Digital and Manual Joints

Construction

Design

Integrative

Prefabrication

Skin

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THIS PAPER CONSIDERS THE PROBLEM OF DETAILING JOINTS BETWEEN MANUAL AND DIGITAL CONSTRUCTION BY TRACKING THE PROVOCATIONS OF KIERANTIMBERLAKE'S SMARTWRAP RESEARCH AND THE EVOLUTION OF THAT KNOWLEDGE INTO PRACTICAL ARCHITECTURAL INSTRUMENTS THAT CAN BE DEPLOYED INTO MORE TRADITIONAL CONSTRUCTION PROJECTS. Over the past several years, KieranTimberlake Associates in Philadelphia has undertaken a path of research focusing on problems of contemporary construction systems and practices. One product of this research was a speculative wall system assembled for a museum exhibit. SmartWrap was to be a digitally prefabricated wall system with embedded technology.

While they have yet to wrap a building with SmartWrap, KieranTimberlake have utilized a number of the construction principles and digital tools tested in the SmartWrap exhibit. One of the most important principles, prefabrication, was explored in a fast-track construction project at the Sidwell Friends School. The compressed schedule drove the design of an enclosure system which incorporated performative elements in similar categories to SmartWrap: insulation, an electrical system, view, daylighting, and a rainscreen. Besides being a prefabricated façade system, the rainscreen detailing became a formal system for organizing many other scales of the project including: site systems, thermal systems, daylighting systems, enclosure, and ornament. At a second project, a similar wood rainscreen strategy was used. However, at the Loblolly House the question of prefabrication and digital modeling was tested far more extensively: thermal systems were embedded into prefabricated floor cartridges, entire program elements – a library, kitchen, and bathroom were proposed as prefabricated systems of self-contained volume and infrastructure which were then inserted into the on-site framework.

In all three projects the joint between manual-imprecise construction and digital-precise prefabrication became the area of richest invention (Figure 1). SmartWrap may not have yielded flexible, plastic architecture; but its conceptual and practical questions have yielded tangible implications for the design/construction processes and the built product in KieranTimberlake's practice.

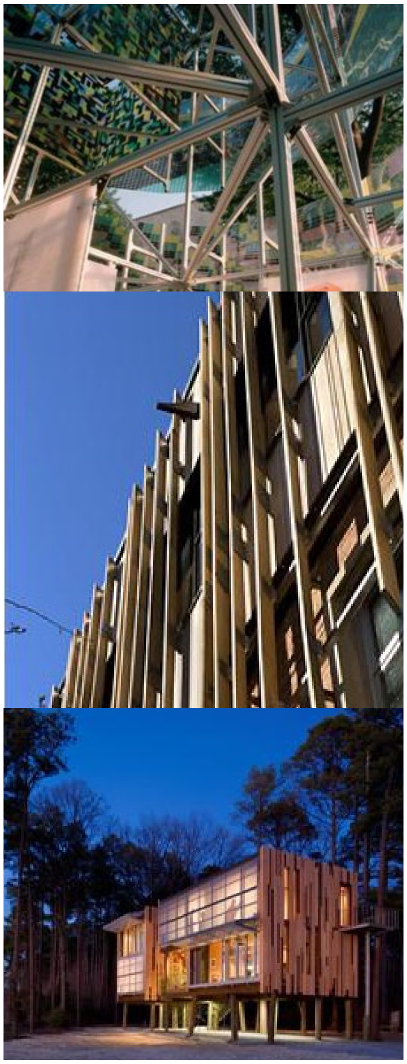


FIGURE 1. SMARTWRAP, SIDWELL FRIENDS SCHOOL, LOBLOLLY HOUSE

1 Introduction

The question of detailing joints between manual and digital architectural construction is an area of practice which is still undergoing a search for formative principles within the established organizational strategies of the discipline (Kieran and Timberlake 2004). The merging of digital and analog means of architectural production and construction should yield sustainable efficiencies, but contemporary buildings are rife with uncomfortable hybrids of both techniques resulting in monstrous juxtapositions (Frascari 1984, 1991). Both literal and conceptual, the joints of this study are manifest in design processes, drawing, construction techniques, contracts, and architectural theory. These joints are of both technical consequence and aesthetic opportunity for integrated practice.

The specific significance of this research concerns itself with the impact of digitalization within an analog world of architecture and construction. The use of digital technologies in the design and construction of buildings is hardly new to architecture, but still architects struggle with managing the transactions between video screens and the handwork of construction. More specifically, the type of joint that this research focuses on is the joint between manual-imprecise construction and digital-precise prefabrication. How do we reconcile joining systems, how do we resolve the question of digital prefabrication when architecture is forever beholden to the messy differentials of mud, rocks, and excavation (Leatherbarrow and Mostafavi 2002)? This resolute imperfection of the earth, where construction tolerances are measured in larger forgiving dimensions is juxtaposed with computer fabricated components with tolerances measured in millimeters. The joints mediating digital and analog components tend to be improvised and non-synthetic. How do architects mediate the different scales of digital and manual construction systems? Lines of aesthetic articulation can be delineated to join different dimensions and proportions, materials and systems; various joints can be constructed for the interplay of shadows and light, to allow for thermal expansion, to control water flow, and maintain insulation. The poetic quality of joints and the development of ornamental systems for navigating the different technical requirements of digital and analog constructions is lacking in both the theoretical and technical disciplines of architecture.

2 Prototypical Knowledge: SmartWrap

The path to SmartWrap began with four questions: to what extreme can the technical attributes of a wall be pushed, what are expectations of enclosure systems, how can the design and fabrication of systems be expressed/represented in the articulation of surface detail, and what is the architect's role in the creation of products? The chosen vehicle for these questions became a mass-customizable wall with embedded infrastructural systems printed directly onto a substrate (Wallick 2007). KieranTimberlake wanted to integrate the currently segregated functions of a conventional wall into a single composite. With the exhibit's conclusion they had not realized most of the technical means by which to produce a fully integrated infrastructural wall through mass-customized printing. However, a number of the ideas about assembly processes and building tectonics were very successful. The idea of a film enclosing a building is asking a lot in terms of durability, weather, and cultural expectations, but the continuous wrapping of the enclosure system represented some success in terms of parts reduction and assembly (Figure 2). Additionally, the prefabricated structural system was beautiful and easy to design and build with in all phases of design and construction.

3 Digital – Manual Joints: SmartWrap

With the exhibit over, the question for KieranTimberlake became one of how to incorporate the speculative thinking behind SmartWrap into their current projects. The main impetus to much of their research had been and continues in current projects to be the incorporation of design, fabrication, and assembly techniques which limit the time and cost of construction, reduce energy demands, and which result in new formal strategies for design and detailing. The specific SmartWrap criteria was generated by similar principles: reduce the struggle for infrastructure space by prefabricating as many systems as possible, stream-

line the currently segregated construction processes by reducing the number of hands and trades needed for installation and fabrication, and the incorporation of self-sustaining energy systems. These criteria have some of their most instrumental value when possible applications to practice are similarly focused around the development of theories of joints, prefabrication, and infrastructure. The problem of joining while inherent in architectural thinking, becomes more complex and requires more precision with larger chunks of building program. Besides keeping water out and maintaining thermal breaks, now mechanical and electrical components need to traverse the joints of chunks and panels. What type of strategy is necessary to maintain the integrity of all these systems? Voided joints, slipped joints, woven joints? What sort of tolerances do these joints require? Millimeters, inches, feet? And how are those tolerances transmitted across systems? Three instances of mediatory detailing at the SmartWrap exhibit may illuminate strategies for detailing manual-digital joints: the structure-foundation connection, the enclosure-structure connection, and the enclosure-infrastructure connection.

The structure used for the exhibit is an instance of complete digital design and fabrication. The design software provided by the manufacturer, Bosch-Rexroth, calculated dimensions, hole locations, and quantities that were directly readable by the digital fabrication equipment in their factory. The aluminum sections arrived at the construction site pre-cut, pre-drilled, and bar-coded and were simple to assemble. The precision of the factory work was near perfect and very little field adjustment was required. However, the attachment of this pristine structure to the earth required substantial manual preparation: to keep the 2-story tall fabric exhibit from whipping apart in a windstorm, a continuous grade beam was specified by our structural engineer which required the excavation of seven yards of dirt. In this case, the operative digital-manual joint became one of illuminated depth whereby the ground-plane absorbed 18" of excavation and was turned into up-lighting for the exhibit.

In the second case, the enclosure-structure connection was a detail which needed to be able to absorb problems of thermal expansion, material relaxation, and post-tensioning. A detail marrying a standard Bosch-Rexroth channel with a polypropylene rod and automotive tape formed a flexible yet robust connection for the skin-structure detail. Of more interest to the category of digital-manual connections would be the tensioning bar which helped the SmartWrap to weave in and out of the structure. This bar was a hollow rod for which there was no standard attachment supplied by Bosch-Rexroth. We fashioned our own by customizing one of their standard parts with a 5" bolt, nut and washer, a strip of cardboard, and duct-tape. In this case, the digital-manual joint is mediated through the flexible shimming of paper and adhesives.

The third detail was the enclosure-infrastructure connection (Figure 3). The SmartWrap panel contained photovoltaics, batteries, and LED's all knitted together through a printed substrate of electrical conducting ink. This electrical matrix was the ultimate expression of KieranTimberlake's goal of compressing architectural technics into easily assembled chunks. However, the joining of the enclosure system to the infrastructure motherboard required a manifold of wires and connectors. While both the infrastructure and enclosure were produced digitally, the joint between them was a delicate and wide array of copper leads managed piece-by-piece and contained within a lattice of zip-ties. The digital-manual joint in this case is resolved through width and multiplicity.

Rethinking the configuration, orientation, or the densification of technical systems has been a primary area of research by KieranTimberlake since the SmartWrap exhibit. Rather than looking to SmartWrap for new materials and composites, it is perhaps more useful to look for a revision of construction assumptions and building part configuration and composition.

FIGURE 2. SKIN-STRUCTURE INSTALLATION

FIGURE 3. ELECTRICAL MANIFOLD AT DIGITAL – MANUAL JOINT

4 Program and Joints: Sidwell

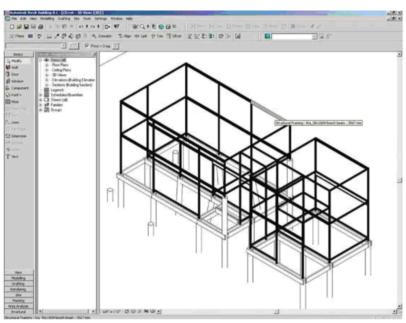
Sidwell Friends School approached KieranTimberlake for help in transforming their fifty-year old middle school into a demonstration of their commitment to sustainability. KieranTimberlake increasingly see prefabrication as a way of adding another tactic to the discourse of sustainable design (Kieran and Timberlake 2005). They assert that employee travel distances, construction mistakes, waste-recycling, and construction coordination are all potential streams of efficiency which can be managed more effectively through prefabrication (Kieran and Timberlake 2004).

The client's goal was to renovate and expand their existing facilities into a LEED Platinum project which could contribute in a didactic manner to the school's Quaker principles. The sustainable touched nearly every aspect of construction including: re-use of existing structures, water retention and filtration, natural ventilation, natural lighting, reclaimed or local materials, photovoltaics, and efficient construction processes.

KieranTimberlake started design by allocating space, program, and budget to these sustainable goals. However, this long list of technical criteria did not immediately address tectonic potentials for organizing a formal project strategy. The focus on achieving the Platinum rating had resulted in greater knowledge about sustainable systems and practices, but had not yielded a coherent design strategy – there was an assemblage of parts, but no joint strategy for holding it all together. One potential means was the exterior enclosure system which could act as a large scale joint system, a wrapper for the entire project (Figure 4). This seemed a useful strategy, since as a system, it would be located on both the new building and the older renovated building. A prefabricated wall strategy was used as a constructive and a compositional tool to integrate multiple agendas including time, cost, and goals of sustainability. While the addition construction could happen concurrently with the school year, the classroom renovation could only take place during the summer break. These renovations included interior reorganization, but also new exterior cladding. The decision to fabricate the wall system off-site was made to alleviate the time-pressures on the interior contractors. The wall design included the usual systems of substructure, insulation, waterproofing, windows, and cladding; however, instead of multiple contractors assembling their individual components, the entire wall assembly would be put together in a shop, brought to the site, and mounted on the building as a complete assembly (Kieran and Timberlake 2003).

The wall panels seek to unify the different character of the existing structure and the addition, mediate their disparate massing, provide a strong urban edge at the sidewalk, and act as a transition element between the institutional and residential zones. Moments of conflict between the purity of the wooden skin and the proposed functions of the skin were exploited as opportunities for introducing syncopation into the skin pattern. These conflicts were typical detailing conditions such as downspouts, various shading orientations, and different structural bays of original and new construction. The new screen seeks a balance between the contradictory requirements of view and shade through the use of vertical cedar fins. Eventually these fins were absorbed from their role in solar performance into the enclosure plane of the facade. This is an agitated system, intentionally ambiguous: sometimes a fin is a joint, an edge, sometimes used for shade, sometimes a rainscreen; it may have both ornamental and performative roles. However, altogether they are subsumed into a rhythmic cladding which seeks to agitate perceptions of function and decoration. The unit of enclosure was defined both by the transport limitations and the structural bay on the building to be renovated at Sidwell. The strategy of working with the wall system was a direct application of the design principles from SmartWrap. The wall would be designed and constructed as a single component to be mounted in the field.

The vertical orientation of the fins, while seemingly in conflict with the horizontal bands of windows behind the rainscreen, is a response to the problem of joining a prefabricated series of panels. One of the concerns was tolerance of fabrication and tolerance of on-site assembly and a design strategy was needed which could mediate this joint. If a horizontal orientation was used, the sticks comprising the individual prefabricated panels might be difficult to align. KieranTimberlake considered deliberately misaligning the sticks from panel to panel, but this defeated one of the goals of unifying the formal quality of the elevations. Turning the sticks vertically provided a means of hiding the panel joints. The agitation of this system with varied depths and widths of wood planks became an ornamental system which served to synthesize the didactic nature of the construction with a com-



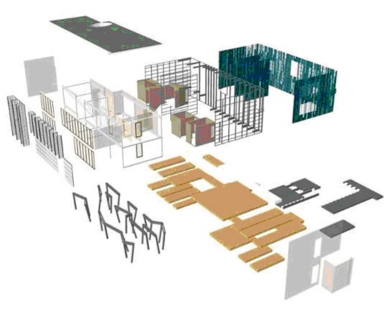
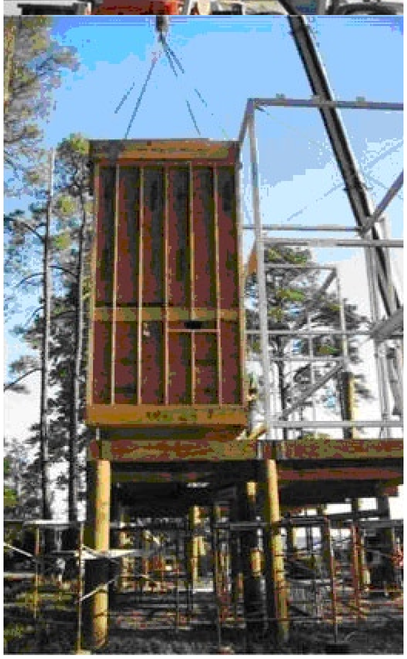


FIGURE 4. PREFABRICATED WOODEN SCREEN JOINED TO EXISTING STRUCTURE

FIGURE 5. DETAIL OF DIGITAL-MANUAL JOINT AT SIDWELL.

FIGURE 6. DIGITAL CONSTRUCTION INTERFACE AND ASSEMBLY LOGIC



positional structure. This pattern of synchopated repetition can be seen in other project elements including: site, window, and ventilation technics. The vertical fins represent the digital half of the digital-manual joint at Sidwell. In this case, the fins are digitally tuned to the correct solar orientation with Ecotect software. This digital design still requires a fair amount of manual tuning in the field as is explained subsequently.

5 Joints and Assembly: Sidwell

In terms of design constructability, the corner and end conditions of the panels needed the most resolution, so these were site-built instead. On the one hand this allowed for a degree of adjustment between the very tight tolerances of the prefabricated system as it was joined to the imprecise conditions of the existing building (Figure 5). Tolerance was also needed within the system and the corners became the give point within the overall enclosure dimensional field. However, a different crew did the onsite work than had worked on the panels in the workshop. Although both crews were from the same contractor, there were differences of opinion between the two teams on the manner of construction and even with the location of insulation within the wall plane. Since there was no construction manager on the job, KieranTimberlake assumed the responsibility of coordinating the different trades. This separation of on-site and off-site work points to a larger problem of the hierarchy of detailed but specific knowledge within the trades versus deeper, comprehensive knowledge of the overall construction project. Trade-specific knowledge and the segregation of labor has not expanded to understand the interface with other trades and larger constructional issues. Prefabrication has also led to the combination of trades within a single building part. The prospect of reducing a building project to various fragments may hold promise for architects in terms of regaining some of the holistic control and input for architects that are wanting in many architect-contractor-construction manager relationships (Kieran and Timberlake 2003). Having all of the trades under the roof of one company may help to reduce some of the territorial issues of labor division and encourage a greater loyalty to the whole architectural project or at least a fabricator's specific fragment. The joints between these fragments will remain territories of potential design and control for architects.

6 Program and Joints: Loblolly

This project for a vacation home was seen by KieranTimberlake as a vehicle for testing some of their more intensive ideas about prefabrication. The Loblolly House is ideal in several other senses due to the remote site: problems with flooding, and seasonal temperature swings. These contextual complexities typify the less-than-ideal specifics any project might have and endow Loblolly with the legitimacy of difficult conditions which might be used by some as an excuse not to innovate. KieranTimberlake take the opposite tack; that with limitations come opportunities to question design and construction assumptions.

The application of knowledge gleaned from SmartWrap is probably most clearly developed at Loblolly House. The same aluminum structural system and many of the attachments developed for the SmartWrap exhibit are used here as an elevated structural cage. However, more to the point than materials, is the way that KieranTimberlake reconceptualize their design and construction process. Above the site structure of timber pilings, the entire building is prefabricated. However, instead of the usual prefabricated method of making the building in one giant chunk, KieranTimberlake wanted to experiment with a different system of components (Figure 6). The house parts were designed as fully integrated and autonomous parts that have been categorized as scaffold, cartridges, blocks, and equipment. The scaffold system contains all of the connectors needed for its own assembly and for any attachments needed for the cartridges and blocks, and like SmartWrap, is put together with a single wrench. Floor and ceiling panels comprise the language of cartridges. This system has integrated radiant heating, domestic water, waste water, electricity, and ventilation ducts. Walls were constructed as panels with integrated windows, interior finishes, insulation, and the exterior wood rain screen. The term 'block' refers to entire

rooms which were prefabricated. The bathrooms and mechanical room were fabricated with all systems integrated and lifted into place within the scaffold structure (Figure 7).

7 Joints and Assembly: Loblolly

Loblolly House represents the most intensive utilization of prefabrication by KieranTimberlake to date. While the overall effort is their most intensive prefabrication effort to date, there were similar issues as at Sidwell with the coordination of shop work and field work. The logic of craft was not always transferable among the different sites and workers.

As might be expected, one of the difficulties was reconciling the site conditions with the prefabricated components. While the shop work measured tolerances in millimeters, the foundation piles were two feet off in several instances. To reconcile this difference, a substructure was added to accommodate the difference between the two systems. Really a site joint, this condition became the operative architectural opportunity. It is chunky and thick, but represents one of the most pregnant possibilities for extending the tectonic grammar of prefabricated construction and questions of sustainability (Figure 8). This problem of site joining was present at SmartWrap (Wallick 2007) and is resolved at Loblolly in a similar manner: depth is accepted as a condition of this joint.

8 Conclusion: Digital – Manual Joints

The operational logics that comprise the detailing of joints within architecture are myriad. As a consequence, architects still struggle to define the role of joints in mediating digital and manual construction within compositional strategies. KieranTimberlake is one office, which has sought to address the more systemic substrate of construction (whether digital or manual) by undertaking a path of research into potential techniques, and technologies that alter fabrication and delivery methods.

The knowledge sought in these projects share much the same goals of similar projects by Jean Prouve, Frank Lloyd Wright, Richard Neutra, Buckminster Fuller and many others. KTA seem close to a different synthesis of technique, technics, and composition with their use of digital and manual systems of production. Their finished buildings and their details are not technically exhibitionistic, but rather formed of a mediatory process between performance characteristics, assembly, and form. At both Sidwell and Loblolly, the architectural form is the result of a dialogue between technics and composition most clearly visible at the joints between manual and digital design and construction.

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FIGURE 7. (OPPOSITE) DIGITALLY PREFABRICATED BATHROOM MODULE JOINED TO MANUAL SITE FOUNDATIONS

FIGURE 8. (TOP) DETAIL OF DIGITAL-MANUAL THICK JOINT AT LOBLOLLY.