become highly monotonous tasks as design possibilities fluctuate (Tan, 2000). Tan's research on vibratory bowl feeders explains the evaluation process that can be embedded in a knowledge-based system with the introduction of new design information. The incorporation of digital fabrication processes in the architectural design process creates the same phenomenon as architects and engineers try to evaluate new design. As tasks become repetitive but offer different solutions, it is necessary to introduce computational systems that construct the necessary information for manifesting fabrication results. This research approach demonstrates the creation of algorithms that evaluate surfaces regardless of the form. This approach allows ideal information to be extracted that is used for creating the necessary assembly components of the design.

Method

Digital Project, Microsoft Excel, and Rhinoceros 3.0 were used to conduct the research in this paper.

Extraction of surface information

Due to the nature of Rhinoceros 3.0 and the freedom it allows for geometric exploration, analyzing the design surface for all the necessary information was feasible. All information was extracted using an algorithm that walked along the surface analyzing the surface at a given point. Each point was evaluated based on its location on the surface (Cartesian coordinates: X,Y,Z) (figure 4.0) and all the necessary vector information. All vector information included the surface normals and the tangencies at the given location.

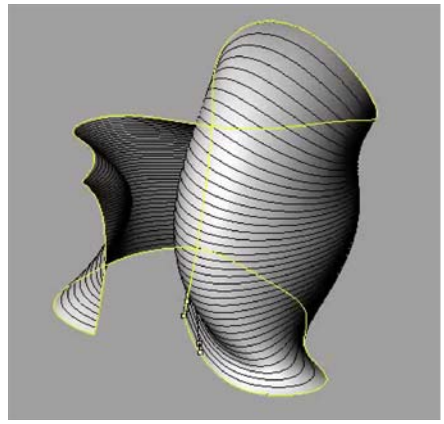
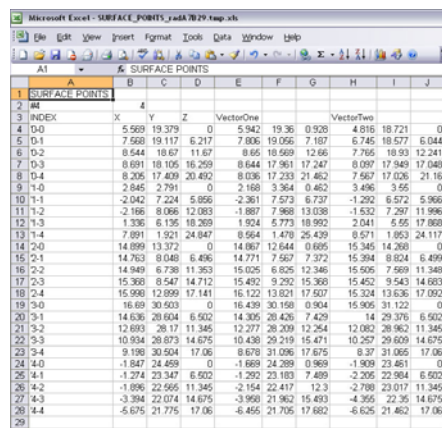


Figure 4.0 *Extraction of surface information*

The extraction process was based on each point and its location on the surface. The resolution of points can be manipulated by user depending on the number of insertion joints needed. The points represented the joint count and location of insertion. The algorithm evaluates the surface at the point location. The tangency information was first extracted as a vector (*v1*) along the u-coordinate of the surface. After the normalization to the unit measure of 1, the vector (*v1*) served as the local x-axis at the point. The aim was to establish a local Cartesian system while maintaining the global coordinate system of the surface. Second vector (*v3*) was extracted normal to the surface as a normal vector. This vector was perpendicular at the local condition of the point at the given location on the surface that served as the z-axis at that point. To obtain the final axis which served as the y-axis vector ($v2$) a cross product calculation was computed from ($v1$) and ($v3$) i.e. (i.e. $\mathbf{v_2 = v_1 \times v_3}$). More precisely, each vector is represented in numerical values in the global coordinate system

$$v3(0) = v1(1) * v3(2) - v1(2) * v3(1)$$
$$v3(1) = v1(2) * v3(0) - v1(0) * v3(2)$$
$$v3(2) = v1(0) * v3(1) - v1(1) * v3(0)$$

All information was converted to numerical values for building a data structure that could be read in an excel spreadsheet (figure 5.0) as unit information. Excel acted as the mediator between the two environments. One application wrote to the excel spreadsheet (Rhinoceros 3.o) and the other read from the excel spreadsheet (Digital Project)


Microsoft Excel - SURFACE_POINTS_radA7829.tmp.xls
File Edit View Insert Format Tools Data Window Help
A1 SURFACE POINTS

	A	B	C	D	E	F	G	H	I	J
1	SURFACE POINTS									
2	##	4								
3	INDEX	X	Y	Z	VectorOne			VectorTwo		
4	0-0	5.569	19.379	0	5.942	19.36	0.928	4.816	18.721	0
5	0-1	7.568	19.117	6.217	7.806	19.056	7.187	6.745	18.577	6.044
6	0-2	8.544	18.67	11.67	8.65	18.569	12.66	7.765	18.93	12.241
7	0-3	8.691	18.105	16.259	8.644	17.961	17.247	8.097	17.949	17.048
8	0-4	8.205	17.409	20.492	8.036	17.233	21.462	7.567	17.026	21.16
9	1-0	2.845	2.791	0	2.168	3.364	0.462	3.496	3.55	0
10	1-1	-2.042	7.224	5.856	-2.361	7.573	6.737	-1.292	6.572	5.966
11	1-2	-2.166	8.066	12.083	-1.887	7.968	13.038	-1.532	7.297	11.996
12	1-3	1.336	6.135	18.269	1.924	5.773	18.992	2.041	5.55	17.868
13	1-4	7.891	1.921	24.847	8.564	1.478	25.439	8.571	1.853	24.117
14	2-0	14.899	13.372	0	14.867	12.644	0.685	15.345	14.268	0
15	2-1	14.763	8.048	6.496	14.771	7.567	7.372	15.394	8.824	6.499
16	2-2	14.949	6.738	11.353	15.025	6.825	12.346	15.505	7.569	11.348
17	2-3	15.368	8.547	14.712	15.492	9.292	15.368	15.452	9.543	14.683
18	2-4	15.998	12.899	17.141	16.122	13.821	17.507	15.324	13.636	17.092
19	3-0	16.69	30.503	0	16.439	30.158	0.904	15.906	31.122	0
20	3-1	14.636	28.604	6.502	14.305	28.426	7.429	14	29.376	6.502
21	3-2	12.693	28.17	11.345	12.277	28.209	12.254	12.082	28.962	11.345
22	3-3	10.934	28.873	14.675	10.438	29.219	15.471	10.257	29.609	14.675
23	3-4	9.198	30.504	17.06	8.678	31.096	17.675	8.37	31.065	17.06
24	4-0	-1.847	24.459	0	-1.669	24.289	0.969	-1.909	23.461	0
25	4-1	-1.274	23.347	6.502	-1.292	23.183	7.489	-2.206	22.984	6.502
26	4-2	-1.896	22.565	11.345	-2.154	22.417	12.3	-2.788	23.017	11.345
27	4-3	-3.394	22.074	14.675	-3.968	21.962	15.493	-4.355	22.35	14.675
28	4-4	-5.675	21.775	17.06	-6.455	21.705	17.682	-6.625	21.462	17.06
29										

Figure 5.0 *Excel Spreadsheet with numerical information*

Once executed within the Digital Project environment, the algorithm was responsible for recreating the information about the surface based on the numerical information provided. The points were created then each joint was created based on the local system extracted from the data structure which created local Cartesian systems.

Design Description of joints

The main goal was to create a description of the type of joints that would be used in the assembly of the design in the fabricated process. A design description gives information about all the geometry involved in constructing the joints which include angles, shapes, rotations, dimensions, and geometric relations (figure 6.0). The information was used for automating the modelling process of creating the unit in Digital Project (DP). The geometry was built and manipulated then inserted and oriented according to location along the surface.

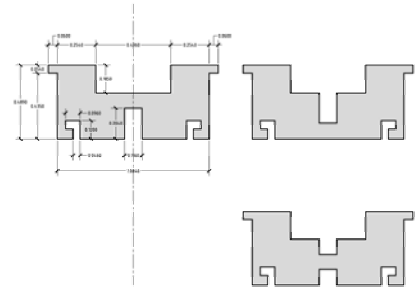


Figure 6.0 *Design description of joint*

The design description was based on planar geometry that assembled to create a 3D joint (figure 7.0). The planar information was necessary to adhere to the thread of the thesis which was to fabricate information using 2D CNC methods.

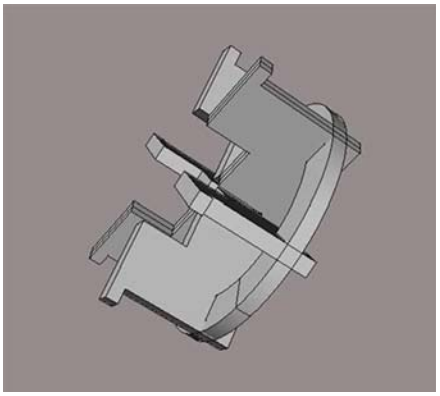


Figure 7.0 *Computer generated model of joint*

Results

The solution tested two different types of surfaces (figure 8.0). It successfully extracted the necessary information from the surfaces and inserted the joints appropriately according to its location along the surface.

Due to the nature and the intention of the system, multiple iterations were conducted and manipulated based on the parameters. This made if feasible to conduct an array of tests for results as shown. The production of the array of tests shows that this approach has indeed expedited the common tasks of modeling and computing such information by hand which would take hours or days for the results achieved. The calculations and computation were stable and gave precise results rather than the mental frustration of aligning geometry (figure 9.0) to the surface at the user-modelling level.

The information for the joint became generic enough to be used on any surface as the algorithms were written to extract the correct knowledge about the input surface. This frees up the mode of design as the joint resulted in a generic solution despite the redesign of the surface geometry.

As this is a new approach to building graphical fabricatable solid data, the processing time for the computation took far longer than anticipated. Each joint was processed at the location of insertion therefore the steps were executed in

$(N+ I)^2$ [I = insertion time] time slowing down the

computation as N increased.

Future research would entail creating a system than can produce this information more efficiently or accessing more Random Access Memory (RAM) space that would allow this computation to occur like the common tasks of current CAD tools.

The process undertaken in this research trimmed down the laborious tasks of manipulating data and geometry at the modelling level. The computation adequately and precisely used its

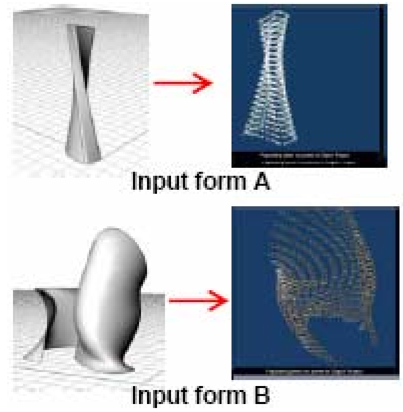


Figure 8.0 *Different input surfaces*

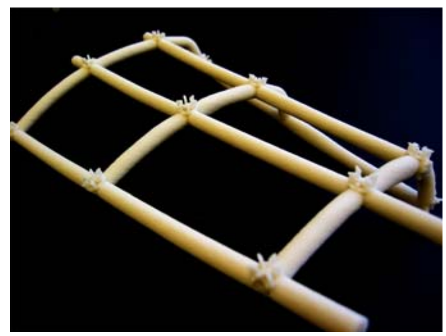


Figure 9.0 *Printed model of joints inserted at location*

power to calculate the Cartesian and vector products for dictating the correct information of the joint in respect to the surface regardless of its topology.

Contribution and Future Exploration

The methods conducted in this research tested a concept of creating design information for fabrication at the assembly level. The computational approaches in this paper displayed the integration of common software (MS Excel) as the intermediate step between Rhinoceros 3.0 and Digital Project.

Despite the results for enhancing the design possibilities with fabrication capabilities, there is need for further investigation. Investigation would need to address building a more robust data structure that can inform the user of previous joints that may be well-suited for the current project based on time, cost, and efficiency. In addition future exploration would entail fully automating a system that can efficiently set up the required relation for direct manipulation (figure 10.0).

While this is a step towards understanding ways of integrating software and fabrication technologies, there is still a vast amount of exploration that needs to be undertaken before this process becomes commodities as desktop icons.

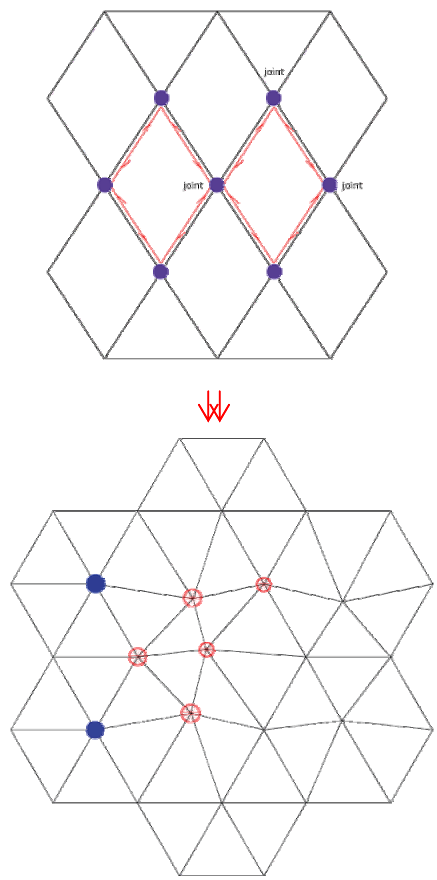


Figure 10.0 *Parametric manipulation of joint variables*

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