Material Contingency in Computation

Digital technology has a scale, as well as material, problem. Modeling at full scale in a virtual environment removes the feedback loop that miniaturization (and its attendant abstraction) provides. The internalized intervals of scale (be they metric or imperial) establish a common frame of reference across the discipline and are a didactic tool used to form the architectural imagination.[1]

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The concept of scale and its companion, material, defines architecture. In a 1976 essay, "Figuration graphique en architecture", Jacques Guillerme articulated the concept of figuration. Guillerme uses this term to distinguish architecture from its companion applied arts. For Guillerme figuration is a scalar activity where the architect uses their body as a referent in establishing distance and dimension. Further, this activity references 'constructions', real or imagined.[2] Thus scale and material (real or imagined) limits the architectural domain.

A conceptual boundary, scale and material also define the agency of architectural production in the contemporary political economy. According to Thomas Piketty in Capital in the Twenty-First Century the greatest threat to social and economic stability is the concentration and unequal distribution of wealth.[3] Through the command of scale and material architects direct resource distribution (quantities and configurations of materials, contractual documentations) and knowledge production (construction methodologies, design principles). The capacity of the figuring architect to command the distribution of resources and knowledge and to equalize this distribution is their greatest social and economic asset.

Because digital modeling environments are scale-less and immaterial their use in architecture destabilizes the fundamental architectural concepts of material and scale. Architecture, conceived through the scalar and material imagination, is thus destabilized both as a body, or discipline, and as a functioning socio-economic agent.

The device of orthographic projection has done a robust job unifying these two domains—scale and material—in a single media for centuries. As a digital co-ordinate system it has also translated to a facile framework for digital modeling environments. This paper explores how projection—a robust framework of scalar-material protocols—situates scale and material within scale-less, immaterial digital environments: the now-dominant environments of architectural production.

PROJECTION AND COMPUTATION

The re-stabilizing of material concepts and advancement of material knowledge has been, without question, a fundamental priority of digital environments since their earliest inceptions.[4] Methodologies not only addressing material performance, but advancing material understanding, are highly developed as are pedagogies that counterpose virtual and material constructions.[5]

The re-stabilizing of scale seems to be a less certain priority. Mark Morris in a recent article in the Cornell Journal of Architecture addresses this agenda in academic environments. Based on its didactic value Morris advocates for the employment of scale for a number of reasons, not least of which is the 'delight' taken in miniaturization. Scale's usefulness in teaching the sequence of decision-making in architectural design and its lessons in abstracting constructions at a variety of stoppages likewise support its cause. Beyond the academy Morris is more ambivalent, relegating it to a useful, if outmoded, professional nicety.[6]

However, this delight in the miniature—pleasure, perhaps, in the illusion of control[7]—is more than just a professional nicety when exercised outside the academy. According to Guillerme, within figuration 'education and production are inseparable.'[8] The figuring architect makes a work and at the same time the activity or the work makes the architect. The use of scale not only aids in decision-making and abstraction, it fundamentally transforms the architect's way of seeing. It does this continually on either side of the academy's doors. The stoppages in scale that Morris cites are useful not only as courtesy, but as a mechanism of architecture's collective authorship by architects. For it is not just an individual architect's way of seeing that defines the discipline, but the collective vision of a larger body of architects.

If orthographic projection has served as the figurative device par excellence, its integration into digital environments has been an inconsistent process. Early digital-parametric projects frequently utilized the serial section as an organizational device. In these instances the projection plane is operative, serving to guide the builder in the assembly of the whole without revealing the entirety of the artefact. The frequent use of sheet stock material requires a negotiation of orthographic ideation. And recent projects have, beyond the mason's template, made these flat sheet constructions self-organizing. At the same time projects like the Barcelona Fish celebrate the absence of orthographic snapshots in the design and execution process and bemoan the corruption and inefficiency of shop drawings and scalar projections.[9] By adopting a historical vantage point on projection's relationship to scale and material orchestration, it is expected that this study will provide insights as to its capacity as a framework for contemporary practice.

PROJECTIVE-DIGITAL PRACTICE

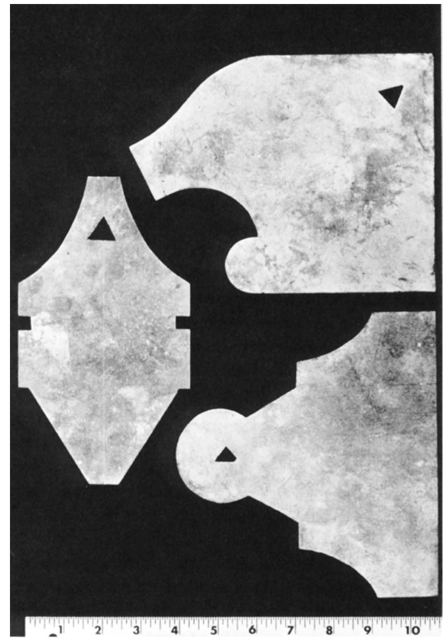
Orthographic projection's mechanisms for unifying material and scale are threefold. First it is a conceptual device: a mechanism for holistic organization. Second, it is predictive: used to test and anticipate material performance and configuration. Third, it is instrumental: a mechanism of construction.

Figure 1: Masons' templates cut from zinc sheets at the Bath and Portland Stone Company, Bath, England. *from 'Mediaeval Masons' Templates', Lon R. Shelby, 1971*

Figure 2: R. Dudleo, Dell'arcano del mare, 1646, third instrument. *from 'The Archaeology of Section', Guillerme, Verin, Sartarelli, 1989*

To understand the significance of projection as a conceptual mechanism we can look to the emergence of a professional class within the history of ship building. Guillerme points out, in the "Archaeology of Section," that what set the artifacts of orthographic projection and their makers apart as a discipline in the European development of naval architecture is—similar to Morris's argument of decision-making at certain scales—these drawings' use as a device for negotiating an object at multiple scales. Guillerme notes that the distinguishing characteristic of naval architects drawings from those of ship builders was that the builder's drawings represented constructions from the stock on-hand; an ad-hoc catalog of parts. The naval architect's drawings, on the other hand, were a configuration of parts at multiple scales describing the holistic integration of an artefact.[10]

Further study of the ship-building art and its drawings—or lofting—also reveals insights into projection's use as a predictive mechanism, anticipating material performance. The discipline of lofting was traditionally married to a particular material class, either wood or metals. It is employed to facilitate the construction of curved surfaces in not only the industries of ship building, but those in aerospace, and automobile manufacture as well.[11] Of chief concern in these industries is a 'fair' surface: one free of curvature deviations disrupting the laminar flow over a hull, fuselage, or body. To construct fair surfaces loftsmen establish fair curves using a device called the spline: a long thin length of wood or metal that relaxes elastically into a smooth curve when fixed in various positions along its length. In this instance projection's use as a predictive mechanism required a mimetic device to anticipate the appropriate curvatures with sufficient material fidelity.



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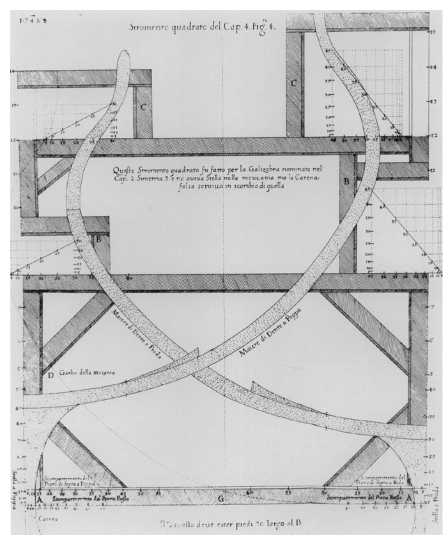
A similar preoccupation with material fidelity can be found in stereotomy: the drawing of cut stones and stone assemblies for masonry construction. Early treatises on stone construction instructed masons on the geometric operations and conventions that would yield appropriately sized and proportioned members for a variety of structural and non-structural applications: from the ribbing for vaults to the mullions for veils.[12] As recent as the early twentieth century instructions on stereotomy included exercises in building and cutting scaled stones from plaster to visualize the required drawings to achieve them. Thus, in order to make orthographic projections, three-dimensional constructions in an analogous ceramic material were first enacted.

Far from simply being exercises in visual proportioning, the drawing of stones in stereotomy accounted for properties of strength, brittleness, and grain—or bed—orientation of the individual stones,[13] as well as the orientation of forces of thrusts and bearing through the network of a stone assembly.

Both stereotomy and lofting provide demonstrations of projection's use as an instrumental mechanism: translating the products of the drawing board to 'live' instruments which guide the builder's hand. In medieval England mason's templates were often the first implements handed to a builder and recorded in financial accounts.[14] These templates were often wood, zinc, lead, or even cloth (figure 1). The elasticity and malleability of these materials suited them to describing both a flat plane and the three-dimensional curvature of developable surfaces.[15] As recently as the early twentieth century federal projects in the United States required the architect to provide the contractor with stone templates of the architect's fashioning.[16]



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Within the ship-building traditions the lofted drawings were often made at full scale on a platform raised above the room where the ship was to be constructed. These rooms had strict requirements for construction tolerances on the floor and attire worn in the room appropriate to a room-sized drafting board. As the naval architect's art developed so, too, did the scope of their instruments. Beyond templating individual ships, in the seventeenth century Robert Dudley developed plans for a ship mould device that could be manipulated into a variety of configurations for multiples of different types of ships in a fleet (figure 2). Competing devices soon emerged.[17]

These modes of operation within projection—concept, prediction, instrumentation—establish a series of avenues for engaging scale and material in digital environments. They initiate a framework for a projective-digital methodology to both conceive and execute material artefacts in computational environments. It is a flexible framework in both the process of ideation and design as well as execution, allowing for fluid and hybrid modes of practice. As will be shown in the following examples this fluidity and hybridity has significant implications for the distribution of knowledge and resources within localized building industry ecologies.

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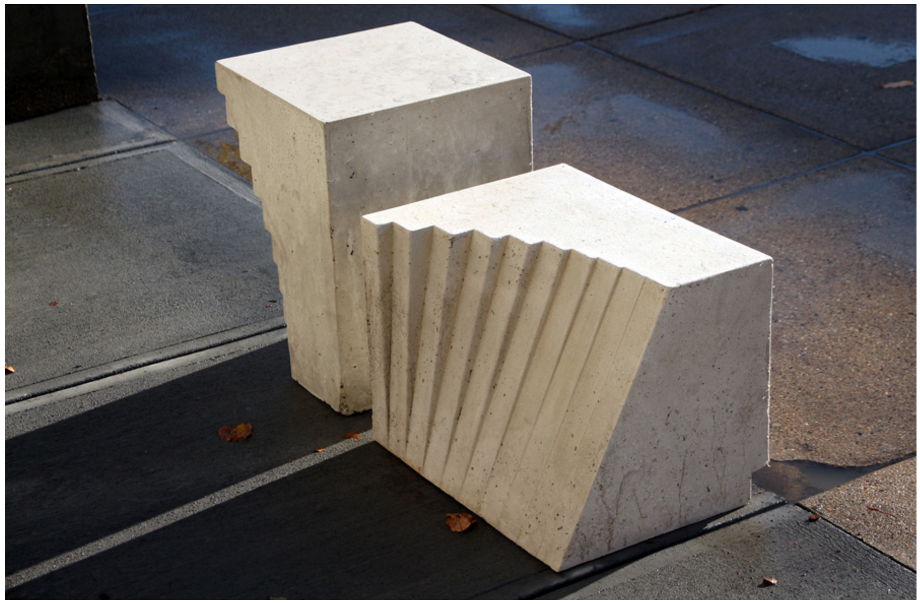

PROJECTIVE-DIGITAL PROJECT: HYPAR BENCHES

Hypar Benches is a series of modular concrete benches in front of a community gallery in Boston's South End. Designed and fabricates by Radlab, Inc. in collaboration with the author, the benches' formwork is a reconfigurable mold whose final product can be rotated into various positions. One face of the mold is a ruled surface constructed of lengths of dimensional lumber so that as each bench is rotated this face takes on an alternate orientation with respect to light and the ground plane: creating the effect of several unique objects from a single mold (figure 3).

The conceptual mechanism of the project was a pair of workplanes: horizontal datums establishing the 'top' and 'bottom' surfaces of the base bench module. These planes were used as a surface of inscription for the edges of the ruled surface: the hypar surface itself then became a product of these curves. The surfaces set the base planes for a Grasshopper for Rhinoceros definition that parametrically modified the geometry and configuration of the hypar surface. They also served as the template for formwork, creating a tight link between a conceptual framework and a material implement.

Through the evolution of the design the Grasshopper definition was tuned to meet the size requirements of the dimensional lumber strips that would be used to define the hypar surface. Here the device of projection was used as a predictive mechanism to anticipate and configure relationships and adjacencies between the wood strips.

Projection's use in the project as an instrumental device manifested in physical templates. These were made to cut the wood strips at precise angles and scribe the location of each adjoining strip on opposing faces.[18] This step highlights projection's hybrid status in this mode of digital design and production. The fabrication of these strips utilized projection within both digital and a manual-mechanical steps in the design-fabrication process. Projection's utility here is as both a conceptual and literal translator between variable modes of production.

This type of hybrid operation—emblematic of low-volume production—is essential in smaller scale, localized construction and fabrication trades. It is a flexibility that is essential to the distribution of returns on investment through a regional construction trade ecosystem: a healthy ecosystem that resists national and international concentration of wealth among the building trades. Hypar Benches was executed for a non-profit organization with extraordinarily limited financial resources while facilitating production and

Figure 3: Hypar Benches. *courtesy Radlab, Inc.*

material research within an innovative, small scale design and fabrication practice. By integrating the dynamic precision of digital practice with the flexible conceptual framework of projection these smaller ecosystems are able to productively leverage technological advances.

PROJECTIVE-DIGITAL PROJECT: THE LANTERN

The Lantern is a wood and steel millwork screen rising four stories in a public university campus center in Lowell, Massachusetts. Design of the Lantern was led by the author working as a digital design and construction specialist at Perkins+Will, Boston. The screen serves the functions of guardrail, work station, and seating and is a symbolic heart to the dispersed urban campus (figure 4). Its illuminated surface can be seen across the river through the campus center's glass façade. The Lantern is supported by a series of horizontal steel armatures cantilevered off the base-building steel at every floor level. These armatures carry a series of through-rods which gang together 1x4" ash slats in several panels. These ganged together panels form larger facets which fold at a series of creases along the height of the screen. The angle of each crease is tuned to accommodate the various functions of the screen, refract light into the atrium, and answer material and code performance criteria. As the lines of the wood slats approach the creases they are carried through by steel splice plates, double bent to negotiate the slats' rotation on either side of the crease.

Similar to the Hypar Benches the fundamental organizing device for the project was a series of four workplanes: one for each floor level and the roof of the campus center. These

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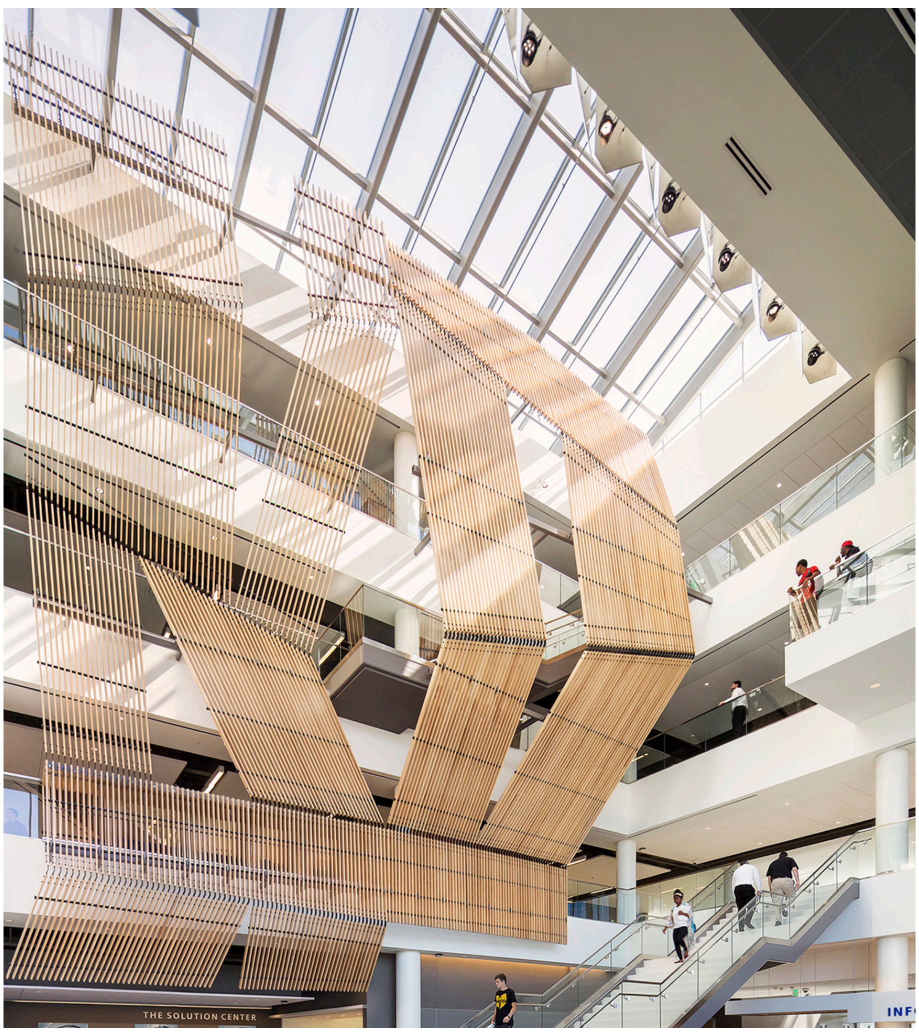

Figure 4: The Lantern. *courtesy Perkins+Will.*

horizontal datums structured the project at multiple scales. At the larger scale they knit the system together as coherent, repetitive whole. Set at the top of the base building steel each workplane systematically connected the assembly back to the base-building structure. At a finer grain they established the juncture between the secondary steel and a continuous through-rod supporting the assembly at each floor level. And at the level of the detail the workplanes operated as predictive mechanism, facilitating planning of the relationships between the continuous through-rods, the steel saddle-plates which supported them, and the wooden slats evenly spaced around the saddle plates.

The steel splice plates connecting the wood slats together was an acutely instrumental device. It functioned somewhere between a mason's template and a permanent building element. Digitally 'fashioned' by the architect it was a developable surface passed from architect to millworker to metal worker to erector. Once on site it directed the erector in the positioning and orientation of the panels of wooden slats. Each set of splice plates (twenty-four in all) oriented its related sets of wood slats out in space towards the next set of splice plates: the entire system knitting together from seam to seam. So essential were the plates to the system's geometry that they directed the sequence of erection: the panels stacked vertically from seam to seam until the entire assembly relaxed into shape.[19]

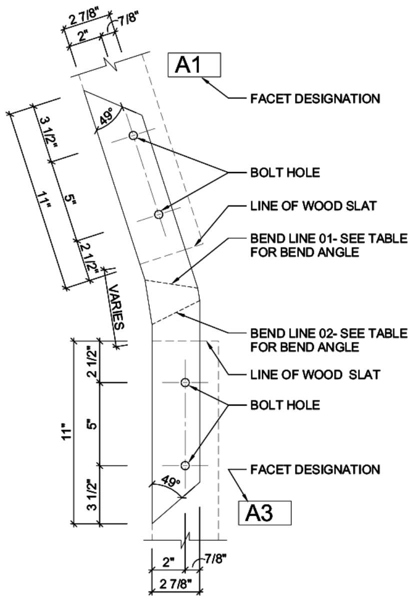

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Figure 5: Double bent splice plate template.

At its two ends the plate is a fixed geometry, set into the wood slat about 18 inches with a three inch deep kerf. These dimensions were engineered based on the cross-grain strength of ash in shear and bending. At its mid-span each splice plate undergoes two bends of variable degrees at a quarter-inch radius (figure 5). This double-bend negotiated the rotated relationship between wood slats from one facet to the next: a rotation set up by the slats being set flat on a table during shop-fabrication. The plate itself is an instrument of construction unrolled and computer numerically transcribed to steel sheet stock. Provided with divots—templates instructing the metal fabricator—at the bend lines the sheet stock was cut and bent to shape based on a schedule of values. Arriving on site it generated the overall geometry.

As with the Hypar Benches, the Lantern engaged a regional ecosystem of construction trades and material suppliers, but on a larger scale. This resulted in both localized resource distribution and knowledge generation, strengthening the independent ecosystem. The project was an assemblage of raw, minimally processed stock material regionally procured and harvested. This was executed under a publicly-bid government contract with strict budgetary constraints. In order to protect the local sub-contractors bidding on the project the design team produced a fully engineered system with explicit descriptive specifications. This established a bid environment with a high degree of accuracy and protected a fabricator from signing a contract only to find out after independently engineering the system that their bid was an order of magnitude lower than the actual project cost.

The flexibility offered by the employment of projective-digital methodologies worked to the project's advantage on many levels. The design team could incorporate data into the engineered system late into the documentation process and rapidly and effectively communicate these changes. Fabricators with both digitally advanced and industry standard knowledge-bases were able to engage the project. This flexibility enabled its execution by an innovative, independent regional fabrication practice and provided a first opportunity for them to interface directly with other trades in assembling a total building system.[20]

WEALTH MANAGEMENT

The projective-digital methodologies outlined above—conceptual, predictive, and instrumental—establish a flexible material and scalar discipline in contemporary practice. This serves to stabilize architecture's figurative apparatus and reinforce its status as a productive socio-economic agent engaging in systemic distribution of wealth and knowledge. Rather than limiting the production of built artifacts as the motion suggests, this methodology feeds the growth of local economies and knowledge bases: an essential ingredient for socioeconomic stability in Piketty's metric. The argument for restricting new construction restricts a primary growth sector in the economy. This constriction shifts resource accumulation away from growth industries to inherited wealth. This kind of mechanism, according to Piketty, privileges the consolidation, not distribution, of wealth.

We can see this cycle played out in the story of the community gallery, the client, for the Hypar Benches. Housed in an adaptive reuse project the novelty of this aesthetic resulted in the escalation of rents and property values. Forced from their home by the property owner it was only though the intervention of a government agency, the Boston Redevelopment Authority, that their existence was preserved in an alternate, but less desirable space in the building. The mechanisms of reconfiguring existing architectural objects do not serve the most vulnerable populations. Rather, they reinforce the wealth accumulation of those who already own these existing architectural objects. In short, it is not a question of new versus old. It is a question of the precise direction and management of resources through the essential elements of architectural ideation and production: material and scale.

ENDNOTES

1. Mark Morris "1:Whatever" in *The Cornell Journal of Architecture*, 9: Mathematics (2015). 76-84
2. Later translated by Hélène Lipstadt in her essay,"Architectural Publications, Competitions, and Exhibitions" in *Architecture and its Image; Four Centirues of Architectural Representation, Works from the Collection of the Canadian Centre for Architecture*. Cambridge, MA: The MIT Press, 1989.
3. Piketty, Thomas. 2014. *Capital in the Twenty First Century*. Cambridge: The Belknap Press of Harvard University
4. Negroponte, Nicholas. 1975. *Soft Architecture Machines*. Cambridge: The MIT Press
5. Menges, Achim (ed.). 2012. *Architectural Design: Material Computation*. West Sussex: Wiley
6. Morris "1: Whatever" (note 1).
7. Ibid.
8. Lipstadt "Architectural" (note 2).
9. Kolarevic, Branko. "Parametric Evolution" in *AD Smart 01; Inside Smartgeometry*. Chichester, West Sussex, United Kingdom : John Wiley & Sons Ltd. (2013). 50–59
10. Guillerme, Jacques, Hélène Verin and Stephen Sartarelli. "The Archaeology of Section" in Perspecta, Vol. 25 (1989). 226–257
11. Young, Michael. "Digital Remediation" in *The Cornell Journal of Architecture*, 9: Mathematics (2015). 119-134
12. Shelby, Lon R. 1977. *Gothic Design Techniques: the fifteenth-century design booklets of Mathes Roriczer and Hanns Schmuttermayer*. Carbondale: Southern Illinois University Press.
13. Barham, George. 1914. *Masonry: An Elementary Text-Book for Students in Trade Schools and Apprentices*. London: Longmans, Green, and Co
14. Shelby, Lon R. "Mediaeval Masons' Templates" in *Journal of the Society of Architectural Historians*, Vol. 30, No. 2 (May, 1971). 140-154
15. Barham, *Masonry* (note 13).
16. French, Arthur. 1902. *Stereotomy*. New York: Wiley.
17. Guillerme "Archaeology" (note 10), pp. 243-246
18. Trimble, Matthew. Prinicpal, *Radlab, Inc*. Personal Interview. 20 July 2015.
19. Goupil, Dennis. Project Manager, *C.W. Keller.* Personal interview. 15 September 2015.
20. Goupil, (note 19).