# Digitally Mediated Use of Localized Material in Architecture

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**ABSTRACT:**

Modern materialization of architecture depends on the use of regularized, highly processed remotely-sourced materials produced through a centralized, industrialized process. This involves energy use, increasing the environmental impact and cost of the final structure. This study investigates leveraging digital technology to capture near-site material geometry, providing design tools and processing the material on-site. Optimization techniques are applied to minimize the use and processing of materials while meeting design goals and engineering constraints. A simulation and prototype using digitally selected and cut trees as main bearing members in a structure is used to confirm the proposed process.

**KEYWORDS:** scanning, fabrication, natural material

## Background

Modern building techniques rely on a standardized kit of parts that are produced by an industrialized process often involving long supply chains. A building consists of a myriad of parts at all scales, which the architect and constructor combine in a standard or slightly altered manner to generate the desired form. Even those bespoke components use standardized material assembled into a part. There is limited use of materials that are naturally occurring without standardizing for size or shape because of the complexity of dealing with this random variation.

The reliance on standardized materials has constrained design to forms derived out of standardized building blocks such as sheet goods and standard stud sizes. Variation from modular sizes of goods has historically increased labor costs. The dichotomy of the modularity of standardized parts and interfaces vs. integration of form and computations role in breaking this "rule" is well documented (Mitchell, 2001, 352-363). Without technological innovation this remains a hard limit to the design freedom of the architect under economic constraints.

Computation has only recently expanded the economic rationalization of complex form through several modes: firstly through the use of post-design rationalization of standardized (or simplified) parts (form fitting), and secondly through the economic manufacture of bespoke parts through computation driven machinery (DDF).

In this research, I suggest another mode using computation in rationalizing form, which has only just begun to be explored: using computation to incorporate non-uniform natural materials into design. Several technologies, such as laser scanning and increased computation power have developed sufficiently to allow this to be feasible.

## Precedence

The emergence of high resolution capture of on-site geometry through laser scanning or other methods is now readily available to construction teams (HDS Laser Rentals, 2010). This has been used largely to capture as-built geometry for renovation or additional work or as a method of capturing as-built conditions for new work. A notable use of interest to this work is for fabrication during the assembly process as used during the construction of the Seattle Public Library building designed by Rem Koolhaas and Joshua Prince-Ramus of OMA/REX. Daily scans were taken of the as-built structure and then this data was post-processed and used for further fabrication (Sheldon, 2009). Although minimal this feedback into the design is similar to the real-world input into the rationalization that this work explores.

Expodach by Herzog+Partners 2000, used near-site timber (50m tall Oak shaped by CNC machines), but this material was largely only semi-optimized for the structure and used as a linear support member. The natural form only indirectly informed the design shaping serving a largely symbolic connection to the tree trunk as canopy support.

Research and practice with performative design is also well established (Kolarevic, 2004, 457-464), using iterative optimization or linear calculation to optimize multi-factor rationalization problems to the design goal. The author has explored the reintroduction of material behavior into the design vocabulary through computational tools; this work provides another vector for using computation and material properties.

Work by Ayodh Kamath (Kamath, 2009, 52-57) in exploring merging digital scanning and fabrication has shown that this method is possible as a capture and reflection in digitally fabricated design. Scans of bamboo were used to digitally fabricate joints that were then tailored to fit the natural joints for interlocking. The scope of Kamath's work did not provide for performative optimization or adaptation of design intent.

There has been some work done on using naturalized form in architecture as exploratory sculpture (Rocca, 2007, 15-21, 68, 137) but only a few using computational rationalized form (n Architects, 2004). These explorations often use naturally "normalized" material which serves as basic "blocks" for the form. Examples of this are the use of Bamboo or Willow, both of which are largely regular in the scales that they are applied to design problems. Use of naturalized form can also be seen in vernacular or historical building techniques where standardization of form was economically infeasible, often because of the ratio of labor to standardized material costs (expense or availability of standardized materials).

The use of computation to rationalize form based on standardized materials has also been explored, including research in single material assemblies (SMA) (Botha & Sass, 2006, 214-215). It has been proposed that in using SMA's to rationalize the intended form and a careful choice of fabrication methods, the manufacture of the parts of the structure can be done on or near site. This reduces the complexity of the supply chain by bringing only standard commodity parts on site and fabricating just-in-time similar to residential balloon framing methods using digital fabrication technologies. This not only allows design flexibility but optimizes material use and simplifies the supply chain; it also allows late adjustments for design time errors or changes.

A classic example used in multiple references is the selection of curved sections of timber selected by shipbuilders for use in producing hull members. This selection by the shipwright was not only for shape, but also for density and strength often sawn from dense root crooks rather than limb wood.

The method I am proposing synthesizes capture technology, on-site fabrication and computationally rationalization of desired form.

## Inspirational Vision

An experienced stonemason when building a random rubble wall will select from the naturally occurring variation in shapes to best fit the negative space that needs to be filled. There is a deft alteration of a stone here and there to make a near fit into a good one. This is done expertly, efficiently and almost instinctively after enough experience. This process is seen as an "art" with an almost aesthetic quality. It is this selection of naturally occurring material to meet a design constraint (a wall) that inspires this work. While the mason can keep track of several dozen stones and rough dimensions while selecting for fit, applying digital technology we can track thousands of shapes and optimize the selection and shaping of the naturally occurring material.

## Discussion

In this paper I show a process that explores the use of naturalized local material in design through computational techniques of scanning, optimization of fit and digital fabrication (Fig. 1).

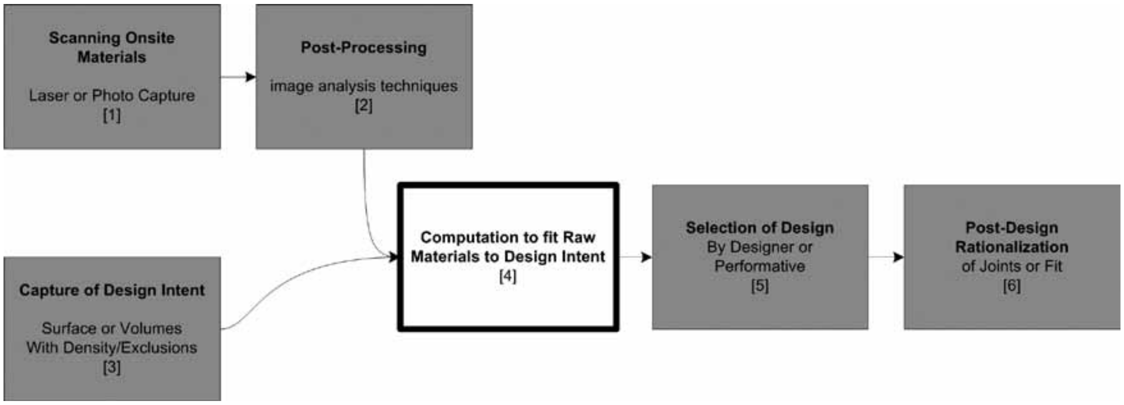

*Figure 1. Process of naturalized material use*

I have broken this process down into generic steps that could apply to any material used. In figure 1, step A the raw naturalized material is scanned and the raw data collected. Step B involves post-processing of the scanning of the material. This is broken out as a step as this is still involves newly developed techniques. Step C is the capture of the design intent of the designer. Step D is the computation needed to fit the captured geometry to the design intent, and is the main focus of this work. Step E is the selection of completed computations for fitness either by the designer or an analytical measure such as FMEA. Step F is the final execution of the selected design by digital fabrication or manual techniques.

Because of the phase of this work, acquiring digitally mapped standing timber was left for future development; however this has been simulated by using a reasonably derived simplification. Methods have been shown on how to take raw point-cloud scans of trees and derive a simplified geometry (Gossett, Chen, & Xu, 2007, 5-7). Simulating this geometry has no bearing on this research until it is materialized and the technique applies equally well to L-system generated "trees" as to natural occurrences. L-systems have been successfully applied as a heuristic for extracting tree geometry from images (Huang, 2008, 253-258).

The designer provides intent by outlining the space that needs to be enclosed as a constraint to the generative system. This space could be arbitrarily complex and could be the output of a generational system itself. There could also be further space exclusions or density maps established based on the needs of the design but this is not implemented in this work. In this model the design intent is implemented as a simple surface.

The raw material "trees" are then sorted through an algorithm to best fit the design intent. The algorithm stops searching for a solution when a certain level of fitness is reached. Fitness in this case is a maximal horizontal span of material as a beam and enough overlapping material to form a strong joint. A critical element is that there is excess raw material to supply the selection algorithms with enough variety to generate a good fit.

Once the algorithm arrives at the best fit, the model is saved for further evaluation. This can be done against FMEA or other criteria or these could be integrated into the fitness criteria of the original sorting algorithm. This process could also involve selection by the designer.

The model is then post-processed to optimize the cuts and joints needed to assemble the structure. These could be executed using fabrication techniques or more computation guided manual cuts.

## Method

As an initial optimization technique, branching is limited to three linear segments and the radius of these branches set. These three elements are cataloged for apparent normal and total radius of span in order to fit the design surface (Fig. 2); a large inventory of these branches is required for the process.

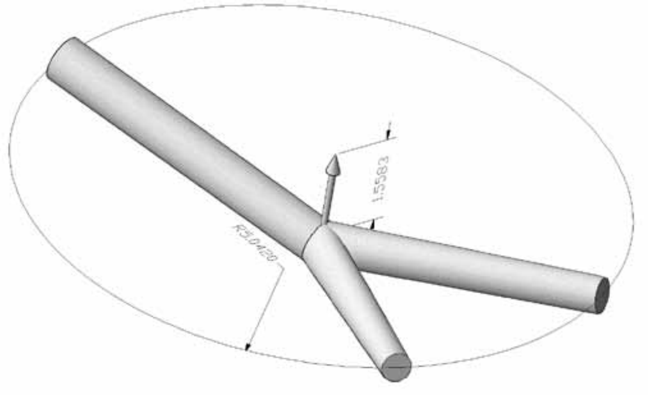

*Figure 2. Normal and radius during inventory*

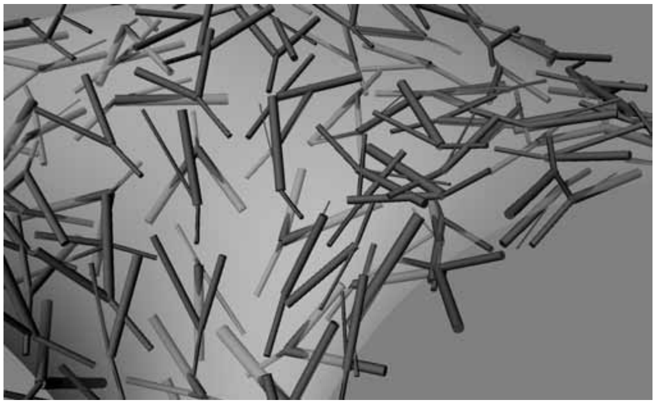

*Figure 3. Initial seeding of limbs before using attraction*

The branches are then distributed across the surface by traversing the UV coordinates and matching the curvature. Rotation of branches is allowed. At this point in the process there may be no interference of branches to create a supportable structure. Branches are placed at a fraction of the total radius to support the interference process.

The branches are then "attracted" to one another and allowed to move across the surface and within a parameterized error from the surface. This iteration stops after there is a degree of interference (Fig. 3).

If after iterating the branches do not come in contact, a second distribution of branches is added to the "gap" areas. The entire iteration of selection, fit and overlap are repeated and each iteration can be compared for fitness.

## Future Work

There are several gaps with the method that was developed. The assumption of 3 linear elements is a simplification and the use of n-branch and curved elements are a logical extension of this. The work to extend this code to handle fully defined l-system trees and refine the curve matching is continuing.

The scope of this work was to focus on the process and the feasibility of the computation step using simulated material. Future work will include obtaining natural scans of scale material to verify the assumption that the computation is valid with "noisier" source data. Fabrication techniques need to be developed to cut the joints into a physically complex tree—either fully automated or as a way to digitally guide through marking a manual cut.

With this work, a naturalized timber frame is produced. A further development would be to create a glazing or enclosure system that would work with this irregular framework.

A further step would be to physically prove the process through the execution of the process in full-scale. This would involve significant effort and support from industry

This example uses raw timber, however, the process could be used in other approaches involving different material, such as returning to the inspiration of the stone masons random rubble-built wall. Stones could be scanned and computation used to optimize the fitting.

## Conclusions

It is clear from the existing research that the incorporation of natural form into architectural forms using computation to deal with complexity is an under-researched field and one which is only recently feasible. This work has proposed a method to incorporate large scale use of natural form into the architecture and building process. I believe this opens up further opportunities for expression that cross the boundaries between craft and architecture.

This is fit into a larger framework of onsite material supply chains and previous research on on-site fabrication. I plan to continue and expand the computation aspect of this project and look for opportunities to collaborate on a full scale implementation.

While this research was only a beginning into implementing the entire process proposed, it does provide validation that the computation element of the project is possible. This method is a blend of both architectural intent and generational geometry from the natural materials which opens new possibilities in both architectural expression and sustainable building processes.

## References

Botha, M., & Sass, L. D. (2006). The Instant House. *Proceedings of the 11th International Conference on Computer Aided Architectural Design Research in Asia* (pp. 209-216). Kumamoto (Japan): CAADRIA.

Gossett, N., Chen, B., & Xu, H. (2007). Knowledge and Heuristic Based Modeling of Laser-Scanned Trees. *ACM Transactions on Graphics, Vol. V, No. N, Month 20YY*. ACM.

HDS Laser Rentals. (n.d.). Retrieved 08 26, 2010, from Smart Geometrics: http://www.smartgeometrics.com/rental.html

Huang, H. (2008). Terrestrial Image Based 3D Extraction of Urban Unfoliaged Trees. *The InternationalArchives of the Photogrammetry, Remote Sensing and Spatial Information Sciences.*, 253-258.

Kamath, A. (2009, 05 24). Integrating Digital Design, Fabrication and Craft Production. *MIT Masters Thesis*.

Kolarevic, B. (2004). Computing the Performative in Architecture. *Digital Design [21th eCAADe Conference Proceedings],* (pp. 457-464). Graz, Austria.

Mitchell, W. J. (2001). Roll Over Euclid: How Frank Gehry Designs and Builds. In J. e. Ragheb, *Frank Gehry, Architect (pp. 352-363)*. New York: Guggenheim Museum Publications.

n Architects. (2004). *MoMA/P.S.1 YOUNG ARCHITECTS PROGRAM 2004*. Retrieved 08 28, 2010, from n Architects: http://www.narchitects.com/frameset-ps1.htm

Rocca, A. (2007). *Natural Architecture*. Milan, Italy: 22 Publishing S.r.l.

Sheldon, D. (2009, 05 22). Lecture Notes - 4.553 Digital Fabrication & Construction: Professional Applications. Cambridge, MA, USA.