Looking to fabrication technologies as a way to bridge the gap between design and execution, this research tested various methods for the digital optimization of flat sheet materials, specifically those which can be reclaimed from building and manufacturing sites. By reordering conventional design processes to begin with (reclaimed) material constraints we are looking to close the gap in the cycle of sheet material manufacturing and reduce the amount of building waste in architectural projects. This paper will discuss the process of embedding digital information and scripting processes into material systems in order to rethink the relationship between input and output in design, especially in the context of sheet material manufacturing, reclamation, fabrication and distribution. Two projects situated within architectural design studios are cited as examples to this approach, with speculation on how the work might shift the role of ‘craft’ in design and fabrication processes.
1 Introduction

The eccentric nature of scrap materials is typically the strongest limiting factor in potential reuse or alternative application. While some materials may be crushed, melted or chipped for remanufacturing into a product of lesser quality, reuse of the existing material for new architectural systems (as opposed to customized, single objects) without employing energy-consuming processes is rare. How to standardize a re-manufacturing process when the nature and properties of the material itself are unknown is the most obvious difficulty. Given the wealth of information around digital design processes, and increasingly widespread availability of advanced fabrication tools, this work sought to develop a method of mass-customizing reclaimed waste material that did not substantially increase the embodied energy of the material nor substantially decrease the quality or formal possibilities. In short, we endeavored to develop a ‘smart’ reclaimed architectural product that might also embody the systems of information used to reprocess it.

Through an architectural design studio in Australia we harvested nearly 900 cubic meters of laminate sheet material and reprocessed it through digital procedures, (rather than shredders or chippers) to maximize the potentials of its flat-sheet quality in terms of design, fabrication, and redistribution. By introducing digital fabrication technologies and scripting techniques we were able to reconsider material efficiency at a one-to-one scale during the conception of the work rather than at the end, such that the schematic design phase could deal with design and construction issues simultaneously rather than in a staged or linear manner. In this sense we were attempting to reverse the conventional design sequence where eccentric material constraints were considered as an input value rather than an output, or standardized component. Figure 1 is an overview of the project structure.

2 Material Harvesting

Each year nearly 500 tons of industrial sheet materials are sent to the local landfills in Victoria, Australia alone. Much of this waste is produced from off-cuts on building sites or full sheets deemed unusable by the manufacturer because of small faults – chipped edges, surface inconsistencies or superseded colors. As such, most discarded material has not lost any of its original use-value from degradation or substantial defects, but is simply impossible to sell, resupply, or exists in odd shapes which defy standard manufacturing techniques. Developing a system that harvests this material relieves users of liability from the small defects, and reprocessing it through digital fabrication techniques may lead to the creation of a new material resource that satisfies industry needs as well...
Our work started by asking how quantitative information might be used to optimize the material surpluses created within the building industry (Figure 2).

Our studios worked in conjunction with The Laminex Group, a major producer of laminate sheet building products; large portions of which are regularly discarded to landfill for superficial (non-functional) defects. Laminex agreed to provide an almost endless supply of material for students to use free of charge in exchange for new ideas about how their material might be reclaimed, reengineered, reused and resold. The net effect was that they might decrease waste production and increase applicability within various product lines. Architecture students were given the task of reprocessing the material digitally, and designing an architectural system that could be easily built with a minimal amount of waste and without the need for highly skilled labor. To encourage efficiency as a design input we proposed four remote sites for the work, thereby requiring the projects to be flat-packable and easily assembled by others. Four full-scale projects were produced and installed in London, Melbourne, Beijing and Shanghai over the course of six months in 2010.

3 Material Networks

3.1 REVERSE PROCESSING: FROM SHEET TO FORM

When architects and designers look to scripting it is typically to assist with the emergent generation of complex forms. These models are then developed into a buildable project where the design and documentation team source materials and systems that best suit the overall idea. We began at the opposite end of this process, starting with material systems and testing their structural limitations, strengths and aesthetic qualities in order to determine properties of formal geometry, program and site. The goal was to produce something that expands the complexity of the material through computational processes rather than applying it to a design off the shelf.

The studio brief for this approach was to design a set of urban installations with discarded laminate material which could be manufactured and sited locally or globally. Students first researched the strengths and weaknesses of laminate sheet through one-to-one tests, and were then asked to develop a structure that combines a variety of input values, such as laminate values, digital scripting processes, rapid prototyping specifications and international shipping limits. Immediately the constraints began to shape the direction of the work and students had to think in modular or repetitive units to ensure that they could assemble and transport the structure easily. At this point students were encouraged to use the laminate for all parts of the structure, the fixings, the surfaces, the substructure, etc. Initial ideas came from the physical modeling of pieces of cardboard which were then slotted together, stitched, interlocked or laminated (Figure 3).
Laminate was then introduced in substitution for cardboard and the scale of work increased to 1:10 (Figure 4), in order to fully understand the brittle nature of the material and how it would act as an assembly, as both form and structure. At this early stage all pieces were manually drawn, cut and assembled, and the resulting form vague. So while the material system was emerging successfully and suited the laminate sheet, it lacked a design.

At this point in the process the students began to employ digital techniques to adapt the system toward the conditions of the site and program, while continuing to develop a strategy for full-scale construction. Scripting with Grasshopper allowed students to manipulate the irregular laminate sheets (off-cuts, drops, fragments) and optimize the complexity of fabrication. During this phase the two aspects of the work, digital design and material processing, became interlinked (Figures 5, 6).

3.2 MATERIAL LOGISTICS: FLAT-PACK

Digital optimization of material waste allows for a variety of complicated constraints to be incorporated into a design process without compromising the quality of final work. While we have so far been looking at how to apply material constraints to digital techniques, namely using scripting to deal with construction and fabrication issues, we also looked at transportation efficiencies in order to efficiently construct the projects remotely. The studio program, a series of architectural assemblies which could be transported and installed in a series of global urban sites, suited the idea of working with flat-sheet materials; the main advantages being efficient transportability, dense packing weight and comparatively low cubic volume.

The merging of digital information and material systems is perhaps most clearly legible in the realm of international shipping and distribution logistics; where the combination of information systems and spatial containerization enable the vast and complex coordinated movement of all physical things, people and objects alike, locally and globally. Containerization marked the moment at which production and consumption became disconnected. Things could be made anywhere (e.g. where labor and land were cheap) and distributed to anywhere else (such as where relative costs were high), and remain perpetually linked through digital networks of barcodes, RFID tags, communication streams and other mechanisms for tracking the location of physical things at any point and place in time. The implications of this shift for design disciplines are considerable, ushering in now-common and highly effective modes of practice – through distributed networks of design and fabrication. Small, nimble architectural practices replace large, centralized ones, where information and resources are shared across the network cloud and twenty-four hour workdays maximize efficiency. Distribution has become a new form of design production.

Our work intersected with these issues through the requirements for remote assembly and installation. The student projects had to understand and integrate shipping logistics – the mathematical formulas which determine optimal material

![Diagram of maximum dimensions and weights from shipping carriers, with formula for calculating volumetric weight](image1)

Figure 7. Diagram of maximum dimensions and weights from shipping carriers, with formula for calculating volumetric weight

!['Softcore' project: flat-pack strategy](image2)

Figure 8. ‘Softcore’ project: flat-pack strategy
configurations when transported across long distances. We considered this from the perspective of both express cargo freight (FedEx, DHL, etc.) and commercial airline carriers (checked luggage restrictions), using their limitations as a design tool in order to determine the optimal component size, shape, weight and overall assembly out of the box. (Figures 7-9). The final projects were installed as part of the London Festival of Architecture, Melbourne State of Design, Beijing Biennial and Shanghai Expo.

4 The Interfaces of Unfolding: From Form to Sheet

The second project reversed this design process again - beginning with a formal idea and then scripting the methods of unfolding it (back) to a flat sheet. The coupling of sheet-based digital fabrication tools and digital modeling in this work revealed a gap between 2D output and 3D input, and we employed a range of tools to bridge this gap – to translate between complex geometries and flat sheet-material. These tools are fundamentally similar to each other even if written for different modeling programs; they all endeavor to translate three-dimensional forms into two-dimensional surfaces which can be fabricated from flat-sheet material, and then re-folded back into the original shape. However, the slight variations in each version of these basic programs resonates further downstream in the design and materialization process, each technique biases particular values which affect the 2D translation and ultimately the physical outcome, such as the location of seams, number of pieces, automation of tasks, density of triangulation or overall composition on a sheet. For example, the programs students tested, Pepakura, Lamina Design, Waybe, Rhino, Sketch-Up and
integrative tools and techniques

Fig. 10

JavaView, each translate between 3D and 2D differently, closing the gap between input data and output material in a slightly different way from each other. We produced a sort of catalog of ‘scripted materials’ by questioning how input variables in these digital translation processes are revealed in material artifacts, comparing programs and their actions on a set of given 3D geometries in order to isolate their inherent biases and tendencies (Figure 10).

The standard shapes that were tested in each application were: a cube, cone, cylinder, rhombic solid, Rasmi dome, pyramid, sphere, ellipsoid, paraboloid, torus, Mobius Klein bottle, Klein bottle, Mobius strip and helix. Some basic limitations and patterns were revealed and documented, but the more interesting outcome was attempting to locate the tipping point in a flattening process, the point at which neither the computer nor the author were fully in control, when process departed from the predictable script and initiated a new way to solve the problem. This point emerged at the intersection between several values, such as resolution, ( quantity of data), geometry (complexity of math), and computational efficiency (speed). When one of these variables pushed beyond an operable limit the object would be unfolded in a way only the program controlled, no longer adhering to the same organization, pattern or scale but approximating a series of points and lines (as opposed to strictly polygons as intended) (Figures 11, 12). This was useful for us an example of when material and information became interestingly hybridized. What may have been lost in the translation between digital and material systems resulted in new patterns and elicited new potentials for how the work could eventually get built.

5 Phase 3: Scripting Assemblies

A third phase of this work is commencing at the time of publication, which will increase the range of material types and assembly systems. Extruded aluminum will be donated by Capral, 18 mil pressed board by Laminex, vinyl and canvas sheet by a local billboard

Figure 10. ‘Sliceform’ project: fabrication tests - successful and failed

Figure 11. ‘Sliceform’ project: urban installations in Melbourne and London
printing bureau, and timber frame Astral Ply and recycled solid-core wood doors from the university facilities office. Entitled “Three Little Pigs”, the design studio will advance the experiments presented in this paper toward more fully integrated digital-material systems, ultimately producing three micro-shelters of metal, wood and fabric. The notion of the micro-shelter is two-fold; on the one hand it scales up the program of urban furniture to an architectural scale, but is still feasible for students to design and construct in the course of a 14-week semester. Secondly, it suggests the development of a small building (or housing) assembly unit which is deployable across a range of sites or circumstances; e.g. tree-house, play-house, temporary shelter, demountable ‘tent’, or study carrel. In short, the studio will produce a small dwelling prototype constructed from recycled building products which might itself adapt, be scripted as a ‘unit’ or be assembled into a larger system across a range of multiple uses.

The goal of the first two studio projects was to link material and informational systems through reclaimed laminate, digital fabrication and shipping logistics. As the first phase of work, it was instrumental in establishing the key issues and limitations within these ‘components’ (materials, tools, and information), and experimenting with various ways in which they might inform each other. The next phase of this work seeks to further accelerate these links and to position the work, for example, as a micro-version of the internet of things, where information is quite literally embedded in the material and communication between inputs and outputs is perpetually linked. A system in which human, material and digital intelligence inform each other, rather than remaining separate systems linked through ‘design’ and ‘fabrication’ as discrete processes. For example, if the material fragments we reclaimed were coded, tagged, digitized and catalogued, they could then be scripted at a variety of scales – as sheets, components, assemblies or other scales or unit. A new variety of assemblies could be produced, new uses and combinations of materials, new scales of work and integration across sites and authors.

6 Conclusions: Shifting Craft Upstream

A significant consequence of combining harvested materials with use of digital fabrication techniques was the ability for the work to be executed by students in an educational setting. The material costs were nil, and the skill and craftsmanship of making that is typically required in full-scale construction (i.e. cabinetry), was shifted to the processes of scripting and unfolding. These phases of the design, while predicated on processes of automation, in fact proved to require a high degree of experience and perpetual adjustment, a skill which builds over time not unlike that of material craftsmanship. Programs like Grasshopper help to accelerate the learning curve for design-based scripting, but it is the combination of this skill and repeated material testing that truly reveals the capacity of these tools in use together. Thus, students practiced their craft at the digital phase, which is simultaneous to and embedded within the construction phase. And this was the specific nature of this research, not in making full-scale constructions or learning to script form per se, but in developing a material intelligence which bridges between the processes of input and output, between digital and material systems. In this context the studio operated somewhere between a research lab, a professional office and an artist apprenticeship, where students were both guiding the work and following where it led them.

In the end, focusing on the interface between digital and analog systems proved relevant in the context of environmentally sustainable practice even if it was not expressly the opening topic. This is evident both through the incorporation of reclaimed material and closing the loop for materials fabrication primarily, but also in looking toward the efficiencies of international shipping and distribution, systems which are inherently embedded in the built environment and contemporary architectural practice.
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References

The publications below were instrumental in the teaching of these studios and cited here as academic reference texts.


