PROTOTYPING ARCHITECTURE

The Conference Papers

Michael Stacey

Prototyping Architecture: The Conference Papers

Michael Stacey: Editor

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Cover image: Image – Fig_0 Detail of adaptive gill like GRP solar shading of Ocean One, the Theme Pavilion of Yeosu Expo, architects Soma

to view the keynote talks go to:
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Contents

Contents

5.2
De-Fabricating Protoarchitecture

Bob Sheil [i]

> *"Tools provide possibilities, from these possibilities we discover advantages, advantages become a convenience, and convenience can too easily become a convention. There are alternatives: rather than supporting just the more efficient execution of conventional tasks, tools can encourage new ways of thinking. The creative use of a tool should include opportunities for the designer to embed his own design logic within that tool. Such customisation should be recognised as a key aspect of design creativity."*
>
> Robert Aish[ii]

This paper has developed from a short article that first appeared in the *Material Computation* issue of Architectural Design in February 2012. It came about through an invitation by the publisher to pose a counterpoint to the issue's overarching themes, and was framed at that time as piece entitled *Distinguishing between the Drawn and the Made.* Rather than construct a deliberately opposing critique of the work described in the issue, the aim of the article was to reflect on a series of underlying issues associated with building things from digital data, a discipline many in the construction industry are still grappling to master. Robert Aish, someone who is a master of this technology is the author of the quote above. Apart from his pedigree as a graduate of Industrial Design at the Royal College of Art, where he studied under David Pye, his PhD in Human Computer Interaction from the University of Essex, his career as a senior engineering software developer with Arup, Rucaps, Intergraph, Bentley, and now Autodesk, and his role as a consultant for many of the world leading practices and universities, it is his early experience in the shipyards of Gdansk where he managed information generation for the fabrication and assembly of hull components that strike me as a formative reference behind these remarks. It is such underlying knowledge and tacit experience in the physical and tactile that forms the basis of this paper and the work it refers to.

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Fig 5.2.1 Manufacturing Protoarchitecture 1: In the foreground, early components of the ‘55/02’ shelter by sixteen*(makers) in collaboration with Stahlbogen GmbH. In the background components of more everyday fabrications by Stahlbogen. For the former, precise assembly of the digital model was not a project objective, for the latter, it is a quality upon which the business depends. Material: Steel

Fig 5.2.2 NW Projection: 55/02 Kielder 07.03.10 1643 hrs: Partial scan of shelter 55/02 at Cock Stoor, Kielder Forest and Water Park, Northunberland, UK. 3D survey carried out by ScanLAB Projects.

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Set within the context of design and fabrication tooling of ever increasing definition and adaptability, the ideas this paper shall explore are:

- The status of the dynamic and adaptable digital design model in relation to the physical results that are built from it;
- The status of the resulting physical assembly as an architectural prototype, and:
- The difference between the drawn and the made.

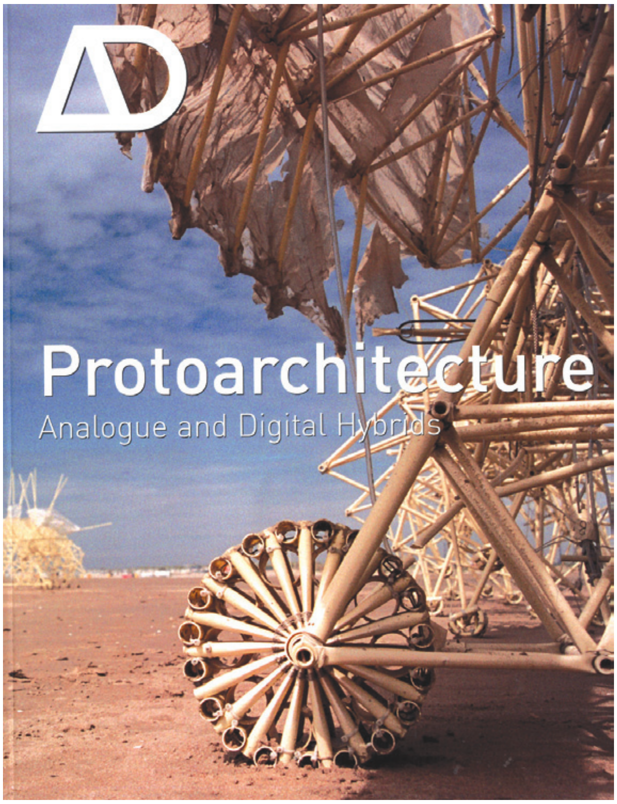

Fig 5.2.3 Protoarchitecture: Analogue and Digital Hybrids

This paper also draws upon and refers to the publication '*Protoarchitecture: Analogue and Digital Hybrids*' (Wiley July 2008)[iii], and a forthcoming title *'High Definition: Negotiating Zero Tolerance'* (Wiley January 2014)[iv], currently in development. Each of these publications seek to examine parallel and immediate developments both in practice and research that present new challenges to established methodologies in design and fabrication. The former title explores the beginnings of a recent period in architectural history (circa 2000-2007) where a significant and growing proportion of experimental design was not exclusively colonised by computational processes or computational theory. The rose tinted glasses of the computational age were slipping off, and a hybrid world, dense with the feedback of unpredictable, inconsistent, and unexpected results was readdressed as a defining ingredient in making architecture.

The term *Protoarchitecture* has been adopted to reflect work that is part real, part ideal, part resolved, and part in progress. It also recognises propositions that are prompted by a compatible interest in analogue and digital techniques and thus parallel constructs of the physical and the virtual. *Protoarchitecture* captures work that does not conform to type, is exceptional, experimental, and transgresses habitual practice in representation with that of making. Examples of work argued in this context include amongst others that by the Founder of the Centre for Architectural Structures and Technology (CAST) at the University of Manitoba, Professor Mark West[v], the products and environment of 'La Machine' in Nantes led by Pierre Orefice and Francois Delaroziere[vi], 'Strandbeests' by Theo Jansen[vii], 'Prosthetic Mythologies' by Kate Davies and Emmanuel Vercruysse of Liquidfactory, and 'Robotic Membranes' by Mette Ramsguard Thompson of the Centre for Information Technology in Architecture (CITA) at the Royal Academy of Fine Arts Copenhagen. Each of the presented works not only portrayed an alternative and critical approach to practice, but an alternative and critical role for the designer as an active participant in the work's production.

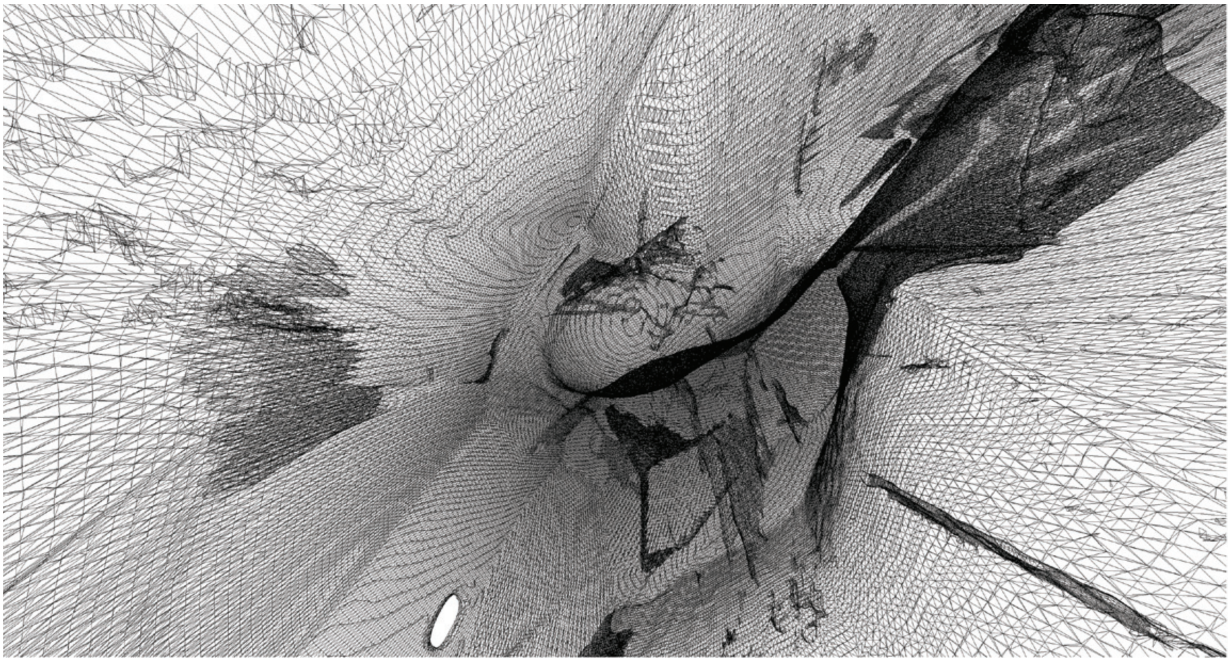

Fig 5.3.4 Subverting the Lidar Landscape by Matt Shaw (Bartlett School of Architecture MArch Unit 23, 2007-09). The point cloud image of a speculative building component is captured from a 3D laser scanner. Material defects and unseen anomalies are detected by the scanner and appear in the point cloud as digital noise. We have yet to fully understand the behaviour of real materials in digital space. Materials: Polymers, grease, hardwood, gelatin and steel

Six years on, *High Definition: Negotiating Zero Tolerance*, 2014, is exploring subsequent developments in design tooling and practice. Central to this forthcoming publication is an examination of Light Detection and Ranging Technology (LIDAR)[viii] in architecture; Presently capable of capturing distances up to 6000m in radius (or more if launched from airborne positions) and generating 3D point clouds to an accuracy of less than 1mm, such tools offer unprecedented accuracy for the development and interrogation of design strategies before, during and post production[ix]. With its roots in the automotive production industry, and applications in crime forensics, mining and marine engineering, mechanical verification,

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medicine and landscape, the use of 3D scanning instrumentation in architectural design opens up entirely new avenues of understanding and engagement with the complexities of context, form, behaviour and volume that heretofore have been crudely approximated, or poorly grasped. As the designer's array of digital tools to propose and make their ideas has become significantly enriched in recent decades, the component of armoury that has remained out of step with potential has been the means to navigate, embed and verify design outcomes as they emerge in context. LIDAR technology has begun to transform this problem.

Without such tools, the exploitation of greater levels of precision, complexity, and dynamic composition in design representation, is curtailed by unmatched resources in execution and delivery. Today, through affordable 3D LIDAR technology and it facilitation of high accuracy data capture[x], this gap is narrowing. Complex design propositions in a number of file formats may be tested and developed within three dimensional point cloud files that are accurately referenced into real environments. Likewise, built work may be scanned and cross referenced to the design information from which it was produced, thus offering a clear mapping of the real upon the ideal. Yet to date, the subject of high accuracy, zero tolerance design production has been exclusively published through didactic, scientific and mechanical themes. How does the technology work? How is it used, etc? This publication will explore such themes on a level of creative and speculative critique, that range from its stretch capability to how it challenges the role of the designer.

Residing within the context of adjacent themes on high definition, examples of work to be argued in this context include the self-assembly works of Skylar Tibbets at MIT, information production, flow and procurement at Gehry Technologies, and the boundaries of surveillance technology explored by Andy Hudson-Smith at the Centre for Advanced Spatial Analysis, UCL, and others who will be referred to later in this paper. Running as a critical subtext is a discussion on the role and value of zero tolerance as a design and fabrication standard. Negotiating zero tolerance asks us to define an appropriate proximity to high definition technology within an industry still very far removed from the laboratory facilities of its automotive or aeronautic cousins.

Fig 5.3.5 Incisions in the Haze from the Prosthetic Mythologies project by Kate Davies and Emmanuel Vercruysse of LiquidFactory (2012). The alchemy of the sand casting is magical. The foam form is buried in sand, packed down and engulfed in its cocoon, molten metal is poured into it, dissolving and replacing the foam - transfiguring it - when the form boxes are opened a fiery hot object shrouded in smoking burnt black sand emerges. Materials: Sand, Aluminium, Gas.

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> *"There is a great deal of mythology associated with craft – and with professional practice generally".*
>
> Peter Dormer – The Art of the Maker (1994)[xi]

Not To, but Through

Over the past three decades computation in architecture has developed an array of powerful tools for the development and evolution of geometric complexity. It has also provided the design and construction industry with additional tools and processes that modify the protocols and connectedness of visualisation, production and procurement[xii]. Yet crossing the material threshold raises significant questions regarding; the objective of digital information as an instruction to make, the subsequent status of the built work being generated, and the difference between simulation and fabrication. Prior to the adoption of computer-aided design (CAD), architectural drawings were made using cumbersome tools that had not changed in any radical sense for more than 2,000 years. Other than the evolution of more precise instruments and more stable materials on which to draw, the standard toolset of the architectural designer remained remarkably consistent until the late twentieth century. For the architect who has wished to break from tradition, one of the greatest challenges has been to transcend the limited possibilities of these tools and understand the difference between design propositions that are possible to make but difficult to draw, or possible to draw and difficult to make[xiii]. Lurking within this equation was intent, a design intent that existed between the drawing and the artefact, and one that relied upon conversation with other disciplines, trades and experts to be fulfilled as a physical entity[xiv]. Implicit information on the specific production tools that might be used to make the design, or how such tools should be used, maintained, deployed or controlled, was limited.

Fig 5.3.6 Terra Therma by Peter Webb (Bartlett School of Architecture MArch Unit 23, 2008-10). Ideas and materials are metaphorically and literally extrapolated from a site in North London and developed as prototypical building components for a space of variable temperature and humidity. The elements are extruded through a digitally controlled variable jig. Materials: London Clay.

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Only in instances such as the illustrated profile of soft joints, or the geometry and materiality of a specific mould and surface for casting, might visual information alone and the technique of how the desired result be made become synthesised. If not conveyed in this way, or augmented in specification clauses, decisions on production tooling were placed in the domain of the fabricator who took responsibility for the selection of appropriate tooling, standards, craft, durability, use, appropriateness of specific material samples, finish, delivery, and so on. In this context, it was understood that the architectural drawing as an instruction to make was highly constrained and limited, and that its primary focus was to define and secure the required outcome while allowing essential room for negotiation on how this was achieved. For the architectural design to be made, other drawings, such as shop drawings, were required as a rehearsal to making.

The nature of this exchange has been significantly altered by CAD/CAM, the fusion of drawing and manufacturing technologies that plug design information with the production equipment that makes what is described. Despite the many advanced levels of capability, this technology provides, its potential to release design constraint, open new frontiers, and extrapolate results not previously achievable has the potential to bypass many of the essential transactions between design and making that are incorporated in the exchange between either field of expertise. Thus not only has the architectural drawing altered its role as a carrier of design information, so too has the architectural model, the prototype and the speculative construct. The neat divisions that once commissioned, sequenced and qualified these key productions are converging, and the degree of cross-fertilisation between each mode of representation provided by digital tooling has generated a turbulent network of information flux.

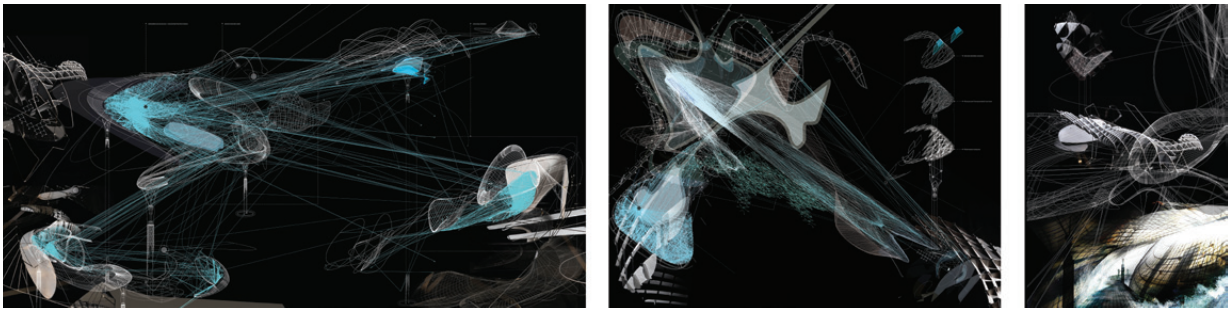

Fig 5.3.7 Spaces of Uncertainty – The Augmented Instrumentalist by Emma Kate Matthews (Bartlett School of Architecture MArch Unit 23, 2010-11). Composite model, acoustic simulation, and sound perspective of a small listening chamber for a proposed performance space on the Venice Moses Barrier. Design as a hybrid of digital representation, physical representation, manufacturing data, sound clips and environmental simulation. Materials: Steel, concrete, air.

The transposition of the performance of physical materials into a computational realm that subsequently decants what is explored back into a physical realm is a sequence of challenging translations. In the first instance it seeks to identify a direct relationship between the performance of digital and physical matter, and secondly it seeks to interpret highly complex, dynamic and living systems as a template for form generation. Quite apart from the inevitable selectivity involved, such an approach has the potential to reduce architectural production to a systematic selection exercise devoid of the immeasurable and immaterial qualities that make it more than the sum of its parts[xv]. It is the manner in which design information allows for indeterminacy and anticipates the possibility of how it can be made that make it work in the form of a built artefact. The skill in describing architecture before it is built is to make design information that anticipates, rather than dictates, how it is translated through time, site, materials, fabrication processes, assembly and use, and to understand the difference between the first prototype and the last.

One of the potential problems facing the age of digital fabrication is its heightened reliance upon data made by experts with a lot of experience in representation, geometry, form, and the illustration of materials, but less with experience in how things are made or perform. Unless the designer is located in the place of production and is at least a witness to on site decisions on issues such as tool paths, machine rates, material orientation, and makeability, the integrity of their information is a risk. And without such critical links, the built artefact is at risk of becoming no more than a physical render of a projected image where the exploration of its performance as a construct ceased at the point of simulation. With the exception of highly simplistic or linear tasks such as mono material 2D cutting or 3D printing, the jaded phrase 'file to factory' is a overly simplified term. A more accurate and helpful term to describe the communication of data between designer and manufacturer might be 'file through factory'. The key change conveys more clearly how the journey is not entirely one way, nor does it cease to evolve at the moment it is transferred from the former to the latter[xvi]. This argument has been further developed as an idea of persistent modelling by Phil Ayres at CITA[xvii].

Fig 5.3.8 Digital Material from the Persistent Model Project by Phil Ayres (2010).

The Birth of the Protoarchitect

Constraints of any kind have long provoked designers both positively and negatively, but as the means to describe design escalates and expands, and the imagination of form, language and complexity is stretched, the question of what conceptual strategies inform the making of a design has become increasingly ambiguous. Key to ensuring that design concepts acknowledge manufacturing constraints is the need to remain critically aware of the difference as well as the similarity between drawn and made things, and how both are produced. Digital manufacturing processes have nevertheless injected a lot more freedom in the domain of the designer, and ideas that might have remained as an experimental esquisse in a previous age are being manifested in physical form to levels of fabrication completeness previously in reserved for the finished article[xviii]. Such early resolution presents the work in a category beyond conventional notions of the prototype, but outside conventional notions of building. They are, I would argue, protoarchitectures of a particular kind; constructs that seek to test, validate, or exhibit speculative design propositions that have emerged through digital investigation of the visual and theoretical; as well as the technical (for example structural performance) or practical (for example workmanship). Such protoarchitectures provide a form of translated architectural evidence between the digital to the material, and as a consequence, exist as a form of proof of concept for research and design questions that lie beyond the artefact on view.

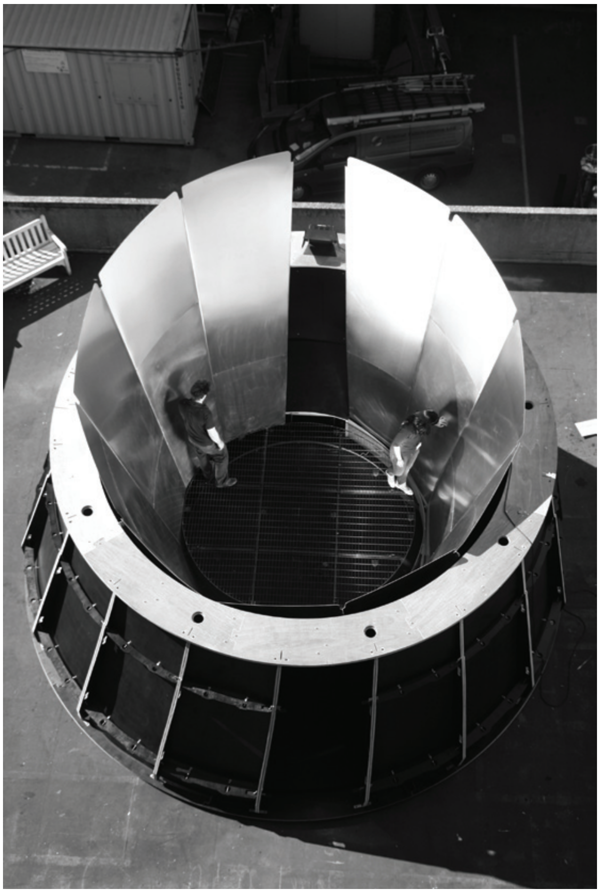

Fig 5.3.9 Hear, Here by Ric Lipson (Bartlett School of Architecture MArch Unit 23, 2007-09). A digitally prefabricated protoarchitecture that tests acoustic properties of a large-scale listening ear. Materials: Plywood, glue, paint.

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These steps are further enriched by the resurgence of 1:1 built artefacts being produced at an increasing number of leading architectural research centres and schools of architecture around the world. The past decade has witnessed an incremental surge of investment in digital fabrication equipment by these organisations; including in some cases the commission of new prototyping laboratories or new forms of shared and expanded facilities with other parallel disciplines, such as civil engineering or computer science. Some have been additionally facilitated by establishing new facilities upon existing traditional workshops, where the experience and inventories of analogue conventions are informing hybrid disciplines, cultures and practices. In parallel to the development and analysis of design information in simulated environments, such fabrication environments are refuelling the visual and visionary exploration of experimental architecture through the essential gains of self production. Central to the significance of this resurgence are two ingredients, firstly co-production (that is the making of protoarchitecture by either by designers in collaboration with technical colleagues, or multi-disciplinary staff who operate in both realms), and secondly the location of design practice within the place of production[xix]. With both components in place such actions and facilities have the capacity to respond to clear requirement for new hybrid disciplines within the construction industry across design, fabrication, computation, and project management. Such new roles will also lead to strengthening the new relationships that are emerging between academia, practice and industry, triggered by the same shifts in technology.

Fig 5.3.10 Manufacturing Protoarchitecture 2: The fully assembled '55/02' shelter at the factory of Stahlbogen GmbH in Blankenburg, prior to dismantling, finishing and delivery to site. Material: Steel.

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For the Protoarchitect set within this context, the as-built speculation provides critical feedback and essential verification unattainable in representation alone. Evidence obtained on how the work operates as a feasible and conceptual construct is derived by cross-referencing physical and digital tectonics, and by measuring how closely the built work resembles both the intent and embedded information of its digital master. Difference between both realms is a measure of its transformation through production, where the cause may not always be clear. This is of particular significance when specific claims are made for the status of the built work in relation to methodology of representation, technique, or associated generative rules that are transferred by its digital master. In this context, if an evident difference between the digital and the physical is not recognised, the resulting construct can only be regarded as a reality of a very exclusive kind; a beta-reality that is stage managed to demonstrate theoretical challenges in design, but not in manufacture, use, occupation or context. Where it is implied in particular that materials are synthesised as physical and digital matter[xx], one could assume that the palette of architectural materials selected for the physical construct should be capable of matching the behaviour of its avatar and visa versa. With the many challenges such an approach presents, this paper will now looks at a number of recent projects that cross the digital and analogue threshold where the difference between drawing and making is a defining principle of the work explored.

De-Fabricating 55/02

Adopting a built work as a test bed for these ideas, the 55/02 shelter in Kielder by sixteen*(makers) and Stahlbogen GmbH, was captured in 3D LIDAR one year post completion. As previous texts record[xxi], the shelter was designed as an oscillation of design decisions made in drawn and fabricated format at Stahlbogen's factory in Blankenburg. Although substantially digitally fabricated, the as built shelter carried many decisions that were made on the shop floor without being recorded on the digital design file. Some of these decisions involved component removal, others component augmentation or adjustment, where judgement varied between the practical and the visual, and also the work's identity. Key to understanding why such changes relate to the points above, is that all were made by the co-authors of the digital design file, who were also co-makers of the work, and they were decisions solely informed by the built work as it evolved, not decisions dictated by the drawing that preceded it.

As previous texts also record[xxii], this practice was adopted from the very beginning of the shelter's fabrication, notably on decisions surrounding the number, proximity and geometry of folds in the shelter's sheet steel skin. Had the facility of scanning been available at these stages, rather than post completion, many further decisions might have been effected. In the first instance, availability of 3D scan data for the chosen site rather than the GIS mapping (which was supplied) would most certainly have influenced primary design decisions such as site configuration, proximity to existing trees, footings layout, and more specific referencing to immediate context. Yet the availability of the technology soon after completion still offered scope to extract lost, hidden or new information, and to gain a deeper understanding on the utilisation of scanning technology as a design tool. For detailed description of LIDAR technology, how it functions, and is controlled, see Vosselman, et al (2009), or Bryan, et al (2009).[xxiii] For additional insight into the role of representation in developing 55/02 see Sheil 2012.[xxiv]

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The scans that were subsequently captured and processed by ScanLAB Projects[xxv] were developed through the following illustrated steps. Through each step, this paper will conclude by examining the most significant consequences for design and fabrication strategies provided by the information acquired, and speculate on implications or revisions that might be adopted in future design or fabrication strategies now that technology is readily available. In the first instance, developments on how the data has been analyzed and visualized stem from a single visit to site in 2010. Similar to the manner in which LIDAR technology is deployed in forensic work,[xxvi] capturing was fully executed without clear expectations on what the data would be used for, or indeed what it would reveal. In this regard, capturing is a pure exercise in the comprehensive recording of high definition geomatic data that is tied into accurate positional coordinates, the greater the saturation of information the greater the scope for later analysis. To following steps illustrate the exercise, which was carried out by ScanLAB Projects, who also advised on the key insights described.

Fig 5.3.11 Data Acquisition

001 Data Acquisition [Fig. 11]

The image shows the placement of reference geometry and markers within the scene. Markers were placed to be visible from as many scan locations as possible, and 6-7 markers were visible from any singular capture point to provide redundancy and cross checking within the reference network. In future, such markers could be embedded within the built fabric as discrete permanent tags, and thus behave as design life registers as the work is made, transported, assembled, installed and used. Positioning of such built-in tags may be reverse calculated to optimize later capture, thereby potentially easing the task of attaching applied reference marks on site.

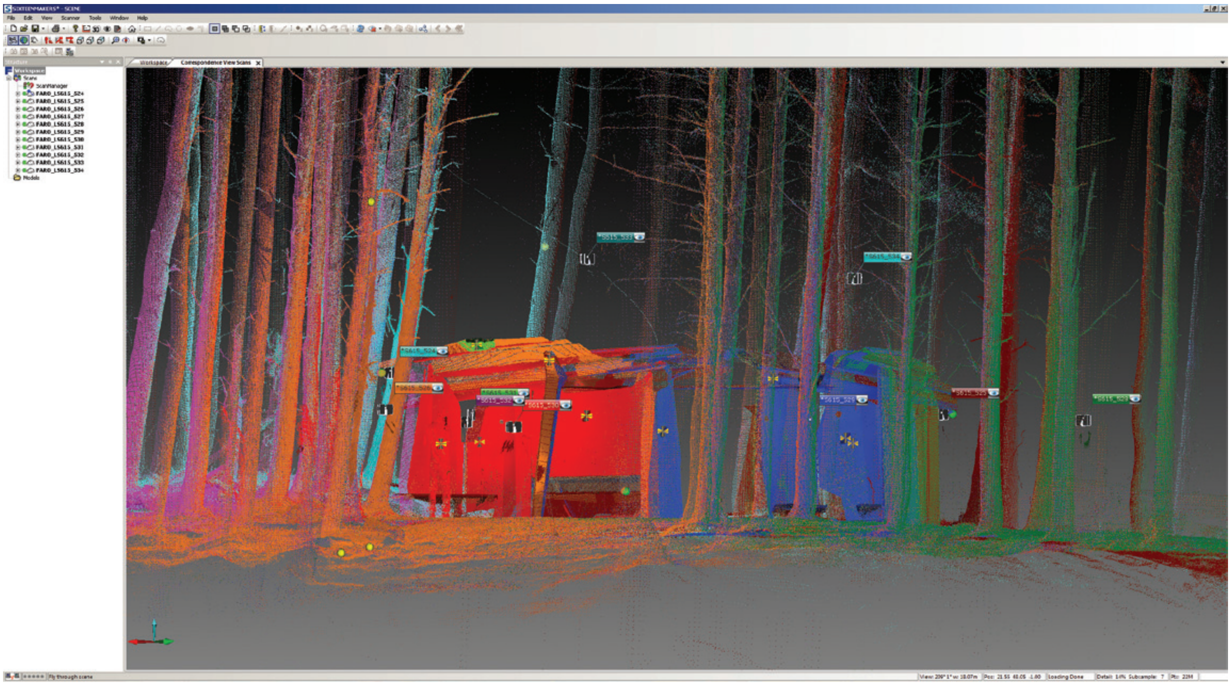

Fig 5.3.12. Post Production of Data

002 Post Production of Data [Fig. 12]

Scan data, including imported RGB values for every point in the cloud, is then passed through conversion software to produce a series of discrete point cloud models that are subsequently stitched together to produce a single cluster by snapping reference geometries. External geo-localisation of the data then places the cluster within a global context and a digital clone of the built work is generated. At this point the model has exportable value as a surveyed, visualization and interrogative tool in both 3D & 2D as animated or still imagery, or vectorised data. The Digital clone has clear value as an accurate record of the built work, but also as the data is rich in definition, it introduces value to the clone as a visually explorable and spatial record of the construct. In this regard, such data and its various visualization exports have currency as a rich 3D archive and verification tool, allowing later changes or removals to be compared against the 'original' built work. Examples of such applications are present in the museums and collections industry where the stable conservation of objects as well as spatial organization has particular relevance.

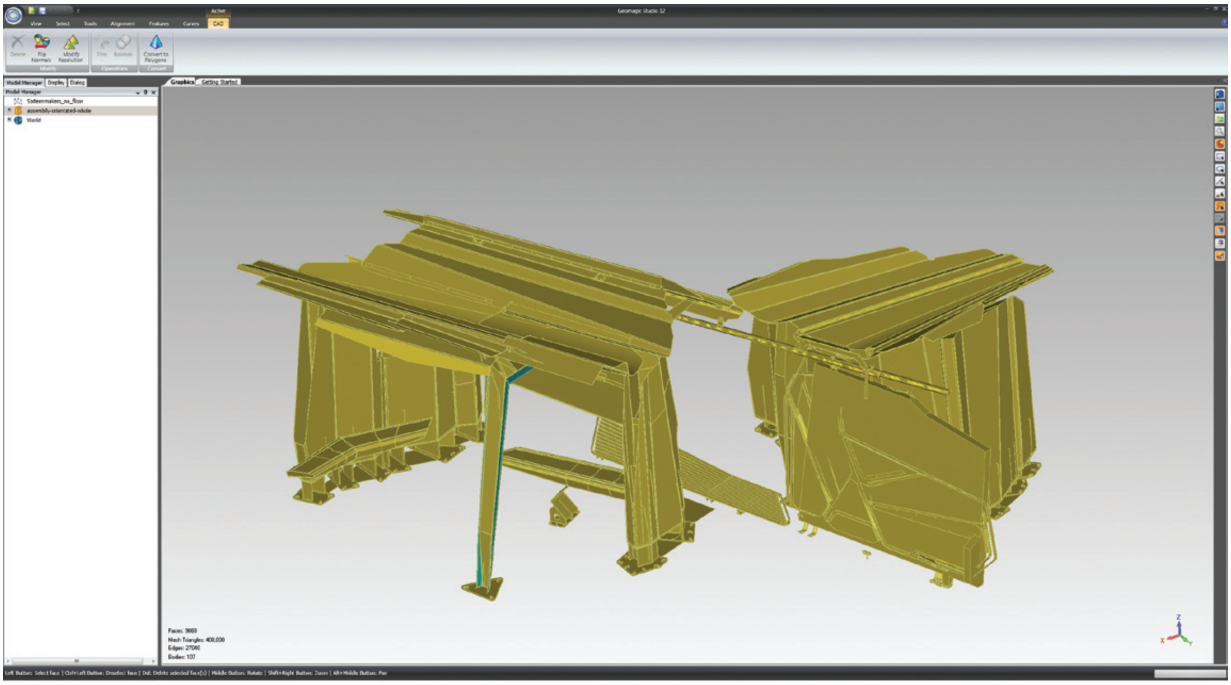

Fig 5.313 Import Digital Fabrication Model

003 Import Digital Fabrication Model [Fig. 13]

Although designed and made for amongst other purposes as a critique of design and manufacturing integration, the making of 55/02 reflects many of the challenging issues facing the construction industry on information flow and verification, albeit on a small scale. Whereas for 55/02 such bureaucratic hurdles were turned into a creative advantage for its hybrid and resident designer/makers, the industry at large faces a continuous challenge in grasping the multitude of unrecorded changes or amendments that are common to complex projects. Underpinning this cycle of continual verification of the 'as-built' back to the 'as-designed' is the stringent requirement to build the design that was agreed with planning and building control authorities prior to construction. Cross referral of as-built data as captured through 3D scanning to BIM data clearly offers an option on whether to concede or adjust these constraints. The next step in this sequence therefore is to import the final CAD model and 3D point cloud model into an environment where both may be superimposed.

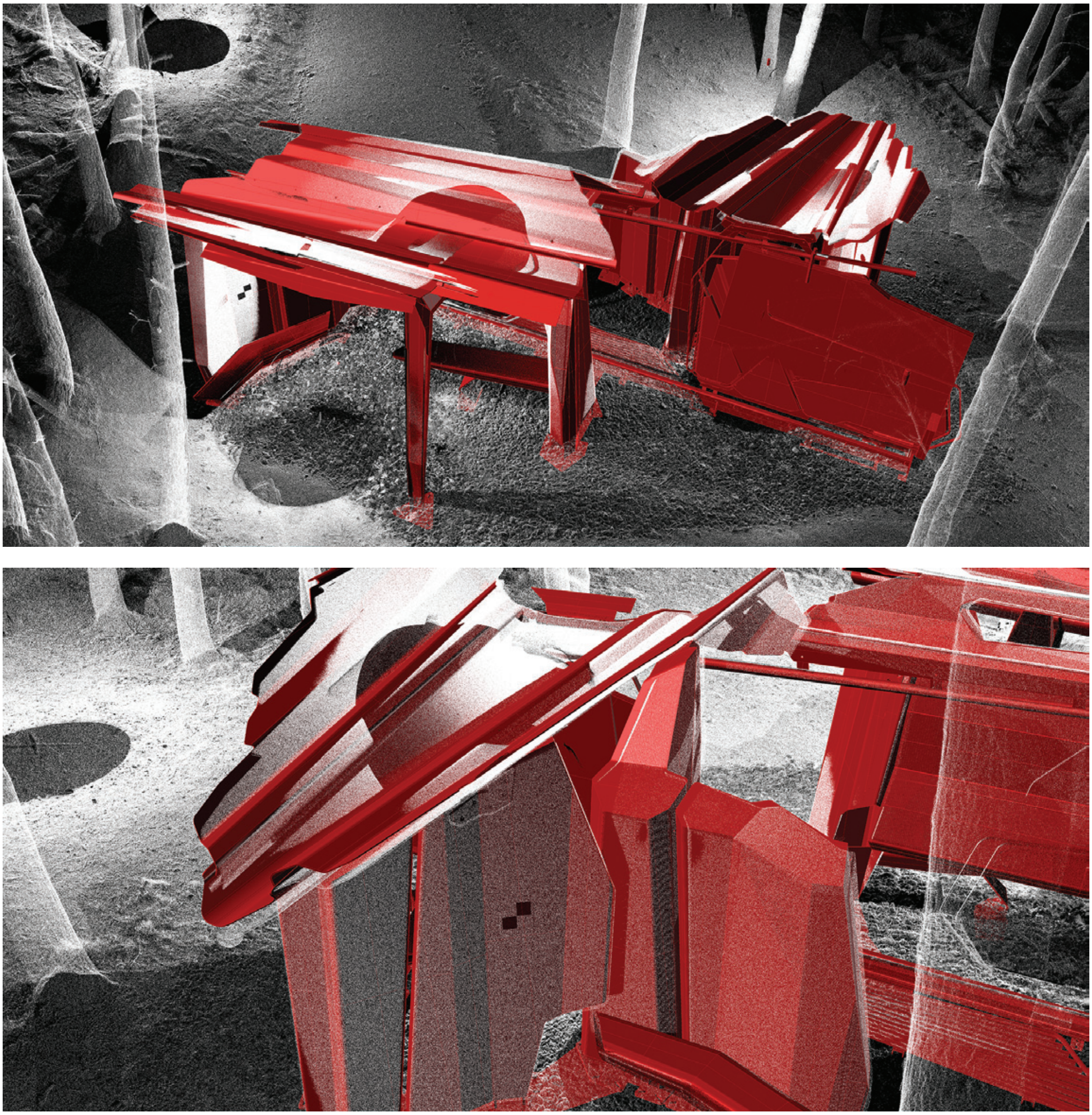

Fig 5.3.14-15 Alignment of Data

004 -005 Alignment of Data [Fig. 14 – 15]

This set of images show CAD data and Scan data aligned to each other where best fit algorithms refine the position of the whole assembly based on sub-sampling the data sets. Where 55/02's vermilion colour shows at full strength, the surfaces of both models are aligned. Ghosted areas highlight noncritical misalignment in some of the tank areas and roof elements, either component by component, or chunk by chunk. As a purely speculative exercise, none of these 'faults' have any significance in the performance, functionality or quality of the shelter, and an exact fit was never set as a requirement in the first place, however the data clearly has value in establishing the presence of difference between the digital model and the final assembly. Clearly additional observations could have been recorded had the shelter been scanned and verified against the digital model as it was first fully assembled in the factory. In this case, it would therefore have been possible to attribute where differences originated in journeys between design data, prototyping,

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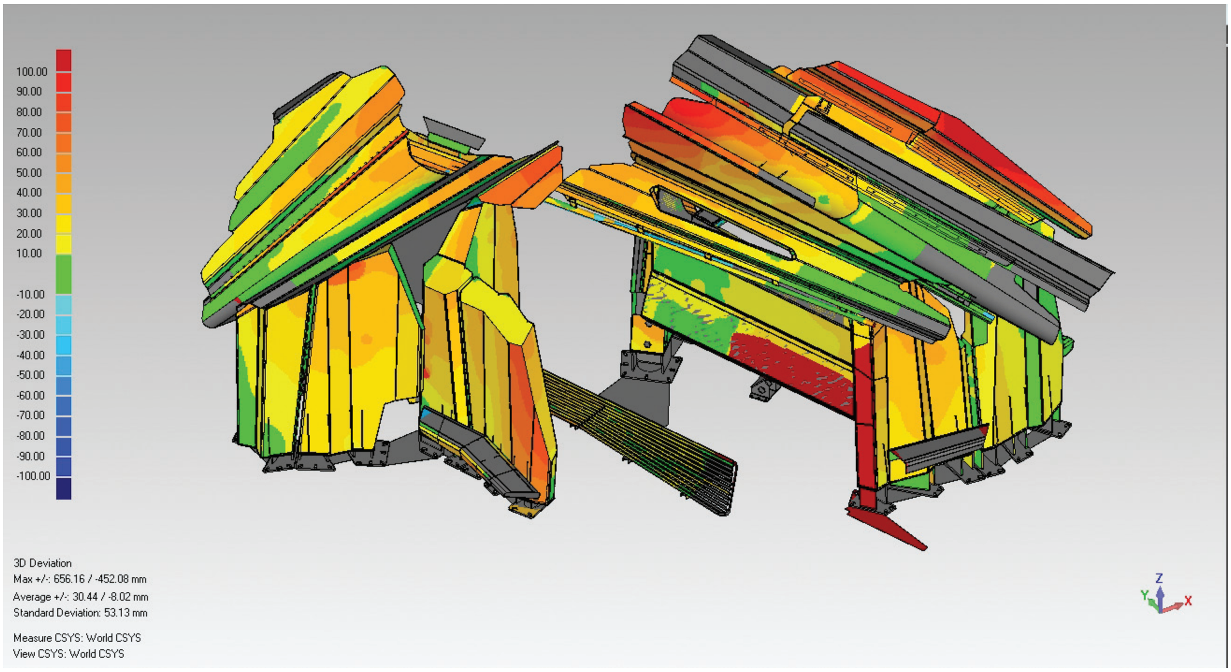
fabrication, factory assembly, transport and site assembly. In the construction industry, we are not fully accustomed to the protocols of precision manufacturing, where it is common practice to tag components with a host of information, including the identity of the fitter (e.g. Rolls Royce engine assemblies). However, mapping of 3D scan data upon BIM modelling is beginning to roll out in the construction industry,[xxvii] and will soon be a regular exercise in updating design files against verified 'as built' data. There are of course at least two ways this asset may be utilised. One, it may focus entirely on the notion that difference = fault, and fault = claim. Alternatively, it may offer a complex and cumbersome industry with the tools to accommodate design decisions through the production of the work. This route would of course reach all the way back to concept design and subsequent immediate stages where a speculative proposition is locked into an expected final delivery. To date parametric design models have offered considerable flexibility in allowing for mass customisation or precision manufacturing prior to the point of production, and to some extent during production. However, progressive feedback from LIDAR data upon design and production modelling now offers greater capability to absorb difference as a regular rather than irregular occurrence.



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3D Deviation
Max +/-: 656.16 / -452.08 mm
Average +/-: 30.44 / -8.02 mm
Standard Deviation: 53.13 mm

Measure CSYS: World CSYS
View CSYS: World CSYS
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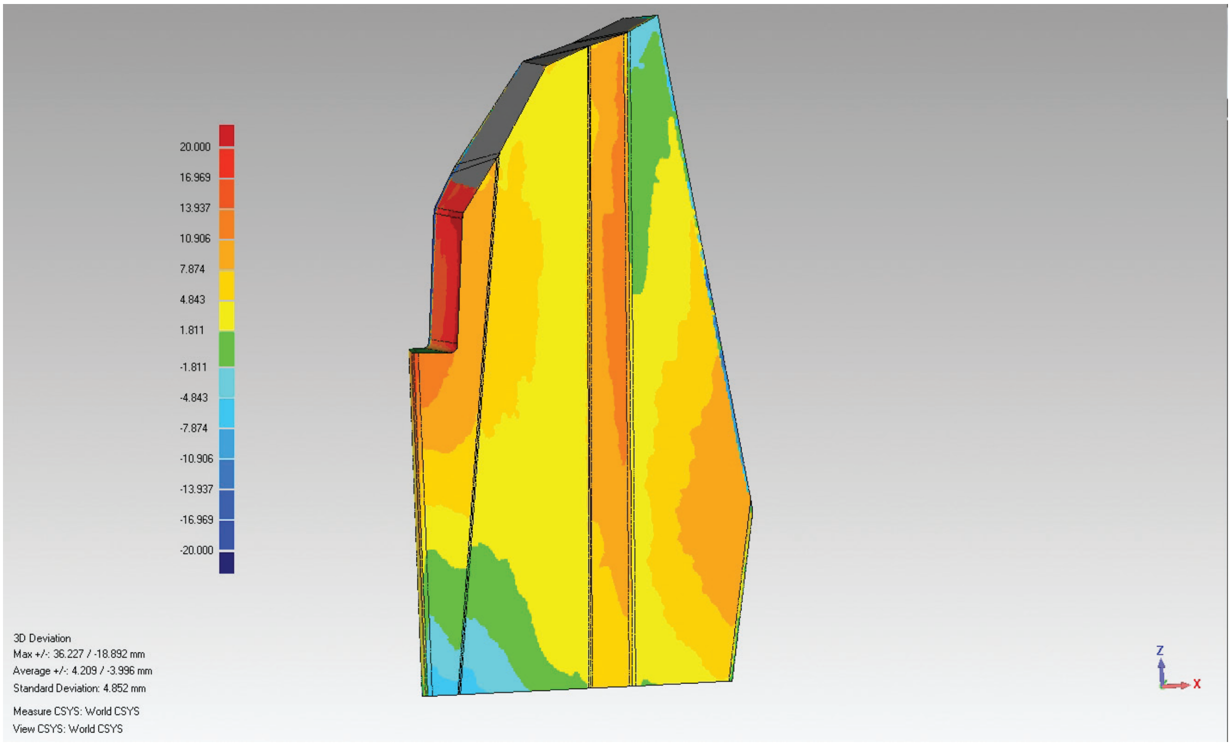
Fig 5.3.16. Deviation of Assembly

006 Deviation of Assembly [Fig. 16]

This slide illustrates a transposition of deviation calculations shown upon the CAD model alone. It more clearly highlights any areas of conflict or disparity. In this instance the spectrum spans from red to grey, signifying elements of 'perfect match' to those of 'total absence'. In the case of the latter, components shown in grey were either taken out or substantially reconfigured between the saving of the final CAD model and the assembly of the final construct. Referring to earlier comments above on the embedding of registration marks as a 'built in' array, equally such marks may be deployed to facilitate calibration and alignment of construct assembly, and furthermore, may be associated with new technologies in material marking.[xxviii]



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3D Deviation
Max +/-: 36.227 / -18.892 mm
Average +/-: 4.209 / -3.996 mm
Standard Deviation: 4.852 mm

Measure CSYS: World CSYS
View CSYS: World CSYS
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Fig 5.3.17 Deviation of Component

007 Deviation of Component [Fig. 17]

The final step in this sequence illustrates alignment analysis for individual components. Again, in this instance ‘errors’ are non-critical, but the information offers feedback to the manufacturer and designer in much the same way that a prototype should. It provides heretofore-unavailable data that refines knowledge on the scope of tolerances in the production process.

Fig 5.3.18 Manufacturing Protoarchitecture 3: Setting out jigs lie on site prior to commencement of final assembly of the 55/02 shelter. Such physical tools are entirely derived from the digital file that generates the architectural assembly, and thus act as ‘difference’ verifiers.[xxix]

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Conclusion

Zero tolerance in digital manufacture is both theoretically and practically achievable, however the construction industry must negotiate its expectations on how valuable such accuracy is. Rather than seek finite calibration between the drawn and the made, such tooling as described above aught to be used for continuous renegotiation on their differences. If for no other reason, acknowledging the gap between both disciplines respects the immeasurable and vital contribution of the craftsman. This paper therefore concludes that the status of the dynamic and adaptable digital design model in relation to the physical results that are built from it, is one of adaptability and facilitation, and conditions that must remain open to the design opportunities that reside in manufacture and production. It concludes that the status of the resulting physical assembly is an architectural prototype, perhaps better identified as protoarchitecture, and the difference between the drawn and the made is a rich territory for collaborative and creative engagement.

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xxv ScanLAB Projects is run by Matthew Shaw and William Trossell, both of whom have backgrounds in architecture and fabrication, http://www.scanLABprojects.co.uk/

xxvi http://www.faroasia.com/products/laser-scanner/sea/forensics-and-accident-scenes.html

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xxviii See Signature Materials Project at the Institute of Materials, Minerals and Mining.

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