From Making the Bespoke to Manufacturing the Bespoke

Bob Sheil

Two co-authored design and make projects are examined here: a chair from 1995 and a small building from 2009. Both projects fit within the author's definition of protoarchitecture,[1] a genre of experimental design that challenges the methods and role of the designer particularly in relation to how and why the work is made. Secondly, and central to the arguments presented here, both projects identify a key transition in the definition of the bespoke that spans a period of significant change in design and fabrication methodologies and tooling. In analysing these projects together for the first time, it will be argued that many of the strategies in designing and making a bespoke piece of furniture that went beyond the realm of the conventional drawing, and were exclusively developed by hand, are now adoptable through digital design and fabrication technologies. It will also be suggested that these new facilities must be seen as essentially hybrid disciplines that are practised adjacent to the point of production. What is also being explored here is an underlying idea that integrated digital design and fabrication technologies have instigated a renewed relationship between the bespoke and the prototype, and that a pursuit to explore either presents opportunities for the other. What is new in this relationship is that these pursuits can be exercised mutually and synthetically, and for those who wish to take advantage of this potential, there are significant implications for the way they might practise and learn.[2]

At a glance these projects might appear considerably more than 14 years apart. Both were made by the same designers, both explored similar questions on the relationship between design and production, and both involved familiar materials. The former was handmade, and the latter was predominantly made using numeric controlled machinery fed by design data embedded within a three-dimensional digital file. Underlying the journey between both projects is the transformation of the purpose and property of the drawing as an instruction to make, and, inseparable from this idea, the role of the drawing maker. In the first example, without the preview or guidance of a scaled design drawing, the made artefact, in this case a chair, evolved as decisions on form, structure, dimension, materiality and technique were synchronised into the act of making. The artefact was at various stages a mock-up, a template and a completed construct. The need for the design drawing as an instruction for others to make was eliminated by the interdisciplinary authors, who acted as designers and makers, and who invested their tacit skills as drawing makers directly in the medium their drawings would have proposed. Likewise, the gap between the drawing and the artefact, always

open to external error or internal naivety, was also erased, and the time that would have been expended on drawing was invested in the act of design through making.

Fourteen years later, through the mainstream adoption of CAD/CAM, the drawing as an instruction to make had undergone a significant evolution and this gap no longer existed. Stripped of the intermediary phase of interrogation and evaluation by appointed makers, digital design drawings were instructing digital fabrication machinery to make and the embedded instruction of the drawing, whether flawless or otherwise, was indeed made. The digital drawing became both the design and the making tool, and the skills of the designer as a maker were implicitly and irreversibly linked to the performance of the works they produced. In this regard the study of the second project, a small forest shelter, explores how the role and operations of the designer were relocated to the place of production, and the adaptive capacities of CAD/CAM as an interoperable set of representational and fabrication tools were deployed across a range of simultaneous frequencies, from virtual manufacture to preview of assembly. Fabrication drawings in this sense are not defined by boundaries of representation, and the scope for tactile experimentation that was sought in the freehand making of a bespoke chair was in many ways revisited on the shelter. As a result, this project represents one of the earliest examples of collaboration in digital fabrication and design in the UK.[3]

The chapter concludes by looking forward through the medium of lidar scanning, a process where high-resolution three-dimensional point cloud surveys may be extracted from built works providing an accurate record of the as-built design, and a 3D model from which it can be interrogated and perhaps at some future point, augmented. In this instance, and by virtue of the way the shelter was designed and made, these scans represent the final drawings of the project and could only exist because of its presence as a built artefact.[4] Visually and informatively fascinating as they are, they provide a powerful means to examine and understand a habitual consequence of making architecture that persists in the digital age, the difference between the design that is drawn and the design that is made. In summary, From Making the Bespoke to Manufacturing the Bespoke, identifies an alternative role for professional designers, one that utilises and transfers their highly developed and adaptable skills in the visual propositioning of space and form, and supplements these skills with the tacit experiences of making and assembly. This new role defines the designer as someone who is also a maker, and one that is directly engaged within the arena of production.

Making the Bespoke

The chair on page 17 was sixteen*(makers)'[5] first commission and was made for a management consultant in 1995 who noticed the collaborative's experimental approach to design and making on projects 'Plot 22' and 'Dartmoor'.[6] The practice was established while Callicott and Sheil were students at The Bartlett School of Architecture UCL. Both were midway through their undergraduate studies when Peter Cook was appointed as the school's Professor of Architecture in 1990, and under his charismatic stewardship the school became a vivacious and inventive forum of experimental ideas. Traffic through the school was highly notable and accelerated, with guest speakers including Enric Miralles as the Igualada

Cemetery was on site in Barcelona; Daniel Libeskind as the Jewish Museum (Berlin) was being designed; Coop Himmelb(l)au, as the Groninger Museum extension was under way; Brian Eno, as he started the Long Now Foundation; Bernard Tschumi when *The Manhattan Transcripts* had just been published; Lebbeus Woods on the publication of his articles on war and architecture in *A+U*; and the first appearance in London of young guns such as Greg Lynn and Neil Denari. The school's rapid transformation provoked a surge of ambition among students to challenge expected career norms and set about establishing the terms of their own practice before graduation. Somewhat against the grain, and cautious of becoming overly enthused by neo techno-narrative, the appellation sixteen*(makers) was chosen by the collaborative in order to become closer to the physical production of architecture, and thereby more actively involved as designers in its making. Deeply provoked by the quality of debate surrounding us, we were also critically influenced by the works, writings, drawings and methods of individuals such as Pye,[7] Potter,[8] Salter, Prouvé, Chareau and Pichler, under the watchful eye of our former first year tutor, the late Steven Groák.

The fee for the chair was a 50 per cent barter on our client's second-hand Macintosh PowerBook 100.[9] One handmade chair in part exchange for a laptop, it seemed the analogue and the digital were destined to be present in the history of our practice from the start. Our client was well travelled, an avid reader, a cinema-goer, a music collector, a squash player, rock climber, mountain biker and a keen chef. At the time of the commission he was practising the Alexander technique, a method of focusing and developing controlled body posture and balance habitually and intuitively. The commission was envisaged as a means to address this practice routinely, and to design an everyday point of support for reading, typing, dining and relaxing. Although widespread and particularly domestic public access to the Internet would remain two years away in the UK, operating a portable or desktop computer would be a prime occupation of the sitter. The particular movements and strains upon forearm, eye, head, neck and shoulders in relation to gizmos of the day, such as the centrally placed trackball, a mouse, a 23-centimetre (9-inch) 600 x 400 pixel resolution backlit LCD display with compact keyboard, were absorbed as essential but not every design criteria.

As a first commission for an experimental approach towards practice, workable terms and conditions were required to allow both client and designers room to explore, develop, reflect, revise and move forward. As students, sixteen*(makers) had developed a series of speculative constructs ('Plot 22' 1995 and 'Dartmoor' 1995) where few if any drawings were produced prior to fabrication and the works were developed on site and/or in the workshop through a process of trial and error as evolving physical representations. Decisions were made on the basis of verbal conversation between the designer/makers (two), iterative tests, challenges set by one another in a spiralling design combat, the feedback of the available material, and process being explored. In many ways the constructs were drawings, only drawings without paper.[10] Our purpose as fledglings was to operate on the other side of *the drawing as information to make*, and to become proficient in the tacit skills our tentative documents relied on. Subsequently, conversing design with our client would not rely on a flat visual forecast but would be based on its evolution and progression as a physical artefact through a series of staged 'fittings'.

left: Sixteen*(makers)' first commission, a bespoke chair made at Sunbury Workshops, Shoreditch, London EC1, 1995. Materials: oak, leather, 35 mm (1.38 in.) mild steel. Photograph: Bob Sheil. © sixteen*(makers).

below: Sixteen*(makers) first and second commissions, the bespoke chair seen against a large table both made at Sunbury Workshops, Shoreditch, London EC1, 1995. Photograph: Bob Sheil. © sixteen*(makers).

Somewhat in the traditions of Savile Row,[11] the client was surveyed, his frame and posture measured and noted, and other chairs and stools were commandeered as adaptable props. They were made higher, wider, more vertical, softer or cooler. Likes and dislikes of the function and form of chairs were identified and key objectives were agreed and marked on jigs, rulers, floors and walls. Issues of comfort and restraint were explored in relation to the chair's purpose and role, and environments where the chair would likely be located were noted for matters such as deflection and vibration. Materials from which to make the chair were also explored, not only for performance and visual preference, but also for their capacity to carry other narratives within the object. Lying about the studio in Shoreditch at the time were a number of speculative test pieces in mild steel, hardwood, acrylic, glass and rope, forming a haphazard library of experiments and assemblages in relatively simple techniques. Among these was an ongoing trait to customise materials, particularly steel, from their origin as extruded standard profiles, into ends, junctions, and limbs through abrasion and forging. Some of these traits had a highly graphic as well as tactile quality, portraying not dissimilar looks to those we once pursued in ink. However, it was their tangible properties, such as weight, surface quality, conductivity, resonance and reflectivity that were the predominant investigation and value.

From this catalogue of references, the design's first move was established in the form of a foot adapted from a short section of heavy rolled tee bar in mild steel. To the central web of the tee bar, a flat bar the same thickness and width as the central web was bevelled and arc welded. The joint was ground, filed and sanded until seamless and the shiny surface reheated with an oxyacetylene torch until black again. Overgrinding was always something to be mindful of, for as soon as the weld surface dipped below the adjoining sections the only course of recovery was to break the weld and start again. The inner and outer radii of the rolled tee bar, and the feathering of its tapered flanges, set a geometric tone for key positions where the chair's limbs would end or meet others. The length of this first element, about 1 metre (3.2 feet), far exceeded what was required, and so it remained as the key datum from which to strike the seat's horizontal axis until the remaining substructure of the chair's legs and spine was complete. Both front legs also stemmed from the same flat bar, but here they were jointed to a parallel square section of the same thickness. The heavier elements connected vertically to form the seat's substructure, while of the lighter, one swerved away on the left-hand side to receive a rigid arm, and the other tapered to finish short of a cantilevered right-hand arm with some give.

When our client returned for his 'skeleton-baste'[12] fitting, the chair's key dimensions and alignments were tested and adjusted. Movements and postures were simulated and marks were made on the chair's steel carcass in chalk. Rough boards were fashioned as jigs to form seats, and various blocks and wedges were positioned to judge the thickening of various elements such as arms and the spine. The torch was reignited and geometries of the frame adjusted before the client departed. As the chair passed through two more fittings, a small pile of reclaimed tongued and grooved oak strip flooring was rescued to form the seat and subsequently jointed to form two panels tied to the subframe with leather thong. The rigid left arm of the chair was filled out with a further section of

jointed and reclaimed oak and the flexible right arm was wrapped in leather from a local upholstery merchant. Our studio was located at the western end of Sunbury Workshops in London's historical quarter of Shoreditch. In the two units beneath us were a shopfitter and an octogenarian wood turner. Next door below were silversmiths working above a frame gilder, and further along a prestigious upholsterer, and a team of glass-blowers. Although not formally organised, the range of skills being practised was highly influential and complementary to our aims as architectural graduates. We could witness at close proximity the vibrancy and vulnerability of an urban micro industry, and realise how little our education did to make us aware of how direct engagement with its potential could inform our design strategies.

Several months after completion, the chair was returned to the workshop as a visual and dimensional reference for the design and fabrication of a large adjoining table in steel and oak. The brief for the table was that it would be used as a working surface, a place to read and pile books, and in particular become a table to accompany this specific chair. The design language and materiality that evolved in the making of the chair would be referenced, and the table's height, width and length would be tied into the tailored dimensions of its predecessor, with the sitter present as mock-ups were assembled and measured. The top was made from six reclaimed oak French railway carriage planks, 50 millimetres (2 inches) thick, 2400 millimetres (94 inches) long, with an existing lap joint in good condition. Joints were cleaned and the six boards were clamped and glued together before only the top surface, which weighed over 80 kilogrammes (176 pounds), was sanded reasonably flat. The table's ends were treated with alternate edges, one as a rounded and tapered oak fin, which became the table's 'leading edge', and the other in squared black steel. Each referred to the different arms of the chair, and established the design rules for the table's two distinct trestles in steel. Like the chair, the table was designed and made without the production of any prior design drawings; key references were embedded in tailored fittings and a series of tacit negotiations between structure, materiality, behaviour and visual judgement. On the basis of acquired tacit knowledge, particularly in works of this scale, the time we would have spent in the past on the act of drawing was instead invested in acts of making. Materials were worked upon directly, in some senses as though they were drawing surfaces. As the project of a fledgling experimental design practice, these acts of meticulous production informed many of the foundations of our attitude to repositioning the designer as maker; however, it was clear that in terms of a critical place in our chosen industry they resembled more the world of the 19th-century artisan than the contemporary professional.

Bridging the Gap

Resolving the bridge to this divide would take us back to our exchange fee for the chair and the presence of a new realm for workshop tooling, that of the digital. As an indication of how fast changes in related technologies took hold in this time, Nick Callicott's *Computer-Aided Manufacture in Architecture: The Pursuit of Novelty* (Architectural Press) was published just five years and numerous operating system and hardware upgrades

later. Sixteen*(makers)' subsequent portfolio increasingly addressed the evolving relationship between digital design and making through a series of speculative projects and publications including; 'Cut and Fold', 'STAC', and 'Blusher' (all 2000–01), *Design through Making* (2005)[13] and *Protoarchitecture* (2008).[14] In parallel, their work shifted further towards a directed stream of academic research into both digital and analogue practices, with Ayres and Leung embarking on related doctoral studies with particular focus on responsive systems, persistent modelling,[15] and environmental analyses. Greatly facilitating further opportunities for academic collaboration with industry, Callicott left UCL in 2005 to set up Stahlbogen GmbH in Blankenburg, Germany, with partner Kris Ehlert. At the time, sixteen*(makers) were establishing speculative proposals as architects in residence at Kielder Water and Forest Park Northumberland, on behalf of the Kielder Partnership. With an open brief, the appointment provided an extended period of speculative investigation on the difference between digital modelling (as the 'ideal') and physical installation (of the 'real'). On the basis of a series of built installations on remote sites, the work, which led to a solo exhibition at the Building Centre in 2007 entitled *Assembling Adaptations*, presented the potential for real-time monitoring of micro environmental change to drive the design of a bespoke dynamic architecture.[16] While this research remained ongoing and formed the core of both Ayres' and Leung's doctoral research, the practice was approached by the Forestry Commission to design a public shelter on a proposed perimeter walkway to the reservoir. The additional brief carried a set of performance requirements and budget that would restrict many of the immediate possibilities of the residency; however, it offered the first opportunity to collaborate with Stahlbogen GmbH from the outset of a new project, and a fresh set of investigations was embarked upon. The shelter, which was named 55/02, provides this chapter with the second of its reflections on the bespoke in our work.

Manufacturing the Bespoke

Completed in June 2009, the shelter is named after its coordinates: 55° 11.30 N, 02° 29.23 W, otherwise known as Cock Stoor, Lakeside Way, Kielder Water and Forest Park, Northumberland, UK. A general analysis, with background information on local context and project sequencing, is explored in an essay entitled 'A Manufactured Architecture in a Manufactured Landscape'.[17] Further additional essays by Ayres, Callicott, Sheil and Sharpe may be seen in a forthcoming project monograph.[18] Pertinent to the discussion here, the key issues that cross-refer in these papers include winning the commission on the basis of strategic information rather than an illustrated design visualisation, clearly positing an underlying intent to develop the built design on highly specific qualities of the final and 'real' site, and making it clear in the award of the commission that the built design would explicitly evolve in collaboration with Stahlbogen GmbH.

Qualities of the selected site that informed the primary aims of the work included the intersection of distant harvest lines, trenches, gouges and trails, and the atypical qualities of the site which overlooked the reservoir from a raised mound on the north shore. They also included orientation to prevailing weathers and sunlight, relationship to key views and

top: Pre-production design development. Early prototype of structural shell component for 55/02 in CNC-cut and CNC-folded plate steel, made at Stahlbogen's workshop at Blankenburg, Germany, 2009. This investigation had a seminal design influence on the project's final outcome. Photograph: Bob Sheil. © sixteen*(makers).

above: Production design development. Designer and maker Nick Callicott of sixteen*(makers) and Stahlbogen GmbH visually inspects 55/02 at near completion stage at Stahlbogen's workshop at Blankenburg, Germany, 2009. Despite the powerful array of tools available to the designer, there is nothing that can fully prepare the author for results at 1:1. Photograph: Bob Sheil. © sixteen*(makers).

The assembled construct. 55/02 installed on site at Cock Stoor, Kielder Water, and seen from above. The image shows a detail of the assembly of painted roof components. Photograph: Bob Sheil. © sixteen*(makers).

distances from other resting points, and the particular spatial qualities of the surrounding plantation of preserved Scots pine and their array of geometric intersections through the loose grid of straight and bare tree trunks, each between 5 and 15 degrees off plumb. These, and the rich matrix of adjacent layers and nodes of orientation, generated a dynamic field of variable spatial depth and quality of light, sound, temperature and enclosure for the design to acknowledge. Collaboration with Stahlbogen GmbH was initiated from the very outset of the commission, with the manufacturers in attendance and taking part in the site analysis and selection visit. In this respect, access and manoeuvrability of plant and personnel was also considered, and it was thereby possible to renegotiate the proposed route of the Lakeside Way and determine the position of a planned temporary road spur for the supply of materials to build the new pathway. At the conclusion of the site visit it was agreed that the shelter should have no obvious boundary between its material edges and the rich constellation of its environment, and that in response to its exposed position it should offer substantial shelter to the north, with a greater degree of openness to the south.

In recognition of non-negotiable budget constraints, a key early decision was to ensure that the design took account of Stahlbogen's existing tooling and expertise. A further agreed constraint was to limit the number of materials to a minimum, and through reading the array of initial proposals, each of which commonly suggested an enclosure of folded linear structures and surfaces, it was also agreed to explore how successfully these could be met by stretching Stahlbogen's established knowledge in sheet steel fabrication, while retaining a close control on cost. On this basis, the design progressed through simultaneous speculative exercises in drawing and making which flowed between the factory in Blankenburg and studios in London and Copenhagen.[19] Flowing from one workstation to the next were images, drawings and comments on 1:1 physical prototypes produced by Stahlbogen, spliced with sketches, handmade models, 3D drawings and 3D prints emerging in London and Copenhagen. The 2009 paper goes on to examine in detail the evolution of the project's 'tank'-like walls, the idea for which was led by a series of 1:1 test pieces at Stahlbogen, which not only distinguished much of the project's formal character, but also informed the development of speculative design drawings and models, and established the unconventional order of exchanging design information between the drawing makers and the manufacturer. As it goes on to describe, once primary decisions on how to approach the fabrication and design of the enclosing walls were established, an entirely fresh CAD model was constructed through which every resulting form was assessed for potential conflict with the dimensions and limitations of the equipment and processes that would produce them.

Production design of 55/02 evolved by constant shuffling between fabrication, drawing, animation and assembly. Once production information for the tank walls was fully developed, they were cut, folded, capped, welded and connected as a structural unit in a few days. Assembled in the factory in the same configuration they would finally be placed in on site, they became for a period models upon which to judge and test propositions for overhead roof elements. Strategies for these elements were visually developed upon in the CAD file, and cross-referred to both 1:20 physical design models

and the 1:1 partially built shelter of tank walls. In this sense, the design exercise became truly synthetic with making and the methodological strategies of the project's 1995 forerunner were resurfacing, albeit now equipped with considerably more adaptable and flexible design tools. Here, design decisions were being made and becoming available that would otherwise be excluded from the designer who might only have provided an initial set of drawings to be followed as instructions to make. In this instance, such information provided by the team was only being regarded as a prompt and a guide, and final decisions were formulated on how the design implied in those drawings might operate both visually and feasibly at 1:1 on the shop floor. Crucially, this critical analysis and subsequent decision was being taken by a designer with ownership over the design and advanced skills in production.

Subsequently, the design of each of the roof elements as built evolved substantially from initial design proposals as developed in model or CAD form. A number of factors played into this outcome including considerations of physical and visual weight, soffit qualities, complexity and physical geometry of surface in relation to vertical elements, and the feasibility of assembly, with very limited resources on site at Kielder.[20] In addition, and perhaps one of the most surprising points to make, is how the final iteration for the design of the roof elements was informed more by the visual language that was emerging from the preceding completed elements than that which was conveyed in initial drawings. This point can best be understood by comparing the somewhat stark quality of the project's production drawings and the more fluid quality of the built work's aesthetics. This is not to say that only through making was a fluid aesthetic found, but that the production drawings that were necessary to construct the work were not being judged in this way.

Such drawings were made as the necessary digital information to feed the digital manufacturing process. In a sense, they partially equate to traditional shop drawings where in the past makers would redraw the designer's drawings at 1:1, and through the act of drawing the makeability of the design was established. However, in this instance, with the maker inhabiting and continuing the role of the designer, production drawings were constructed in order to facilitate a desired outcome in making, and if in view or in print the subsequent drawings were deemed to be aesthetically odd or unappealing, this was ignored in the knowledge of the results they delivered. This aspect can be understood globally in plan and section, which is a form of information on the project typically requested by publishers. Through the conventions of reading such literal projections, these interrogations struggle to capture the central qualities of the built work. The graphics that are generated greatly overstate gentle folds as harsh creases, and the resultant complexity of overstated lines and geometries are all that the eye sees. Little of the subtlety that easily transmits from the formed and assembled materials is conveyed and it is very doubtful whether, were such drawings presented to the client in the first instance, the commission would have been awarded. By letting go of the design drawing as the primary instruction to make, and by reading such initial drawings solely as strategic intentions of spatial and material organisation, an otherwise unexplored architectural response is found in the place and process of production.

The post-production construct. Visualisation of 3D point cloud model constructed from a 3D terrestrial lidar scan carried out a year after the shelter was installed. The point cloud model can be mapped upon the original digital design file, revealing the difference between pre-production design information and the as-built construct. Scan by ScanLAB. Photograph: Bob Sheil. © sixteen*(makers).

A year to the month after 55/02 was assembled and installed on site, the building was captured as a 3D lidar scan using equipment on loan to UCL by the international instrument and measurement manufacturers FARO.[21] This technology has been developed for precision engineering and industrial applications over the last decade, but only in recent years, and coinciding with the evolution of point cloud modelling, has it entered the domain of the design and construction sector. With the potential to provide users with rapid and accurate feedback on existing structures in the form of exportable digital models, the capacity to exploit the resource of accurate and usable measured data is broad and deep. In this instance, it provided the authors of 55/02 with an asset from which to trace and record decisions that had not been developed through drawing. The scanned model may be overlaid on the CAD model and anomalies identified. In this instance such data would not be regarded as a fault but as a difference that was not documented. One can easily imagine, however, that a less positive conclusion might be drawn in other circumstances. As in a world of increasing regulation and accountability, design differences that are undocumented tend to be labelled as 'faults' or at the very least 'disputes'. Drawing, whether digital or analogue, is without doubt an essential process and tool in the production of architecture. Both the act and the product of drawing are also central in defining the role of the designer, but as I hope this exploration has conveyed, in an age when we are bypassing the translation of drawings by those with the tacit skills in how they are realised, we might wish to consider their bearing strength in this great task, and what we can do to ensure their best intentions are fulfilled.

Notes

1 See B Sheil, 'Protoarchitecture: Between the Analogue and the Digital', B Sheil (ed), *AD Protoarchitecture: Analogue and Digital Hybrids*, vol 78, no 4, John Wiley & Sons (London), 2008, pp 6–11.
2 See N Callicott, *Computer-Aided Manufacture in Architecture – The Pursuit of Novelty*, Architectural Press (Oxford), 2000.
3 See M Stacey, 'Folding into the Landscape', *Building Design*, 1880, 14 August 2009, pp 16–17. Illustrated article on the role of Stahlbogen in designing and building 55/02.
4 The scans and post-production imagery were carried out and prepared by ScanLAB Projects. To view an animation of the survey visit: http://scanlabprojects.squarespace.com/latest/sixteenmakers-5502.html
5 Sixteen*(makers) operate between practice and research, and between design and making. Established at The Bartlett School of Architecture in the mid-1990s, the group includes Phil Ayres, Nick Callicott, Chris Leung, Bob Sheil and Emmanuel Vercruysse. Throughout its life, members of the group have remained independently active in academia, practice and industry, as they have worked together on a project by project basis from respective bases in London, Paris, Copenhagen and Blankenburg. Callicott has since gone on to establish Stahlbogen GmbH, a subsidiary of Ehlert GmbH in the Harz region of Germany, while Ayres, Leung, Sheil and Vercruysse continue their ties with the Bartlett in design, research and teaching. The group now operates as an architectural consultancy at UCL. Further details may be found at www.sixteenmakers.com
6 S Groák, 'Board Games', a profile of sixteen*(makers) in N Spiller (ed), *AD Integrating Architecture*, vol 66, no 9/10, John Wiley & Sons (London), 1996, pp 48–51 and seven illustrations.
7 D Pye, *The Nature and Art and Workmanship*, Herbert (London), 1968, and *The Nature and Aesthetics of Design*, Herbert (London), 1978.
8 N Potter, *What is a Designer: Education and Practice*, Littlehampton Book Services (Littlehampton) 1969, and *Models and Constructs: Margin Notes to a Design Culture*, Hyphen (London), 1990.
9 The Macintosh PowerBook 100 was introduced on 21 October 1991.
10 See M Ramírez and T Papanikolas (eds), *Questioning the Line: Gego in Context*, The Museum of Fine Arts (Houston), 2003.
11 See B Sheil, Introduction to *Manufacturing the Bespoke*.
12 'Skeleton baste' is a term used in tailoring to describe the first and rough fitting of a bespoke suit. The second fitting is known as the 'forward', and the final as the 'finish bar finish'.
13 B Sheil (ed), *AD Design through Making*, vol 75, no 3, John Wiley & Sons (London), 2005.
14 B Sheil, 'Protoarchitecture: Between the Analogue and the Digital', *AD Protoarchitecture: Analogue and Digital Hybrids*.
15 See P Ayres (ed), *Persistent Modelling: Extending the Role of Architectural Representation*, Routledge (Oxford), due Spring 2012.
16 See B Sheil and C Leung, 'Kielder Probes – Bespoke Tools for an Indeterminate Design Process', in O Ataman (ed), *Smart Architecture*, ACADIA (Association for Computer Aided Design in Architecture), Savannah (Savannah College of Art and Design, Georgia, USA), pp 254–9.
17 R Sheil, 'A Manufactured Architecture in a Manufactured Landscape', in *arq* (*Architectural Research Quarterly*), vol 13, issues 3/4, 2009, pp 200–20, Cambridge University Press (Cambridge).
18 R Sheil (ed), *55/02, a sixteen*(makers) project monograph*, Riverside Architectural Press (Cambridge, Ontario), 2012.
19 From where Phil Ayres collaborated.
20 The site at Cock Stoor is four miles from the nearest car park and delivery point. It is accessible via an unstable forestry road or by boat and is without power supply. At the time of installation, it was also beyond the reach of a mobile phone signal.
21 The scan was carried out and post-processed by Matthew Shaw and William Trossell of ScanLAB Projects.