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CATALYSIS:
A Paradigmatic Shift in the Production of Architectural Morphologies
by
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ABSTRACT

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Through the advents of digital technologies we are witnessing a catalytic change in the technological processes and ideologies of building design and production. Digital design and manufacturing technologies have further advanced the capacity of manufacturing firms to mass produce building products and systems, but the paradigm shift is in the flexibility of these processes to mass customize. These new processes have also changed the system form of building production. Ideologies in manufacturing have changed from mass production of goods, to be stock piled in speculation of use, to an ideology of "lean production" where technology has allowed production to occur closer to the point of demand, optimizing the supply and demand chains. This has the potential to catalyze the contemporary conditions of building production as the flexible notions of mass customization are overcoming the pitfalls of mass production. It has become evident that with the advent of CAD/CAM technologies and the employment of the computer as a design tool there are powerful new ways to produce buildings. I believe that there is significant evidence that the digital revolution will continue to affect the design and productions processes as well as the morphology of the built environment. Design processes, project organization, and information exchange have been the most effected as of yet, however there are still yet vast potentials for developments in the way buildings are "manufactured" and "assembled." This thesis researches, tests and exemplifies processes of building design and production that embraces the technological advancements produced by the digital / information revolution, and catalyses the limitations in the design and production process of the "mass produced" building processes that are employed today in an effort to free architecture from the confines of the architecture "catalog" of components.
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Emily Kirkland, would have been lonely pushing through january...

Neil & Mary Lou Andrews, drive...
Dan, Lyn, John and Chris Andrews, even more drive...
Crystal Burgett, this is the big one, would never have made it this far alone.
This thesis is dedicated to Mr. Marley (not bob) the wonder dog.
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This thesis is an attempt to bring some sense of material understanding (in the sense of materials and matter processing) to a continual strain of research that I have been conducting while studying at Rice.

Unlike many thesis which start out as a stated problem and end with some sense of resolution, this one starts somewhere in the middle of a long track of work, and ends only a bit further ahead, but with no real "conclusion". This was very disconcerting prospect for a thesis that I was concerned about throughout the project. It was the conversations that took place during the thesis defense in January of 2003 that really made the work viable in my mind as a "thesis." Critical and valuable questions were asked at the review, many of them were definitively answered in the context of my work, but a great number of them were left unanswered. These questions required significantly more research and experience with the processes and burgeoning technologies that I have researched in order to be answered with any resounding authority. After much discussion Lars Lerup, Dean of Rice School of Architecture, brought clarity to not only this thesis, but my body of work at Rice University. He explained that in general there are two kinds of thesis projects. First is the thesis that I had mentioned earlier, one with a statement and a resolution. The other is one in which the student uses the thesis as another project to continue work on a set of issues that have developed throughout their studies. I happen to fall into the later.

My interest in researching CAD / CAM methodologies started during my undergraduate education at the University of Colorado when I became aware of what was occurring in the construction industries in parallel to the affects of the digital revolution in architecture during the late nineties. Strains of this research have culminated in all of my work here at Rice, and this thesis has been another opportunity to take on a rigorous investigation into the potentials of digital computation in the building industry.

This thesis does terminate with some resounding resolutions. However, all of the unanswered critical comments that were posited at my review are the questions that I shall continue to research in the course of my career. It is in this light that I feel this thesis is a success, as did the critics at the end of the review. There are many critical questions to be asked about all of the work presented here, but for me the answers require years of work, research, trial, repeat. This is only the beginning, a scratch on the surface, a launch pad for a lifelong body of work.
"The digital revolution should be thought of as one element added to a complex mix, fully coexisting with older components (energetic and material), not all of which have been left in the past. In other words, digital machinery is simply a new node that has been grafted on the expanding auto catalytic loop. Far from having brought society to a new stage in its development, computers have simply intensified the flow of knowledge, a flow which, like any other catalyst need matter and energy flow to be effective."

Manual De Landa
A Thousand Years of Nonlinear History

The processes and methodologies employed by manufacturers, fabricators, and contractors in the building design and construction industries have experienced many transformations since the beginning of the industrial revolution. Performative production ideologies based on mass production have facilitated the developments of complex high velocity economies and markets worldwide. World War II and the explosive advancements in technology that it demanded has become a historical marker in the emergence and development of automated and/or standardized building production methodologies as we understand them today. Out of industrialization and the developments of WW II we have witnessed the rise of suburban “mass produced” developments that include housing, office parks, strip malls, and big box shopping complexes. Today the built environment is constructed from assemblages of components, pre-fabricated in locations around the globe, packaged, stockpiled, ordered, delivered, assembled, and ultimately used and occupied as assembles of these components. This has caused significant transformations in the traditional roles of architects and their relationships to the built environment.

The role of the architect has evolved from a “master builder,” an expert in material craft and construction techniques, to one of a master coordinator, an expert of specifying mass produced products to be used in building assemblies. In this process the architect has lost much of the design and contract control of the built environment and been left to be a “manager” at the mercy of clients, engineers, contractors, specification writers, and various other consultants. Granted the architect is still the designer and author of buildings, in the same spirit as the master builder, but the capacity in which the architect can be active in technological progress has been stagnated by the “catalog” of conventional components and methods.

Relatively minor technological progression has occurred in the fields of architecture and construction in comparison to other industries of production. The methodologies of many manufacturers has shifted from that of “mass production,” to that of “lean production” and “mass customization. The differences between lean production and mass production have to do with a producer’s capacity to meet demand based on production cycles. Under the model of mass production the producer manufactures enough products to meet all future demands based on market speculations in one production
cycle and stores them to be distributed as the demand arises. The production cycle is optimized by how much product must be produced and sold in order to recover the overhead of developing the product, which can mean a very large number of units must be produced, stored and sold to be economically viable. In this model the production process is rigid, any changes to the product or production line are costly and time consuming. In lean production the production cycle only makes enough of a product to fulfill current demand, with a slight margin of surplus to meet future demands of a very short period. This ideal of production has been made economically viable due to developments of flexible manufacturing processes and the notions of mass customization, the idea that standardizing a process of production, rather than standardizing the product. By looking at manufacturing process in conjunction with product, changes in market demand can quickly be incorporated into the product without detrimental investments of overhead to the production firm allowing for economic flexibility and market adaptability.

Computer aided design (CAD) and computer automated manufacturing (CAM) are the primary changes in manufacturing technologies that have caused these ideological shifts in production processes. Through the use of computer numerically controlled (CNC) manufacturing hardware such as routers, mills and various cutting machines, “mass customization” is overcoming the pitfalls of mass production such as production set ups, overhead investments and fluctuations in market demand. CAD / CAM technologies have revolutionized the manufacturing industries. Product designers are now capable of designing products with CAD software and seamlessly get the product to market in record times. Manufacturing processes have become so adaptable that issues such as down time on production lines, overhead, and set up costs are minimal to the development of many products.

In the building industry, digital technologies have advanced the capacity of manufacturing firms to mass customize building components, expanding the architectural catalog. However, there is still the potential for a greater paradigm shift in the capacity of these novel processes to allow architects to further progress the methodologies of every aspect of building delivery, from design to erection. Digital production processes have facilitated the capacity of an architect to develop complex building components on a per project basis and have them manufactured within feasible budgets and realistic time frames. These technologies have brought the capacity for “rapid prototyping” and lean production to the building industries, and the potentials for this shift in production process is vast.

catalysis in architecture

Through the advents of digital technologies we are witnessing a “catalytic” change in the technological processes and ideologies of building design and production. Catalysis is
“a reaction between two or more persons or forces precipitated by a separate agent.” In the case of architecture and building industries, the two “forces” that are the architect / contractor and the built environment. The relationship is complex and the process of producing a building is fraught with points of contention between those involved. The strongest forces that exist within this relationship are budgets and economies of scale in relation to the means of production, and production technologies. Due to the tight constraints that budgets play on the production of an architectural endeavor, buildings are commonly produced as a collective of mass produced products brought together through a coordinated effort of all the participants in the building process. These parts are specified by the design team, acquired by the various contractors and erected by the tradesman that builds the physical edifice. Based in this ideal of building delivery, architects are only capable of novel work as long as they are keeping within the catalog of mass produced architectural components, and the traditional flexibility of building systems such as steel and wood that have a certain inherent flexibility. With the introduction of CAD/ CAM as a catalytic agent architects gain a greater capacity to customize and is free to begin resuming a more historical role of master builders by taking a greater role in the technological aspects of the building manufacture. Design specifics must no longer come from the catalog of components, but new components can be developed for specific projects. This does not call for a complete overall of the building and design process; in fact for it to be successful it must be able to operate within that existing context. To catalyze the existing condition, a new set of parameters and new information must added to the existing systems, causing novel and progressive systems to be produced. In this process of technological progression due to digital technologies certain traditional relationships in the process of building delivery will be drastically changed.

There are many architects working with CAD / CAM production processes a significant spectrum of how these technologies may be exploited has developed. At one end of the spectrum architects are only looking at more efficient ways to keep conventional projects on track, not allowing the new digital work flows to affect their design theories. However at the other end of the spectrum are architects that have radically enveloped their practice in these burgeoning technologies and let the new logics of digital production guide them. Architects as radical as Greg Lynn, Lars Spuybroek, Karl Chu, Marcos Novak, to name only a few, have taken on the digital capacities onto the realms of new utopias where the geometries of built form is no longer bound to Cartesian space, but describable only by the UV coordinates of spline data and the virtual world of the computer. Their holistic embrace of the digital has ranged from the very abstract theories that drive their design processes to the materialization of their work in the built world through the use of CAM production. The computers capacity to model, analyze, and describe any geometry coupled with the ever expanding technologies of Computer Aided Manufacturing (CAM) is
opening potentials for developing new forms and typologies in architecture. However, there are major points of contention amidst the profession as to what extent these technologies are providing viable architectural solutions to significant problems like the capacity to customize versus mass produce buildings and building products. Many of the practitioners that are at the forefront of “digital architecture” have received much criticism for their work. The works have radically questioned traditional architectural design processes and developed building forms that have been coined as “blobs” and arguably un-buildable. The arguments for their materialization rest solely on the capacity of CAM machinery and digital tools of production. Although possible, the vast majority of these projects will not materialize in the “real” world due to exorbitant budgets, issues of coordination, and lack of trades willing to take on the projects. However, there is still very interesting and progressive work to be produced using these digital technologies. The middle of the spectrum where repetitive production, flexible manufacturing and the seamless transfer of information occurs is where the greatest impacts to the field of architecture may exist.

thesis process

This thesis was executed as a series of distinct but related investigations, each one building upon the previous and fueling the next. The first investigation looked at the historical relationships between the architect and the built environment, especially the developments in building design and delivery since the Industrial Revolution and the technological developments of World War II. (Here in this document I only discuss some key examples of my historical research). While investigating precedents I looked intensely at architects that have already been working on the issues of CAD/CAM production in architecture and the methods and theories that have already been developed establishing the range in which these technologies may be exploited. Tectonic investigations of conventional building systems through the construction of accurately detailed models revealed issues of economy, standardization and limited flexibility. It was in these investigations that the potentials for digital methods of building delivery were questioned in the context of competition with existing, and proven, building systems. The mechanics of CAD design and the execution of CAM manufacturing is the topic of the third investigation. Here I gained the “material” understanding of these production technologies. Once I had a better understanding of how these technologies worked from experience, I was able to analyze the implications of these methods of production in relation to the overall process of building delivery. It is here that I began to understand the extent to which digital technologies can affect the integration of building design to production, ultimately reshaping the system form of building delivery. The final investigation questioned how using digital design tools to model the building envelope directly translated into the specifics of how it would be produced through the use of digital manufacturing technologies.
the "master" tradition

Traditionally the relationship of the architect to the built environment has been very intimate. Architects obtained their skills through apprenticeships with masters of construction technologies such as masons and carpenters as well as other experienced architects. Out of this process of education, the architect had an intimate relationship with the materials that were to be used in the construction of an edifice. In classic times an architects were as familiar with the processes of shaping marble and granite as they were geometry, proportion and order. The term "master builder" or "master masons" were the terms used to describe the architects of the medieval Gothic cathedrals. These master builders designed these marvels as they were constructed in conjunction with the numerous skilled craftsmen. Even in the era of the Beaux-Arts traditions, where the structure of the modern architectural "practice," was born architects were required to have intimate material knowledge gained through hands-on experience. However as the role of architects developed into that of strictly designers, not of fabricators, there was a loss of material knowledge. This was the start of a separation between the craft of a building and the design of a building. Architectural production became more focussed on the development of drawings and architects began "coordinating" the construction of buildings, and the intimate knowledge of their material palette began to wain.
empirical knowledge

For thousands of years the art of designing, engineering and constructing buildings relied on empirical knowledge gained through years of precedent experience. Though trial and error new technologies were developed. For an architect this put a great deal of emphasis on having experience with materials and work in direct conjunction with craftsman, as they were the traditional engineers. Architects and craftsman built structures not by calculations that we know and use today to optimize structures, but rather empirical knowledge that a certain size beam was needed to carry a certain general load because it worked before. This is of important consequence for building types that were repeatable, such as houses, barns, village churches. As they were developed over time and they became very efficient, even mass produceable, but nonetheless each building was to be hand crafted, and each by a different builder with different knowledge ultimately causing variation distinct variation in an otherwise “standard” building. It was this variation in construction that propelled an increase in knowledge, progressing the potentials of what could be produced.

The ability to repeat a module, or building component was very laborious, and accuracy was possible but difficult to maintain in large quantities. Tools and machinery existed that assisted in producing building components, but the cost of their use made them typically out of reach to the common building endeavour, therefore craftsman had to be highly skilled in order to produce the details that defined the architecture.
catalytic change in the 1700's

With the advents of the industrial revolution, and the forces behind mass production came methods of metalworking and machining that were exponentially more efficient and exact. The necessity for precision and speed forced industry to retool itself and develop technologies that would facilitate the production of products that were continuously becoming more complicated. The processes of milling became one of necessity, for its ability to produce a product of higher tolerance than casting or forging, but it was the most difficult method of shaping materials. With steam power came the proliferation of material machining tools that facilitated the mass production of products that were carved, pressed, stamped, rolled or extruded.

Steam powered equipment were essentially the first products to demand a level of precision that was produced by carving a piece of metal. When James Watt improved the Newcomen Steam Engine, the first steam engine invented by Thomas Newcomen, it was necessary for him to be capable of boring the engine cylinders to a high degree of accuracy. John Wilkinson was able to produce the cylinders within the strict tolerances that James Watt demanded by using a boring machine that he invented in 1775, the first metal machining tool. The Watt's steam engine would become the power source for production until the invention of the combustion engine. Following these developments in metal working came the screw cutting lathe, metal planer and the milling machine during the early 19th century, all made using the Watt's steam engine as a power source.

With the advent of new tools that were capable of precision repeatable metalwork, people like Levi Whitney, inventor of the cotton gin, were able to mass-produce interchangeable parts. Whitney coined the term "interchangeable manufacture" to describe what Henry Ford would revolutionize into "mass production" during the 1920's.

During the early 20th century metal machining tools and the products they produced were in such high demand in the United States that the production of metal machining tools in the US more than doubled, making the United States the most highly industrialized nation in the world. The advancements in metal machining technology continued into the post war era of the fifties, when machining tools went through drastic changes in the ways they were controlled. NC (numerically controlled) and CNC (computer numerically controlled) further facilitated the processes of fabricating metal and have become the predominant systems of control today.

Computers and machining tools have become highly integrated in today's high tech world of manufacturing, and with the ability to directly output digital work from the computer to the material world, along side techniques like casting, forging, and fabrication, the potentials for working metal are becoming ever more prolific.
design documents

Because of the developments in production technologies in the industrial revolution several drawing types were developed out of the necessity to convey information to the ever expanding group of participants in the production processes. These developments also mark the separation between the processes of the designer from the processes of the manufacturer. Design historian Christopher Jones discusses the difference between design by drawing and design by craft (Baynes, 11):

... The essential difference is between this, [now] the normal method of evolving the shapes of machine made things, and the earlier method of craft evolution, is that trial and error is separated from production by using a scale drawing in place of the product as medium for experiment and change. This separation of thinking from making has several important effects:
1. Specifying dimensions in advance of manufacturing makes it possible to split up the production work to several pieces which can be made by different people.
2. Initially this advantage of drawing before making made possible the planning of things that were too big for a single craftsman to make on his own...
3. The division of labor made possible by scale drawings can be used not only to increase the size of products but also to increase their rate of production. A product which a single craftsman would take several days to make is split up into smaller standardized components that can be made simultaneously in hours or minutes by repetitive hand labor or machine.

He goes on to describe how design through drawings allows simpler management of highly complex projects:

The effect of concentrating the geometric aspects of manufacture in a drawing is to give the designer a much greater 'perceptual span' than the craftsman had. The designer can see and manipulate the design as a whole and is not prevented, either by partial knowledge or by the high cost of altering the product itself, from making fairly drastic changes in design. Using his ruler and compasses he rapidly
plots the trajectories of moving parts and predicts the repercussions that changing the shape of one part will have on the whole design.

The increased necessity for drawings during the industrial revolution spawned essentially five drawing types (Baynes, 11):

1. Designers drawings are the sketches that illustrate initial concepts and ideas. These are free hand and used to develop ideas without the restrictions of details and measurements.
2. Project drawings are the beginning of what we understand today as conventional construction drawings. These drawings are measured drawings produced to some scale, and are typically line “weighted.” Drawings of this nature are used for the development and analysis of a project.
3. Production drawings are complete design documents that are used in production of a manufacture. These drawings describe in detail through dimensions and notes the specifics of a project.
4. Presentation and maintenance drawings are drawings that are used as devices for clear understanding of a project once it has been designed. These are typically drawings such as manuals, as-builts, and instructional devices.
5. Technical illustrations are produced for books, publications, and collectors. They typically are produced using the conventions of measured engineering drawings, but are rendered and detailed for representation, and leave out information that would be necessary for production.
MORE
MORE
MORE
MORE
MORE

PRODUCTION
The ideals of modernism at war

The production demands produced by World War II created an environment for industry that spawned the perhaps the greatest technological boom in history. Unprecedented strain was placed on all sectors of industry to meet the demands of the war machine. In America the scarcity of conventional resources such as metal forced scientists to develop new materials and production methods. Industrialists built massive new plants to accommodate the production demands, while designers developed amazing and adaptive uses for the plethora of new materials and processes. This was a time of great ingenuity and resourcefulness at a time when production was at an all time high. The products, and methods of production the were developed during WW II ultimately paved the way for industry after the war. Methodologies of building delivery today are direct descendant of the production efforts that burgeoned during the war.

When the United States entered WWII the country was in a state of economic depression. Nearly instantly the country was put into a mode of mass production as a scale never imagined. Massive industrial complexes were needed all over the country, and once built required massive quantities of labour to operate, and workers needed places to live. The sheer scale of construction that was demanded throughout the country was nearly impossible, and time was of the essence.

The Federal government turned to the then avant garde architects of the modernist movement. Architects like Walter Gropius, Mies Van de Rohe, Albert Kahn, only to name a few were enlisted by the government to assist and the building endeavors that were necessary for the war time build up. These architects were already dealing with issues such manufactured buildings, pre-assembly, and new material technologies.

Albert Kahn was known as one of the world’s foremost industrial architects. Kahn adapted bridge building techniques and used 300 foot long trusses in a plant facility for the Glenn L. Martin Company in Baltimore Maryland. The uninterrupted floor plane could house a full squadron of airplanes. Kahn’s firm continued to adapt to technological changes and scarce building resources like steel to build numerous large plant facilities in record time out concrete, wood and the new composites that being developed.

The works that have had the longest impacts on the methodologies of building production took place in the housing construction. Prior to the war the federal government was reluctant to sponsor housing projects, but with the increase in demand for housing due to the massive migration of people to the industrial centers the government had no choice.

< This war propaganda poster from 1942 captures the essence of American production mentality during WW II. (Albrecht)

(following pages)
The construction process of defense houses in Vellejo, CA, William Wilson Wurster Architects (Albrecht)
Picture 1 shows Homasote sheets being wet down before use, in order to swell sheets so that subsequent shrinkage will stretch material on frames. 2 shows precutting of openings for electrical outlet boxes. 3 precutting of studs and other framing lumber outside the plant.

4, 5, and 6, show assembly of a typical, room-size wall panel on a “jig table,” marked off in modular units. Door opening is cut after the sheet is applied, using plywood templates and skill saws; sheets are glued and nailed to 2 x 3 studs, using mechanical glue spreaders.

7, 8, and 9 show fabrication of a roof panel, complete with overhang and screened vent. Homasote ceilings are applied to furring strips on the bottom of the rafters; tops of rafters centered to receive sloping roof at job. Four such panels, plus seven smaller units, roof one house.

10. Trailer-truck loaded with three complete houses ready for 20-mile trip to site.

SITE PREPARATION. Picture 11 shows form for casting foundation piers in batches of 64 piers. 12 shows pole-boring apparatus for drilling foundation holes, and operation of setting piers.
Pictures 13 and 14 show the assembly of a special jig table for floor framing panels and erection on post foundations. Single thickness framing is laid in the conventional way. Picture 15 shows traveling crane unloading wall panels from trailer truck.

Pictures 16, 17, and 18 show successive stages in the erection of wall panels on the floor platform. Assembly is handled in two stages, with a fifteen minute intermission (during which the crew shifts to the next house in the row) for installation of prefabricated plumbing.

Picture 19 shows completed walls, ready to receive roof panels, which are lifted into place by a light traveling crane (19 and 20), covered with roofing in the conventional way, and surfaced with tile roofing (21). Picture 22 shows application of trim to the larger picture below completed houses.
THE AIRPLANE HELPS BUILD THIS HOUSE
The Farm Security Administrations (FSA) was initially placed in charge of administering the government defense housing programs since they were already highly experience at building minimum standard houses for thousands of squatters during the depression. However as war effort carried on, housing construction fell behind schedule the most of all federal building programs and in 1941 the Division of Defense Housing was established under the Federal Works Agency. The Division director, Clark Foreman, immediately hired private sector modernist architects William W. Wurster, Walter Gropius, Marcel Breuer, George Howe, Louis Kahn, Alfred Kastner, Hugh Stubbins Jr., Antonin Raymond and Frank Lloyd Wright to take on eleven new housing projects. The architects were issued strict guidelines that offered little design flexibility and on the average cost $3,000, yet many innovative designs were produced.

Nearly all of the architects that worked on the Defense Housing projects had to deal with issues of quick construction, tight budgets and lack of materials. Many of them, such as William Wurster, took on the challenge and used many of the new technologies that had been developed such as plywood, Homosote, bent wood frames, and composite masonry systems. Wurster was also the first to take a head strong position in the idea of manufacturing the defense houses as modular components that could be produced in warehouses, delivered to the site and erected. This was the first large scale executed example of prefabricated housing in America, and received much critical acclaim.

As the war appeared to be coming to an end because the allied forces where taking ground, many people began anticipating what would production would be like when the war was over. What would happen to all of the workers that had been employed to fuel the war machine? Many companies and designers began speculating and planning for the day the war would end. Large scale industrialist planned to convert their factories for armaments to factories for houses. Modernist designers again took the lead and began making propositions for new building models and products. R. Buckminster Fuller was one of the more radical in terms of embracing existing production methods with his Dymaxion Deployment Unit. The house was produced by the Butler Manufacturing Company and was manufactured on the same lines as grain bins. The house was supposed to revolutionize the housing industry with it entirely prefabricated construction, low cost, and rapid erection, but due to limited resources only few hundred were ever built.

Throughout the war building methods and production processes changed drastically. By the end of the war construction processes were dominated by prefabricated products, assembly lines, and alternative building materials that did not exist ten years prior. The developments that occurred fundamentally changed the ideals of building design and delivery.
“After total war can come total living”
the war machine comes home

As the war was coming to a definitive close people were looking ahead to peace time life. America had a bustling post war economy that was faced with a slump due to the vast numbers of returning soldiers who would be looking for work, flooding the job market, and raising unemployment levels. Industrial firms were faced with retooling their production facilities to produce peace time products, and this period in time would mark the beginning of another great shift in production and material technologies. Novel uses were found for the recently developed materials and the highly efficient post war production lines mass produced products that were eagerly consumed by the American public. However there were still serious shortages in housing, concerns about unemployment, and the fear of an economic recession. The Federal Government and industrialists

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YOUR GOVERNMENT, with an unstinting hand, has cleared the way to provide you with life's most cherished possession... A BRAND NEW HOME OF YOUR OWN.

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ARE YOU GOING TO TAKE IT?

Thousands upon thousands of American families through the new government F.H.A. are awakening to that bright new interest in life which home ownership alone can bring.

Surely you will not deny your family and yourself a proper share of the joy, contentment and independence which is within your grasp today!

<WW II Era illustrating the anticipation for life after the war. (Albrecht)
took up the charge to fulfill the housing demands and fuel the economy.

The Federal Housing Authority, a pivotal post war agency in the shaping of the built environment, continued to assist those that were in need of housing, only now instead of displaced depression era workers it was soldiers returning from foreign soil. The FHA offered low interest mortgages to the thousands of returning soldiers as long as the homes they purchased were new construction. This limitation served several purposes. First it continued to keep a wartime construction industry viable by creating new work for its labor force. Secondly law makers knew that with new houses other industries that supplied the construction industry would also be flourish.

The effects if the FHA programs after the began war began catalyzing the residential building industry into what it has become today. Industrialists and developers across the nation took advantage of the effect of these new FHA programs by shifting their wartime efforts of production for the military to meeting the private sector demands of the aggressive housing industry. A great majority of the building delivery methodologies they developed and executed have become the conventions of modern residential construction.

KAISER TO BUILD 10,000 HOMES

Cartoon depicting the desires of the Kaiser Community Homes Corporation (Cuff)
from battleships to suburbs

Industrialist Henry J. Kaiser was a major wartime shipbuilder and defense housing contractor, so for Kaiser steel to position itself as major home manufacturer after the war no surprise. Kaiser was a huge proponent of technological innovation especially if it turned a profit, and he saw the potentials for major profitable innovations in the housing industry due to the development of so many new material technologies during the war. Plastics and plywood were what he was most interested in exploiting.

Kaiser’s Housing Division extensively researched building materials, efficiency, and precedents of mass produced pre-fabricated homes. During this research Kaiser’s corporation developed an all aluminium and an all plastic house. The plastic house was of a sleek modern style with one entirely glazed wall flat roofs and an open plan. All who were shown the houses felt they were very progressive and would have been successful models, however the cost analysis for production made them short live. Nonetheless other ventures were more cost effective and Kaiser Community Homes was founded.

Kaiser Community Homes (KCH) focused on prefabricating homes in near major urban centers where demand was a guarantee. Their focus was to not only build homes but entire communities. KCH houses were produced as subcomponents mass produced in warehouses and delivered to the site to be assembled. Production lines that were set up in warehouses that once turned out aircraft subassemblies now repeatedly produced partition walls, exterior walls, floors, plumbing risers, and banks of cabinetry that could all be trucked off to the sites.

Plywood was the major new material technology that Kaiser embraced that made his production line feasible. Using plywood KCH adapted the concept of “stress skin” panels from the wartime aircraft industry. The concept is simple, build a light wight frame that is sheathed in plywood to make it structurally sound, and movable, in fact a large portion of the contemporary housing industry still uses plywood in the same manner. KCH performed extensive tests to prove to the public the soundness of this new material, some rather ridiculous like shooting it with a gun to demonstrate durability.

Kaiser Community Homes was only in production for several years as the homes were still ultimately more expensive than what they had hoped they would be at the outset of the venture and they had been optimized to the point of being cramped. Nonetheless the advancements made in material use such as plywood, plastic, aluminium, and prefabricated components was significant contribution to the cause of housing production in the post war era.

Ultimately there were many manufacturing firms that took on building ventures like Kaiser. Some focused only on building components and others on building systems like the Butler Building Corporation. Overall, it is the experimental and innovative methodologies of this era that have shaped modern construction.
cases of interpolation

One of the major tenets of this thesis is to look at how digital modes of representation in architecture are not only capable of changing the ways in which architects visualize and develop buildings, but also how these technologies streamline the process of building manufacture and production. This is achieved by effecting the amount of "interpolation" that must occur between the architect, fabricators and contractors.

In the traditional model of building delivery a set of contract documents are developed that describes the project in complete detail through conventions of drawing and specification. In most cases it takes multiple drawings, from multiple vantages and scales to describe even the simplest of spaces and structures. It is then up to a contractor to interpolate those 2D drawings into the 3D world of architecture. With the advent of digital modelling programs it is now possible to model buildings in exacting detail and use this digital data in the production of the building, a 3D-centric process, therefor reducing the amount of interpolation that is traditionally necessary and opening the potentials for the architect to be more intimately involved in the production process.

In this chapter I have investigated architects that have preceded this 3D-centric working methodology as well as the machinery and processes necessary to materialize these virtual designs in the real world.
CAD design - 2d interpolation
Gier & Gier Architects
Brine Baths, Bad Durrheim Germany.

The development of the roof system for Gier & Gier's Brine Baths in Bad Durrheim Germany would not have been economically feasible to build without the use of CAD packages. In this case, the design was produced through the use of early CAD packages, but before it was simple to produce the necessary G-Code to CAM produce the components. Instead it was necessary to interpolate all the digital 3D data into conventional 2D drawings that could then be used by traditional tradesman to produce the complex roof structure.
CAD Design - Partial CAM production
Jakob + MacFarlane sarl d' architecture
Restaurant Le Georges
Centre Pompidou, Paris France

Dominique Jakob and Brendan MacFarlane have extensively taken on CAD/CAM production methodologies in their work. In this particular project Mechanical Desktop was that initial CAD program that used to develop and theorize the design of the project. In this project the architects theorized the programmatic performance of the existing floor of the Centre Pompidou, and developed a scheme for the restaurant that would be made of "pockets" that were to be fabricated from steel frames and aluminium sheets. The blob forms were developed in the computer, then prototyped to scale in cast aluminium and clay to analysis the volumes. Once the designers were content with the formal aspects of the project, they then began working on the engineering aspects of the project. Each individual pocket was developed through the use of computer software that performed finite element analysis, material optimization, rib and panel development, and ultimately the G-code that was necessary for the material production of the project.
Experience Music Project, Seattle WA.
Top: Shape Grammar algorithm panel variations
Middle: Front and Rear elevations
Bottom: Final design model
[Name]

02.04
CAD / CAM integration
Frank O. Gehry and Associates
Experience Music Project (EMP), Seattle, WA USA

Frank O. Gehry and Associates has been the trend setter for many years in terms of CAD / CAM integration in the building delivery process. Gehry does not develop his work conceptually in the computer in the ways firms like Jakob + MacFarlane or Greg Lynn Form would through digital generative processes. Gehry still develops his concepts through analog technologies like clay and wood. However, once he has developed the forms of his building, he embarks on what may be the most sophisticated use digital technologies in architecture and building production. Gehry’s firm pioneered the use of CATIA in architecture, a software package that was initially developed for the aerospace industries. Clay models are digitized into the computer, then prototyped from digital data to verify that the initial digital data is exactly the same as the initial clay data. Once adequately digitized, the development of a building begins. All aspects of the building is accurately modeled in the computer, from structural systems, cladding, to mechanical and plumbing systems. CATIA is used to engineer and coordinate the design of the entire project. Once the project has been completed in virtual space, all structural aspects are analyzed and refined by finite element analysis. Digital shape grammar algorithms are used to assist in panelizing and developing the most efficient was to subdivide the complex surfaces of Gehry’s projects. One design is completed, construction documents are produced. Again Gehry was one of the first architects to include digital files as a component to the contract documents of his projects.
production with CAD/CAM - mechanics

With CAD/CAM there is an increase in control to the designer, and ultimately a more precise product. Using the computer the designer creates a 2D or 3D CAD model of the product that is desired. From this model a series of tool paths called the G-Code are created by the use of CAM software. The G-Code is nothing more than a set of points described by x,y,z coordinates that the computer can instruct the machine to follow. For the production of complex three dimensional objects the rotation and movement of the billet is also described. CAM software will cut virtual planer sections through the digital object model in order to create a series of stacked cutting path. With finer the resolution of the paths, and increased density in section cuts greater detail and smoother surfaces can be achieved.

One of the major benefits to this method of working is that subtle and extreme changes to the product have little effect on the process of manufacturing because changes are automated through the computer software and controlled by the computer and the G-Code. This has become highly beneficial when prototyping products.

The machinery of CAD/CAM operates in two general modes, through additive processes and subtractive processes. The additive processes operate through technologies that add layers of material to one another in a layered manner. Some of these processes are stereolithography, 3D printing, and laser sintering. Although these technologies do have uses in architecture, for the most part they are used at the scale of industrial and product design and when they are used in architecture it is for visualization purposes like building scale models. The subtractive processes of CNC production however have much greater implications to the production of the built environment. Theses processes are essentially automated processes of material removal and the CNC equipment that is capable of these operations exist at very large scales. The most common types of machined are mills, routers and cutters.

milling & routing

Mills are the most versatile of the CNC tools. The fundamental methodology of milling is to use a “cutting tool” that is made from a material that is harder than the working stock to remove material through shearing action caused by immense pressure at the surface of the raw material, also known as “chip form cutting.” Technically, a mill is any machine that uses cutting tools in rotation to achieve the removal of stock, an example would be a drill or router. General purpose milling machines are highly versatile and can be used in multiple configurations and combinations to achieve the desired product. However, for simplicity of terminology they are divided into two working categories, horizontal and vertical, depending on how the cutters are positioned. Typically the working stock, or billet, is securely mounted to the table of the mill and then the material is moved into the cutting tool via movement of the table. The cutting tool
can also be plunged into the billet by movement parallel to the rotational axis of the cutting head. When these operations are done in conjunction with one another it becomes a multi axes mill, with x, y, z always the primary axes of cutting head movement but with the addition of the mill being capable of rotating the stock, or rotating the cutting tool additional axes, in nomenclature, can be achieved. For example a five axes milling machine is one in which the supporting table can move in the x, y, and z axes and it can rotate the stock about one or all of the primary axes, in addition the alignment of the cutting tool may be able to vary from vertical to horizontal. In some newer mills the head is completely free to move, however these machines are very expensive and only found in specific industries.

Mill control has been one of the greatest advancements in milling technology. Early technology was for the mill operator to control the movements of the support table and the cutting tools through the use of cranks and screw drives. This would allow the operator to move the stock with precision, achieving tolerances of less than a hundredth of an inch. However it was difficult to repeat the process accurately in succession and maintain consistent tolerances. Numerically controlled milling (NC) was the answer. With this technology a set of numerical coordinates were able to be programmed into the mill in order to maintain a consistent repetitive cutting path. The numerical coordinates were input into the mill by punch cards, and the mill would use motors with gear drives to move the stock into the cutting head. The next big advancement was with the ability for Computer Numerically Controlled (CNC) milling. CNC allowed the mill operator to control the mill through the interface of a computer, thus allowing significantly more control and smaller tolerances, nearly ten thousandths of an inch. However the greatest advancements have been made by integrating computer design, and the output of the final product via tool path instructions, known as G-code or geometric code, generated by the computer. The process of design to production is becoming more seamless with developing computer technologies, such as CAD/CAM (Computer Aided Design / Computer Automated Manufacturing).

**NC Water Jet Cutting**

Water jet cutting is the product of a very fine high pressure stream of water that carries a fine abrasive material which removes stock and has become one of the most versatile methods for cutting sheet metal. It is capable of cutting very large stock, only limited by the size of the table and track that the cutter is mounted to, and capable of cutting metal stock up to 12" thick. One of the major benefits of water jet cuts is that there is no deformation to the stock from heat, therefore causing no stresses or metallurgical changes. It is a process that is capable of achieving tolerances of +/-0.005" and produces no slag or burn marks that are produced with heat methods of cutting.

**CNC Plasma Cutting**

The plasma-arc torch was developed about 1957. The
Stretch-formed piece of aluminium.

Stretch form press.

Stretch form press, note the CNC machined die in orange.
torch forms a plasma (a hot, ionized gas) by passing a gas, usually nitrogen, through a restricting nozzle. An electric arc also passes through the nozzle. The resistive heating of the plasma raises the arc temperature and voltage, the gas leaves the nozzle as a high-velocity, intensely hot plasma jet. The plasma jet has the distinct advantage of being able to cut almost any metal. The quality of cut produced by the plasma torch is equal to that made by an oxyacetylene torch. The main disadvantage to plasma cutting is the high initial cost of equipment.

**CNC Laser Cutting**

The most common application of lasers in metalworking is for light-duty welding of small parts such as pacemakers, electronic packages, and hydraulic components. Gas lasers can be used to weld 3/4-inch steel plate at rates up to 50 inches per minute. Carbon-dioxide lasers also are used to cut and drill holes in metal. Some CO2 lasers are used as an adjunct to punch presses to cut odd-shaped parts by computer numerical control. Hard tooling would be very expensive, but a CNC laser is ideal for prototype work or short runs. Higher-power laser units are capable of cutting 5/8-inch thick cold-rolled steel with oxygen assist. Lasers are used also when localized heat treatment is required on inaccessible areas such as small bores and complex shapes. Cladding and surface alloying also are easily done. Materials such as Stellite (a hard, wear-resistant material) can be applied in powder form, then melted and fused to the base metal by the laser beam.

**Production with CAD/CAM - Secondary Processing**

CNC technologies are also used in manufacturing to do what I call secondary processing. Primary processing is when the work that is being produced is the final product, i.e. the plasma cutting of a steel panel to be used to clad a building. Secondary processing is when CNC technologies are used for set-ups of production, like mold making and the production of tooling for various production processes, and final machining and trimming of products like the parting seam of an injection molded piece of plastic. It is in this capacity that CNC technologies have the most power to effect the production cycles of manufacturing. As described earlier, the ease of editing a digital model and the direct capacity for those changes to be output through CAM hardware facilitates productions and modifications to traditionally expensive set-ups. With these technologies the production of molds, dies and tooling for manufacturing processes like injection molding, spin molding, thermofoming, casting, stretch-forming, extrusion, stamping and pressing is highly flexible and exponentially more affordable.
There are many complex systems and components that make up the building assemblies of contemporary architecture. The following studies were performed in order to (re)gain an understanding about some of the more rudimentary building systems that are employed today. By building detailed scale physical models these building systems I was able to critically analyze the various aspects of each assembly and understand the performative strengths and weakness of each. This process of analysis also forced me to research and understand why these building systems have either flourished or withered in the contexts of economy, flexibility, labor, etc.

**interjection about process**

It is obvious to say that there exists by far more than the three tectonic assemblies that I have investigated here, but for the sake of this thesis I have had to be concise. It was at this point in the project that I began to struggle the most as to what the thesis “project” or design was going to be. I toiled over the prospects of working with several various programs from housing, to power plants to commercial structures and came to the conclusion that the project was going to be nothing more than an “envelope” or shell of a building. This decision was important because it would allow me to focus solely on production methods and not the rhetoric of program. However, since the vast amount of my material knowledge comes from experiences working in the housing industries and a large majority of my historical research has focussed on the production of housing I chose to limit my scope in this investigation, and the design of an envelope, to building systems that would be used in residential applications.
pre-fabricated wood trusses

nominal site built wood wall framing

prefabricated wood or vinyl clad windows

fiberglass or blown cellulose insulation

gypsum wall board

site built nominal wood floor assembly, sheathed with 3/4" plywood

concrete block foundation walls

mid-span girder comprised of nominal wood frame members

cast in place concrete pads to support mid span beam
conventional wood framed construction

Wood framed constructions are the most common building system employed today. It has a high capacity for flexibility and variation in architectural form. It is easily modifiable throughout the construction process can be produced with only minor overhead. Components are readily available and assembly does not require extensive knowledge. However, it is highly dependent upon numerous products and multiple tradesman to be constructed to sufficiently perform.
pre-cut 6" steel perlin

custom off site facricated steel moment frame

off site fabricated corrugated steel panels, (composite)

light gauge metal framing w/ finish surfaces

steel wide flange header

pre-cut 6" steel girt

opening in end wall, facilitates multiple potential finish configurations

4" hard board insulation panels, (composite)

cast in place concrete floors with integral thickened edge / grade beam

compacted soil with appropriate drainage implemented
conventional steel moment framed construction

Moment framed systems at the scale of residential construction was initially developed by the Butler Steel Building Corporation. Today they are typically discounted as one of the lower forms of construction because they are deemed generic or kits. In reality each Butler building is custom. Each one fabricated to the particulars of the client. This building system is the perfect example of mass customization architecture, but yet never really exploited to it's full capacity.
CNC cut reinforcing frames

pre-fabricated glass window assemblies

exterior layer of "stress-skin" is GFRP (Glass-Fiber Reinforced Plastic)

urethane foam or EPS foam insulation in pre-fabricated "stress-skin" composite insulated panel

pre-finished interior GFRGP layer of "stress-skin" (Glass-Fiber Reinforced Gypsum Plaster)

site installed floor system

cast in place concrete piers to support mid span girder

mid-span steel floor girder
**composite stress-skin construction**

Composite materials are typically some form of hybrid resin or binding material reinforced by a fibrous material like fiberglass. In this model, the thin interior and exterior surfaces are fiberglass-reinforced plastic and gypsum, they are finish and structure in the same component. The skins are laminated to the insulation material which acts as an armature or web making the entire assembly act as if it were a beam stretched around a volume. In terms of material, this is a highly efficient building system, but it has traditionally been labor intensive, and unforgiving in terms of making modifications in the field.
As discussed earlier in this thesis many architects are working extensively on the issues of CAD and CAM in architecture. Those that are the most interesting to me are the ones who are attempting to bridge the gap between design process and production process, although many of them that are attempting this are still much more bound in theorizing the CAD aspects of their work. From their experiences, or lack thereof, they have made many claims about the ability to translate digital information into material production, and there are several successful examples of this, yet a great many of them just make grand claims in order to fend off criticism about the feasibility of building their projects. Those that have produced material manifestations of their digital designs have done so by having amassed the material processing experience to do so.

The intention of this thesis has been to understand in detail the potentials of CAD design and its direct connection to CAM production. As I pondered this relationship I came to some insights. The operations of CAM production hardware, especially milling, has a logic that is more conducive to certain forms than it is to others. The ways in which a mill removes material by following paths is much more topological than it is Cartesian. This means that when producing material products with a tool of this nature it is more natural for that tool to want to create surfaces rather than edges, contours rather than ridges. This led me to then start asking questions about modelling techniques and architectural forms that were more apt at being milled. I was aware that there are already people thinking about production in this way, especially Greg Lynn, but he was also theorizing form as well as production. At this point in my thesis I was more interested in production than form, but I came to realize that they cannot be separated. However, I also came to a conclusion that before I can take a stand on form and how it is informed by production means, I need to first understand those means more intimately.

The following investigations are about gaining some first hand experience in the “virtual” and the “real” worlds of digital production processes.
digital surface manipulations

By using NURBS based modeling software, a flat surface undergoes deformations that define the performative qualities of the otherwise benign surface, as well as embed information for its materialization through CAM production. Three different surfaces were contrived with different agendas in mind. None of them were to be any “thing” in particular other than molds for use in secondary processing of other materials.

All of them started as 6” x 12” flat surfaces that were subdivided by a grid that defined the control vertices that would be used to deform them into experimental shapes. The first “lump” model was just a simple deformation of the surface in two directions, and was intended as the first to be used as a mold. The thought was to start out simple. The second and third molds are similar to one another because I was thinking about how structure could be potentially embedded into a surface as well as addressing potential issues of detail that may arise later like “how to terminate the surface at a window” or “how to turn a corner with a surface.”

The next step was to consider mold design, since these were intended to be used as such. I decided that the products of my efforts were to be 1/16” thick. By using the offset commands of the modeling software I produced a copy 1/16” of away from the original surface. From here I set up the two surfaces to be milled as male and a female molds.
CNC mold studies

The digital models of these molds was transferred from the modeling software to a CAM software that generates "G-Code," the 3-D "geometric" code that instructs the fabrication device to produce the defined form to within tolerances of .010". Once the G-code was produced the blanks of wood were mounted to the bed of a CNC mill.

I learned several things in this process. Software packages, file formats, and the ability to translate digital data can be a major problem. In my case the CAM software that I had to use did not support any of the files that I was able to produce that maintained the smooth attributes of the NURBS surfaces that I had designed. I therefor had to convert my models to polygonal, or faceted, data in order to get them produced. I thought the resolution of the polygons was high enough the molds would appear to be smooth like NURBS. What I got is what I should have expected from a machine that is capable of such high tolerances, an exact faceted surface.
an example of mold use.

First the molds are pressed together with a layer of fiberglass between them in order to create the fiberglass blank. This facilitates getting the strands of the fiberglass mesh to lay down matching the contours of the mold. Next the mold is opened up and the fiberglass is “wet out” with epoxy resin. Various other resins like acrylics and urethanes were also used in other trials. Once the glass is fully saturated the molds are pressed together until the resin cures. After the resin has cured the molds are separated and the “plug” is removed. (A plug is any product of a molding process.)

This particular sequence shows the first attempt at using the mold. The mold suffered some damage from inadequate mold release agents and the lack of any way to break the vacuum that develops between a mold and a plug. All of the problems were resolved before any other attempts were made, and all of the other molds were also analyzed and adapted to prevent these same problems with their use.
m old use and material performance
Repetitive use of the molds by working with a variety of materials lead to a greater understanding of mold design, material performance and potentials for these processes at a larger scale.
Reorganizing production processes and delivery

The following investigations compares the 3D centric design and delivery process to traditional models and speculates about the shifts in project organization and material supply chains related to the advents CAD / CAM technologies.

Next page

Organizational Implications of CAD / CAM based production processes

This diagram compares and illustrates the reshaping of organizational strategies and relationships between the owner, architect, consultants and contractors that would have to occur with the implementation of a 3D-centric project delivery.
Conventional Material Delivery
Raw materials and mass manufactured components are delivered to the site to be fabricated and assembled by on-site sub-contract labor. This produces waste that by relative location from source and commingling of materials, is cost prohibitive for recycling.

Manufactured Building
The model of manufactured building does not differ greatly from conventional methods when discussing material delivery. The fundamental difference is that the raw materials are consistently shipped to permanent "plant" location, then fabricated, and delivered to the site. This process does begin to facilitate efficient material use and recycling, improving overall delivery costs, and increases the tolerances of the overall construction process.

On-Call Service Bureau
The overall benefit to this process is that the building is fabricated in shops near the sources of raw materials, facilitating the process of closing the material waste loop, increasing the efficiency of material usage. Production through the use of on-call service bureaus also optimizes the delivery of materials to the job site, or market, by only shipping finished goods and not future waste. Ultimately material savings, automated custom fabrication, and decreased shipping costs effects the capacity of an architect and/or client to afford more customization of their projects.
Computer aided design has led many practitioners to theorize and speculate about the future of architectural design processes. The advancements in production technology due to computer aided manufacturing has opened up an entire new arena for the production of novel products. Coupled together CAD / CAM has been shown to revolutionize the industrial design and manufacturing industries. Architecture and the building industry have been slow to become fully entrenched in this design revolution when it comes to CAM production. (Design with CAD however is highly advanced). This lack of CAM production has to do with many factors, scale of projects, shortage of sufficient hardware, inexperienced contractors, nervous clients, and economics to name a few. Nonetheless, as these production technologies continue to grow in scale and become more ubiquitous architecture and the building industries will take advantage of their benefits.

At this time I feel if there is to be any claim for these technologies to revolutionize the building industry they must first continue to prove themselves in the ideologies of mass customization. Here CAM can be coupled with existing production systems that have proven to be viable economically and can catalyze them into new forms, new organizations, and new methods of delivery. It will have to be a slow progression overcoming many of the real world obstacles like budgets, labor forces, and indecisive clients, that don’t exist in the utopian worlds of many “blobmiester” architects.

It is here that the final investigation of this thesis finds itself. Here I have looked at how computer aided design helps architects and designers visualize their work, but more importantly I am attempting to develop a “sensebility” throughout the design process that facilitates the use of CAM technologies in the means of production. A reciprocal relationship also exists in that I am attempting to let the logics of CAM production effect the way I approach a building design. It is also here that this thesis makes an attempt to take a stand at prototyping the building system by producing a scale component, but also working through the project development is a manner that reflects the 3D-centric building delivery process.
the concept for an envelope
The building “envelope” for this investigation was conceived as a project that wants to embrace the natural flow of air that predominantly cuts across its site during the hot summer months. The site is a narrow plot, on a sloping hillside, bordered on two sides by neighbors (east and west), open to the south and faced to the street on the north. Site access is rather restricted and what access there is is impeded by several old growth trees that must be preserved.
surface manipulations
Through the use of NURBS based modelling software an infinitely thin continuous sheet is folded and shaped into the final formal response to site and design conditions. This method of modelling has imbedded within itself an intelligence that facilitates the logic of formal manipulation, but is also coded to limit manipulations to a logic that is cohesive to CAM production technologies.
breaking from orthographics
Continuing with the use of NURBS based modelling software the conceptual surface is intensely analyzed in through the use of perspectives, walkthroughs, and sun analysis to verify that it is performing spatially.
begining to occupy the envelope
These are earlier “sketches” that look at scale, circulation and spatial relations
breaking down the envelope

Material and physical limitations of manufacturing equipment and optimization of erection creates a new set of parameters for the project that forces a new regulating pattern to the designed surface. Through a process of sectioning and strategically planning the fabrication, erection, structuring, water proofing, and materialization become the driving factors. Any previous design decisions that were based on the digital design technology that are not feasible begin to make themselves apparent.

1. Through a process of slicing the design surface on 48” intervals any rib structures that are needed to supplement the SIFs are defined.

2. The design surfaces are offset to the appropriate thicknesses to provide the necessary structure and other design parameters. This step is the first step in which the infinitely thin design surface becomes “thickened.”

3. The thickened design surface is partitioned into manageable sizes, in this case a three “parted” cross section measuring 20’ in length. These parted sections are then further broken down through into components that do not exceed the size limitations of the production hardware.

5. (next page) Each digital part is used to make a negative mold for it’s material counterpart. These molds can be produced in a number of ways that use cutting, milling, forming or a multiple combination of these.

6. As the building design and design of the fabrication molds develops, strategies for seaming the panels become critical. Shown here are the most conventional seaming methods for a SIP panel.

7. (next page) The completed envelope as erected.
thickening the surface - stresskin approach

Once the NURBS surface has been manipulated to define an envelope, it must be defined with a thickness. This is the first step towards rationalizing the surface in the terms of the material world. It is also at this point that material strategies must be addressed in relationship to fabrications methodologies.

Here the concept of an existing building system was adapted. Structurally Insulated Wall Panels (SIPS) are constructed in a stress-skin fashion, structural skins on the interior and the exterior held apart form one another by insulation. In essence each panel acts like a beam.
06 prototype envelope / t
BIBLIOGRAPHY


