



INSIDE SMARTGEOMETRY

Expanding the Architectural Possibilities
of Computational Design

BRADY PETERS & TERRI PETERS

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SMARTGEOMETRY**



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of Computational Design

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ISBN 978-1-118-52247-9 (hardback)

ISBN 978-1-118-52244-8 (ebk)

ISBN 978-1-118-52245-5 (ebk)

Executive Commissioning Editor: Helen Castle

Project Editor: Miriam Swift

Assistant Editor: Calver Lezama

Cover design and page design Emily Chicken

Layouts by Karen Willcox, www.aleatoria.com

Printed in Italy by Printer Trento Srl

Front cover image © Smartgeometry

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FOREWORD

BRETT STEELE

ARCHITECTURE & INTELLIGENCE: INSIDE SMARTGEOMETRY

'Everyone designs who devises courses of action aimed at changing existing situations into preferred ones.'

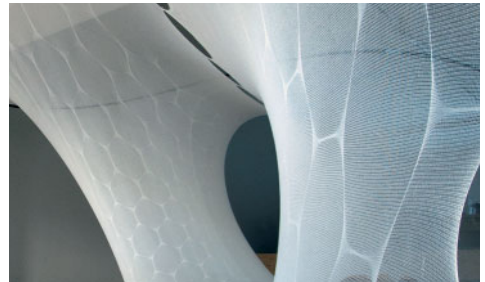
'What information consumes is rather obvious: it consumes the attention of its recipients. Hence a world of information creates a poverty of attention.'
Herbert Simon, Sciences of the Artificial

The Nobel Prize-winning polymath Herbert Simon wrote the above observations more than half a century ago at the time the world's first CAD systems arrived. His freakishly prescient declaration of the extreme consequences of modern, cognitive models captures both the potential as well as the challenge of a) design worlds conceived (enthusiastically) in terms of information-based problem solving; and b) the unexpected consequences (somewhat more tentatively) to time, and not only space, in an era dominated by the production of information.

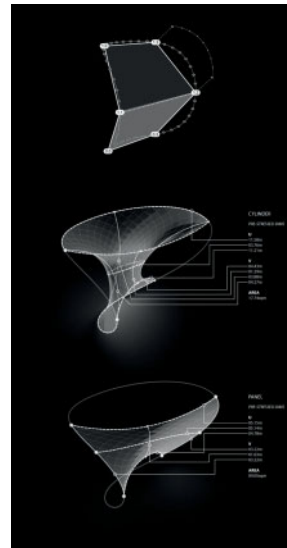
Long after Simon's foresight we all know now that the construction of attention is amongst the most difficult of all architectural undertakings, in a world of relentless media, information and access. Surely one of many remarkable accomplishments of Smartgeometry is its least obvious feature: its genuinely sustained, focused attention to a bounded set of architectural, geometric and linked questions, from which immense knowledge has been advanced. Like other computational cultures and not only digital design technologies, Smartgeometry is now a truly global enterprise; a regularly convened, creative space of like-minded architects and others interested in an open experimentation, exploration and invention of new design systems alongside the projects for which these associative systems have been developed.

Conceived a little more than a decade ago by Hugh Whitehead, Lars Hesselgren and J Parrish as a cross-disciplinary series of design workshops, presentations and discussions, and soon joined by Robert Aish and other key collaborators giving from its earliest days both breadth and depth (in an architectural world too frequently describable by means of a surface), Smartgeometry has by now come of age. This fact is the first of many demonstrated in the wonderful volume that follows; a book that is both a document and proposition, not only for recent (rapidly evolving) concepts, tools and techniques, but also for future ones. This is an interest Smartgeometry's founders share with a cast of thousands that by now have participated (myself included) as presenters, workshop leaders, design gurus, students, teachers and curious observers at the group's annual gatherings.

1



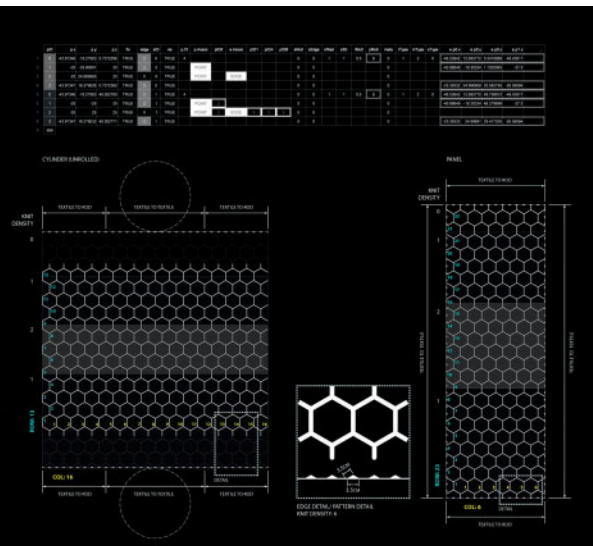
2



1 Sean Ahlquist, Bum Suk Ko and Achim Menges, *Material Equilibria: Variegated surface structures*, ggggallery, Copenhagen, 2012.

Material Equilibria is a part of a larger body of research done by Sean Ahlquist, a professor at the University of Michigan and a tutor for the 2010 Smartgeometry workshop cluster 'Deep Surfaces'. The project focuses on the development of computational design methodologies and techniques which enable the generation of self-structured spatial forms through the generation of informed material behaviours.

The following volume provides an in-depth record of these gatherings, and has been wonderfully edited by Brady Peters and Terri Peters as two dozen chapters containing insightful accounts of both the history of these events and highlights from their various undertakings. What follows is part post-post-modern super-nerd primer (filled with fascinating weird things like ‘augmented composites’, ‘shape grammars’, ‘swarm algorithms’, ‘parametric acoustic surfaces’, or ‘particle spring solvers’, amongst many other things), while also being a remarkably accessible, straightforward demonstration of how contemporary design tools are at work in unexpected ways. They are reconfiguring the concepts emerging alongside the various forms of machinic, digital and physical modelling, prototyping and testing that provide the more visible outcome of Smartgeometry’s remarkably robust, sustained attention. It’s an approach that, like the impetus of contemporary ‘object-oriented’ programming cultures, crucially prefigures as well as continues to inform the generative model-making activities surrounding Smartgeometry. What we see above all else in this book is how contemporary experimentation wrestles ultimately with the most complex architectural projects of all – the cognitive architecture of the architect’s own mind.



2 Sean Ahlquist, Bum Suk Ko and Achim Menges, *Material Equilibria: Variegated surface structures*, ggggallery, Copenhagen, 2012.

The parametric model shown here controls the knit of shifting patterns and densities, influencing the structure of the tensile spatial surface. Through computation, the micro-structure of the textile is varied to create particular organisational and structural behaviours. The accumulated material phenomena are calibrated to derive an equilibrium which works with the resistance of an actively bended glass-fibre structure at the boundary.

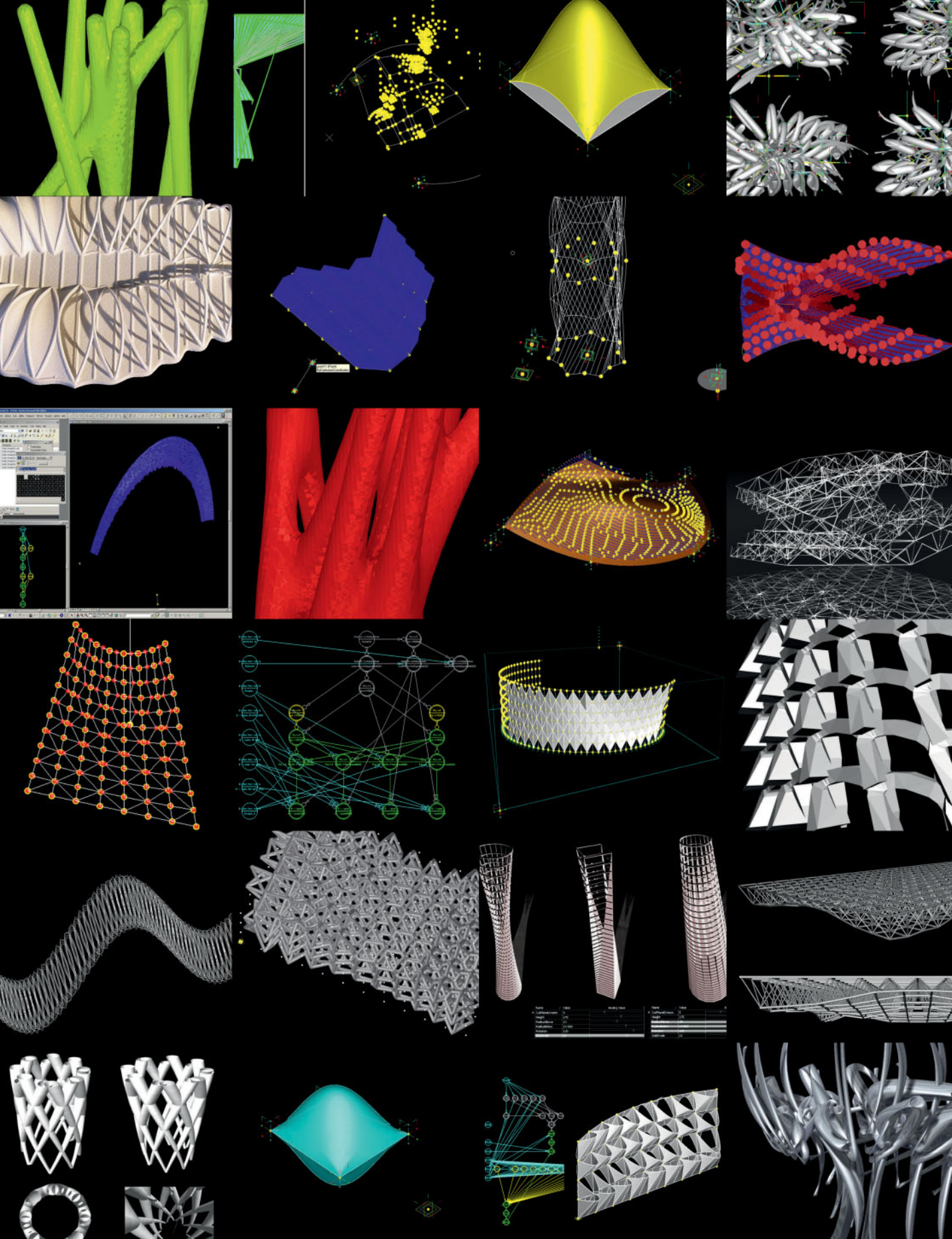
What follows is far more than a demonstration of just how far and fast contemporary experimentation has pushed architecture’s millennial reliance on geometry and advanced mathematics. Writing half a century ago Herbert Simon understood the figure of the modern architect as a perfect demonstration of what it means to design today. ‘The modern architect’, Simon wrote, ‘is the maker of instructions’. The architect’s job isn’t the ‘making’ of things in a conventional sense – it is the recording of design intentions, ideas and ambitions in the form of documents (drawings, sketches, models etc.) whose real purpose is to tell others what to do. Architects, in Simon’s view, ‘make instructions’. In this sense, the artefacts produced in the architect’s studio are hardly anything other than memory structures. In this sense, we can grasp the real values of Smartgeometry’s remarkable, collective, collaborative and sustained focus: not only on the role of information-based approaches to architectural design, but also on the making of the most difficult of all architectures, the architect’s own cognitive structure. It’s a memory structure of a very different sort than most kinds of architecture, and in the hands of the protagonists whose examples follow it is proven no less elastic, and intelligent, than other forms of building.

TEXT

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IMAGES

© Sean Ahlquist, Achim Menges, Institute for Computational Design, University of Stuttgart



INTRODUCTION

BRADY PETERS TERRI PETERS

Smartgeometry (SG) was founded in 2001 as an informal network of designers interested in harnessing the powers of computation for architectural design. Friends and former colleagues Hugh Whitehead, Lars Hesselgren and J Parrish felt frustrated by the lack of resources and network surrounding computation and architecture and sought to redefine ways that architects could use digital tools. At first, the trio of architects drew on their network of friends and collaborators such as computer scientist Robert Aish, academics Robert Woodbury and Axel Kilian, and experimental practitioners architect Mark Burry and engineer Chris Williams to put together a few modest conferences and workshops. These began with a lecture and workshop in 2003 in Cambridge, UK, then in 2004 at the University of Waterloo, Ontario, Canada, where the focus was on software development, new tools for architects and engaging with ideas outside the boundaries of 'architecture'. These early workshops provided inspiration and a testing ground for the creation of new parametric software GenerativeComponents (GC) that was introduced to the group by Robert Aish and Bentley Systems. Rather than being concerned solely with software or form-making, SG focuses on the creation and application of digital tools and technologies, and in cross-disciplinary fertilisation of emerging ideas in practice. In workshop groups, designers are able to work on projects 'off the books', away from their offices or university settings, creating pure explorations of technique beyond the confines of the design project. SG embodied new ideas and new ways of thinking. The event now spans six days, with a four-day curated workshop and two-day public conference, and attracts more than 300 international participants and attendees each year.

1 Design explorations at SG 2006, Cambridge, UK.
Conceptual geometric design explorations using GenerativeComponents.

WHY GEOMETRY?

Architectural design software at the time SG was founded was created by software developers using object-oriented programming that almost literally translated software 'objects' as building 'objects'. SG co-founder Lars Hesselgren has written that they wanted to build new design tools and founded SG as a rejection of these conservative influences that promoted computer-aided design (CAD) solely as the organisation of building components.¹ In order to be free of these predefined tools and have a higher-level discussion of building form in terms of first principles, this led to a discussion of geometry and mathematics. As this is a more generic approach, thinking of architecture and form in this way allowed them to share computational tools between disciplines. It allowed architects to design conceptually and create their own custom 'objects' rather than use the specified objects provided by their CAD software.

As Robert Aish explains in his chapter, SG explores the ideas of design computation, with the notion that there is a distinction

2 'Responsive Acoustic Surfaces' workshop cluster at SG 2011, Copenhagen, Denmark.
Participants engage in a design discussion.

Digital models from the 'Responsive Acoustic Surfaces' workshop cluster at SG 2011, Copenhagen, Denmark.
Participants work on digital models of hyperboloid geometry using a variety of software.



'Use the Force' workshop cluster at SG 2011, Copenhagen, Denmark.
Participants discuss design and computation.

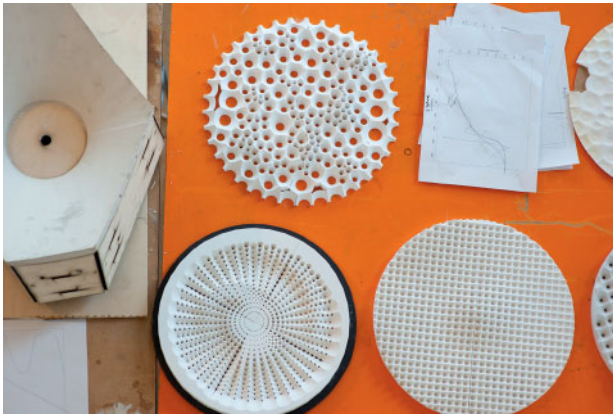
between the generative description of the building, and the resulting generated model of the building. Therefore SG is more about the exploration of design intent and how this is inscribed in the design tools and the design environment, rather than specific technology for the integrated delivery of building projects. It is about designing a system, rather than working on a more detailed 3D model.

SG is an agile network. It is purposely structured to be able to react to and reflect ideas in contemporary practice; there is no overriding goal or charter. The idea is to engage with current issues and debates in a collaborative and non-competitive environment. Digital design leads logically to digital fabrication. Over several years, but culminating in 2010 where it was a central feature, the event embraced digital fabrication, interaction and simulation with 'workshops' that more equally split experimentation in digital and physical realms. As Xavier De Kestelier and Shane Burger explain in their chapter, the evolving workshop structure is due to shifts in participants and leadership. The earlier events attracted lower numbers of workshop participants and leaders and these were almost exclusively from professional practice. Recent SG events have had multi-day programs with larger audiences and an increased focus on academic and research questions. This shift is discussed in the chapter by CASE, where they identify the move away from the pragmatics of designing for construction of buildings, towards workshops based not only on research and experimentation, which does not necessarily rule out the practical building issues, but also on creative explorations using these same methods. The five current SG Directors are all from architectural practice, but each year attendees and workshop leaders come increasingly from research and academia.

TALKING ABOUT COMPUTATION

'The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from them.'² This statement from computational pioneer Mark Weiser in 1991 is relevant to architectural practice today. Computation is everywhere; should it really be the medium and not the message? Architects desperately need to talk about computation, and over the past decade SG has provided the only experimental workshop-based discussion forum on this topic. It is not enough to say computation is ubiquitous in our field; it is not 'just' a tool – there can be no doubt that it is fundamentally changing architecture. Computation is not what architecture is, but if architecture can be understood as a practice, concerned with technique, then computation is a technique intricately connected to designing for meaning and experience in architecture. Even architecture as edifice, separated from any discussion of technique, reveals the tool of the maker. While meaning in architecture can come from symbols and symbolism in the building itself, it also comes from the experience of that building.³ Therefore the better we can simulate the experience of architecture, the better we can design for it. The technologies explored and discussed at SG are still quite visible. However, one hopes they will be customised,





3



3 Prototypes and analysis from the 'Responsive Acoustic Surfaces' workshop cluster at SG 2011, Copenhagen, Denmark.

1:10 scale prototypes were tested for their acoustic performance and this data was used to inform the design of the full-scale prototype wall.

4 Workshops at SG 2011, Copenhagen, Denmark.

View of participants and workshop clusters.

4



tested and engaged with by architects even as they continue to be woven into the fabric of the design environment.

Of course, the mere fact of using a particular computational technique does not guarantee good architecture, the same way that using the same pen as Norman Foster will not guarantee a great building. But why shouldn't architects share techniques and tools? It would be pretty silly if architects each had to invent our own pens, drafting boards and drawing conventions. So while it is the building that matters most, rather than focusing on the process of design and making, in the context of design it is critical to acknowledge that design processes are changing, and SG is at the forefront of this change.

CREATING KNOWLEDGE AND TECHNIQUE

The ways that computation and architectural design are explored at SG are unique. The idea is to nourish a collaborative environment where participants feel as though anything can happen. The theme of the event is set in advance and then workshop leaders apply to lead a cluster based on their own research: for example, in 2012, 40 detailed applications were submitted for 10 positions. Participants also apply to join workshops, submitting portfolios and statements of interest, with only 100 selected. Carefully curated by the SG community and directors, the selected workshop themes are developed and in the four days, focused questions of design, digital technique and physical making can be explored. In contrast to many other design workshops with traditional student-teacher dynamics, workshop leaders do not bring work they have done earlier to get 'students' to build, participants do not come to learn something they know nothing about, and experts do not arrive with 'answers' to disseminate. Research and knowledge is created during the workshops. The challenge is not to construct a research question that can be 'answered' in four days but rather to construct a line of thinking that can be investigated intelligently and discussed through experimentation. The SG environment is part research and part professionally focused, which seems to inspire productivity, as participants work long into the night to actually *do* something as a group within the given time, to produce some results to share with the wider group by the end of the workshop, and to work together. In Robert Woodbury's chapter, he calls this the 'flow' of design computation. There is of course a healthy fear of failure and underlying pressure to make it perfect, or at least beautiful. This is architecture after all.

SG makes no claims to produce 'architecture'. It is not about form, it is about how we arrive at form. SG is about technique. There are, of course, many valid ways to design and SG celebrates this plurality of concept. It is not the place for design crits. In the four-day workshops, there simply is not time. Instead, techniques and tools are developed and tested. Participants find where a tool hits the wall, then how to mash it up with other tools and make it work better. It is like building a racing car – how fast and how hard can we push this machine – not how nicely can we drive it.

5 Aggregate module structure from the 'Agent Construction' workshop cluster at SG 2011, Copenhagen, Denmark.

The participants operate as 'agents', building and altering the structure without pre-made drawings or plans, instead being guided by rules responding to local conditions – 'here and now'.

6 Virtual agent model from the 'Agent Construction' workshop cluster at SG 2011, Copenhagen, Denmark.

In the computer model, a swarm of virtual agents gradually and collectively build up a structure. Different agents are guided by different rule-sets, and the only communication between them is through the environment which they manipulate and which in turn affects their behaviour.

7 Visualisation of scan data from the 'Agent Construction' workshop cluster at SG 2011, Copenhagen, Denmark.

The emerging physical structure is continuously scanned, and the data imported into virtual formats for analysis and further processing. In this format it can be directly analysed beside the virtual agent models, or used as an input in these.

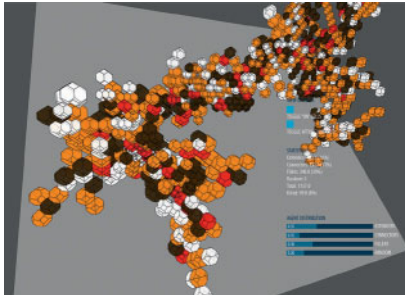
8 Airflow simulation from the 'Agent Construction' workshop cluster at SG 2011, Copenhagen, Denmark.

The scan data allows for simulation of the structure's performance, here through a fluid dynamic simulation in X-Flow.

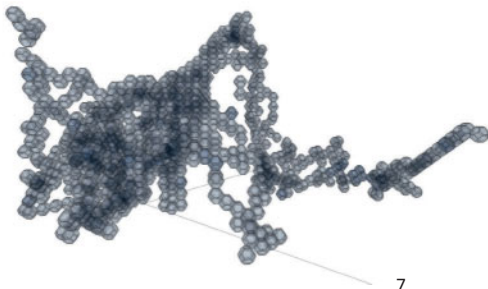


CODING

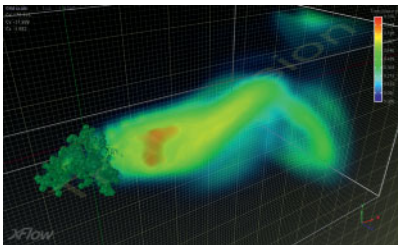
'The ability to 'read' a medium means you can access materials and tools generated by others. The ability to 'write' in a medium means you can generate materials and tools for others. You must have both to be literate. In print writing, the tools you generate are rhetorical; they demonstrate and convince. In computer writing, the tools you generate are processes; they simulate and decide.' Alan Kay⁴



6



7

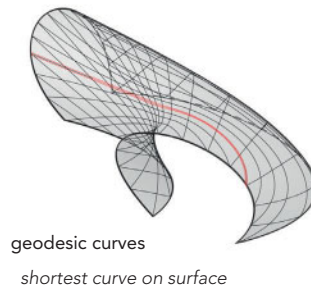
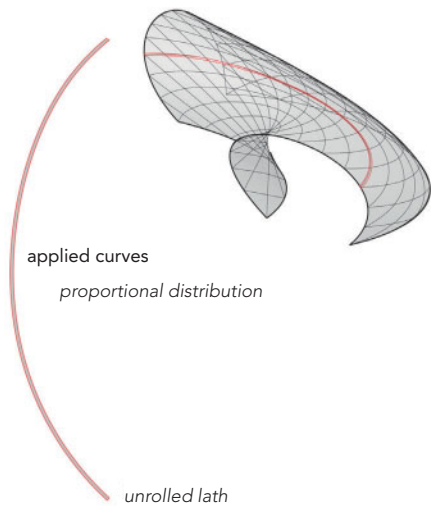


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When a designer writes a script to solve a problem, the algorithm becomes part of the design and may then be explored in a creative way. But, as Fabian Scheurer explains in his chapter, algorithms are both a description of the problem and the solution. They define the solution space and they are built around the definition of the problem. He argues that design is all about decisions and that delegating these to an algorithm always means following predefined paths. Often the use of existing tools leads to existing solutions. Through the creation of new tools, new ways of thinking and new solutions can be found. Algorithmic thinking means taking on an interpretive role to understand the results of the generating code, and understand how to then modify the code to explore new options, and to speculate on further design potentials. As designers, we are influenced by the tools and techniques that allow us to realise our visions. It has been said that the tools determine the boundaries of art, and that it is the use of the right tools for the thing that one is making, and a deep relationship between the use of the tool and its formal results, that establishes the potentials of what can be made.⁵ With computation, the boundaries of what can be made just got a lot bigger. Parametric systems and computational tools have enabled the realisation of projects that were previously inconceivable.

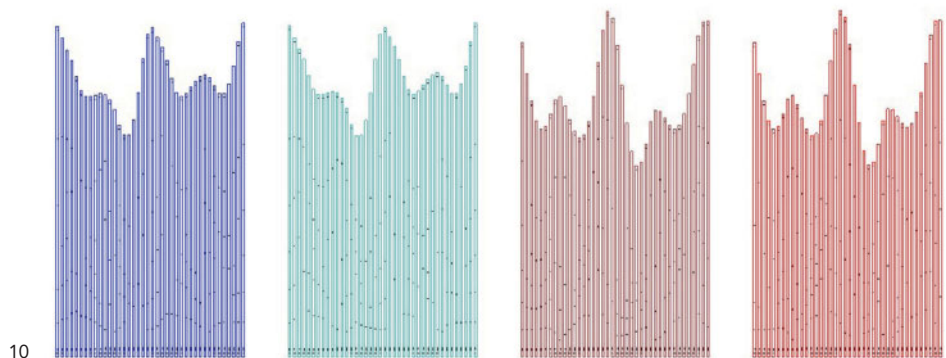
Nicholas Negroponte introduced the concept of bits and atoms, arguing that atoms make up physical, tangible objects around us – the architecture that we inhabit – while our design environment and our digital models inhabit the space of the bits – the information that is contained within the computer that we use to design.⁶ So, how does this relationship affect the architecture we design? This relationship between bits and atoms is becoming blurred. Not only do the experiments undertaken at SG work in between physical and digital realms, but design tools are increasingly used that simulate real-world performance and provide feedback on designs. Computational tools become co-creators in design, extending the intellect of the designer, and so the role of the designer becomes one of tool builder, of interpreter of results, and of a guide through solution spaces. In his chapter, practitioner Neil Katz explains that the technology needs to disappear: it is the design intent and process that is more important than the tool itself.

'Software modified by the designer through scripting, however, provides a range of possibilities for creative speculation that is simply not possible using the software only as the manufacturers intended it to be used.'



unrolled lath

9

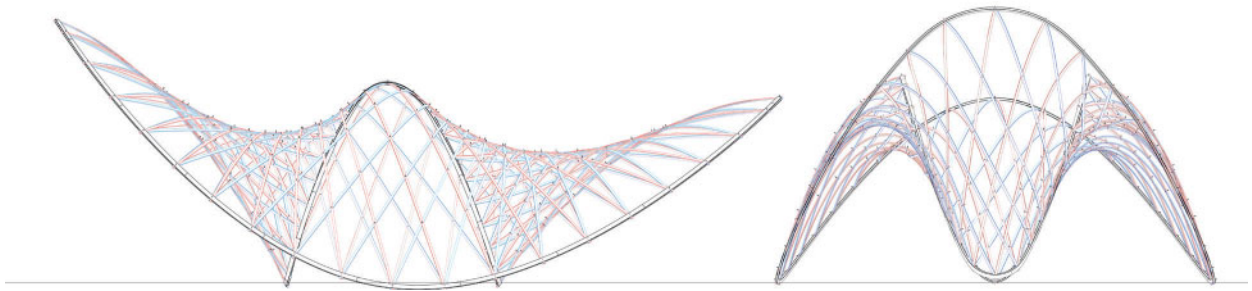


9 Geodesic curves from the 'Gridshell Digital Tectonics' workshop cluster at SG 2012, Rensselaer Polytechnic Institute, Troy, New York, USA.

Geodesic curves allow for complex curvature from straight segments.

10 Fabrication layout of laths from the 'Gridshell Digital Tectonics' workshop cluster at SG 2012, Rensselaer Polytechnic Institute, Troy, New York, USA.

Geodesic laths are unrolled with precise lengths and spacing of nodes for pin joints.



11

Because scripting is effectively a computing program overlay, the tool user (designer) becomes the new toolmaker (software engineer).’ Mark Burry⁷

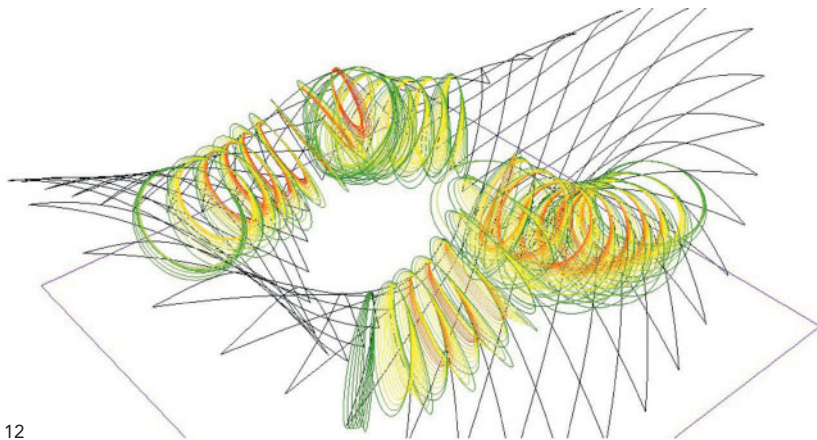
SIMULATING EXPERIENCE

Architecture can be thought of as drawing, but should be thought of as simulation. Architecture is the act of imagining a building at a remove from its construction, and then communicating this concept for others to build. To date, the imagining and communicating has been largely through drawing. However, it is not necessarily drawing that defines architecture, but this ability to create an abstraction of the building through some means. Through the drawing, the architect is able to imagine how light and space and material relate in the creation of architecture. Although largely within the mind of the architect, this simulation of effect and experience is a necessary part of architectural design. The pragmatic aspects of performance can be simulated as well. The digital design environment can be a design partner for this simulation of architecture. Through the adoption of new technologies, the creation of design techniques, the coding of custom design tools and the gaining of critical performance feedback, the abilities of the architect are extended.

SG was founded on the premise that a first-principles exploration of geometry in relation to design intent could benefit architectural design. The development, discussion and dissemination of these explorations of technique have been central to the SG workshops and conferences. The SG community explores these through parametric design, computer programming, digital fabrication, interactive design, simulation and optimisation. The scope of these approaches is enlarged at each yearly event. SG has been, and continues to be, a place where these concepts are not only discussed, tested and critically reflected upon, but critically, a place where this knowledge is created. A place for designing, coding and building.

11 Elevation from the ‘Gridshell Digital Tectonics’ workshop cluster at SG 2012, Rensselaer Polytechnic Institute, Troy, New York, USA.

Diagrams of the lattice gridshell identified the location of each piece in the four-layer lath system.



12



12 Curvature analysis from the 'Gridshell Digital Tectonics' workshop cluster at SG 2012, Rensselaer Polytechnic Institute, Troy, New York, USA.

Curvature analysis determines radii of curvature to verify the minimum radius allowable for the bending of lath segments.

13 Completed gridshell from the 'Gridshell Digital Tectonics' workshop cluster at SG 2012, Rensselaer Polytechnic Institute, Troy, New York, USA.

13



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TEXT

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THE ORIGINS OF SMARTGEOMETRY

HUGH WHITEHEAD,
LARS HESSELGREN
J PARRISH

Smartgeometry (SG) was founded in 2001 by former colleagues and friends Hugh Whitehead, Lars Hesselgren and J Parrish as a way to recapture parametric and computational design for architecture. At the time of founding SG they were leaders in the London-based architectural practices Foster + Partners, Kohn Pedersen Fox (KPF) and ArupSport respectively, and were strong proponents of digital design. Each was striving to create architecture through the use of parametric tools and computational methods. Through SG they hoped not only to create new digital tools, but to foster a community that would develop, test and disseminate these ideas of architecture and design to a wider audience. Whitehead founded the Specialist Modelling Group at Foster + Partners in 1998 which has been responsible for a host of innovative buildings and consistently pioneers computational design methods in architectural practice. After years at KPF in London, architect Lars Hesselgren is now the Director of the Computational Design Research Group at PLP Architects. J Parrish is a globally renowned sports stadium designer leading teams to design some of the most iconic stadium projects in the world. After many years at ArupSport, he moved to AECOM where he is currently working on the venues for the Rio Olympic Park. Here each tells their story of the origins of SG, now an international multidisciplinary community of professionals, academics and students in the fields of architecture and engineering.



1

HUGH WHITEHEAD

BACK TO THE FUTURE

Four people were sitting in a car travelling to a Bentley conference. Robert Aish, in the front, was due to host a research seminar; and architects Lars Hesselgren, J Parrish and Hugh Whitehead, in the back, were enjoying the opportunity to tease a captive software developer. It was a familiar formation: we had all worked together with YRM back in the 1980s. So we began the light-hearted banter with a searching question: 'Why is it that ten years have passed, and we still cannot even get close to the kind of capability that we had then?'

At the end of the 1980s boom, YRM had grown to an international multidisciplinary design consultancy of 600 people, and took the strategic opportunity to acquire Anthony Hunt Associates, the engineering firm of choice for Norman Foster, Richard Rogers, Nicholas Grimshaw and many other leading architects. What Anthony Hunt Associates needed was access to computer modelling expertise, which was already well advanced at YRM. The dialogue between architect and engineer was shifting rapidly from back-of-envelope sketches to digital representations, where 3D geometry became the input to analysis routines and setup cycles of design iterations.

1 Hugh Whitehead, Lars Hesselgren and J Parrish, the original SG founders, at SG 2011, Copenhagen, Denmark.

2 Foster + Partners (architects), Anthony Hunt Associates (engineers), Faculty of Law, University of Cambridge, UK, 1995.

The geometry of the diagonal panels and offset supporting structure was formed by proportional subdivision of a cylindrical vault. A parametric model was developed by Hugh Whitehead so that changes to the radius of the vault caused the geometry to regenerate the data needed for structural analysis.





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The acquisition of Anthony Hunt Associates brought exposure to a whole new world of adventurous designers, who were expecting us to provide them with new design technology. Where would we find it? Engineers and product designers always seemed to have far better tools than architects, and we realised that we were looking for something that was generic rather than discipline-specific.

Around this time we saw a presentation by Robert Patience who led the development of the new Intergraph Vehicle Design System (I/VDS). It was a revelation. That rare kind of presentation that seems to come from another time or another place and brings you out in a cold sweat! There, back in the 1980s, we saw a first glimpse of the power of parametrics, associative geometry and relationship modelling, all in full 3D, at a time when leading computer-aided design (CAD) systems of the day were still only trying to mimic and crudely automate flat drawing-board technology. Robert Patience ended his presentation with the throwaway line, 'Last weekend I did HVAC [heating, ventilation and air conditioning], with automated duct sizing and routing just from a rule-based schematic, all in full 3D with clash detection!'

We invited Robert Patience to visit YRM to discuss the potential for developing his ideas in an architectural context. He brought with him Robert Aish, who was working with him in Paris, helping to implement the new technology for the Gdansk shipyard, where the aim was to directly flame-cut steel from a rule-based 3D design model. Design-to-fabrication was already happening.

The show-and-tell session lasted far into the night, while we explained the design challenges we were facing and the two Roberts talked about the potential of associative systems. At the end we asked, 'Why label the product as a Vehicle Design System (VDS), when it clearly has the potential to provide generic solutions which could support a far more integrated approach to design?' Robert Patience replied, 'I always think in generic terms, but as a software developer I can only get funding from the Marketing Department by pretending to be discipline-specific, so I chose vehicles because at least they include cars, ships and aircraft. All have structure, services, form, space and aesthetic requirements, just like buildings! Perhaps we could describe buildings as very slow-moving vehicles, almost tending to the limit!' At this moment an idea was born, and we convinced Intergraph to develop an architectural application based on VDS technology. The result was a specification for a product called 'Master Architect'. Robert Aish joined us at YRM to help develop the brief and explore concepts based on the challenges of live projects. With Robert's help, Lars Hesselgren produced a fully associative 3D model of London's Waterloo Station for Grimshaw while Hugh did a similar exercise on the University of Cambridge Faculty of Law for Foster + Partners. We all worked with J Parrish on a modular concept design called 'Stadium for the '90s'. The stadium roof was a tensile membrane structure supported on cantilever beams with a retractable centre section.

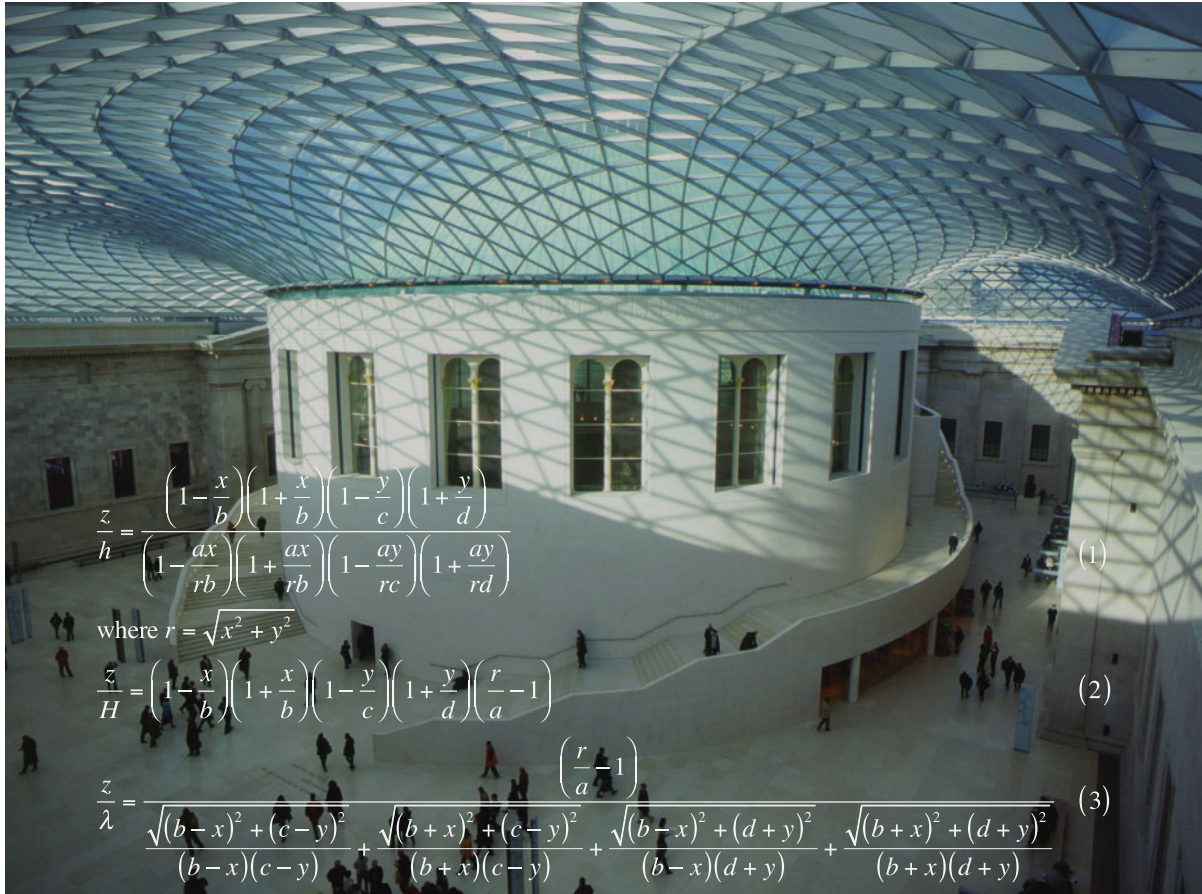
3 Antoni Gaudí, Sagrada Família Basilica, Barcelona, Spain, 1883–, central crossing of the nave.

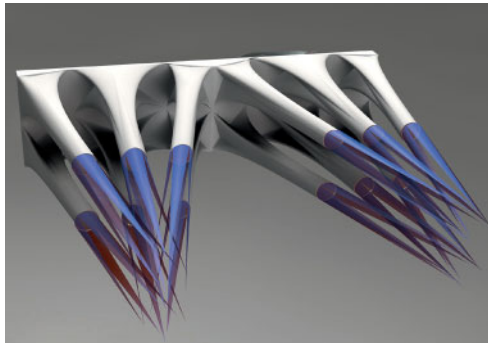
The progression from constructive geometry to parametrics and then to scripting and computational design was already mapped out by designers like Gaudí, who worked only with models and raw intellect.



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4 Foster + Partners (architects), Buro Happold and Waagner-Biro (engineers), Great Court at the British Museum, London, UK, 2000.

The elegant resolution of complex aesthetic and structural requirements is reflected in the elegance of the mathematics derived by Chris Williams. Three functions describe the transformation from rectangle to circular boundary, maintaining singularity of curvature. The triangulated pattern floats on this surface using dynamic relaxation to achieve continuity of geodesic curvature.

5 Digital model by Mark Burry of the Sagrada Família Basilica, Barcelona, Spain, 1995.

The work of architect Mark Burry helped to decode Gaudí in terms of a language of intersecting helicoid, hyperbolic paraboloid and hyperboloid surfaces. This enabled contemporary design technology to engage with traditional craftsmanship and so to realise a vision that had never been fully described.

So what happened in that decade between the introduction of VDS to YRM and the car ride to Exton? How was parametric design lost to architecture in those 10 years? The 1980s bubble burst: YRM went down, Intergraph went down, Lars moved to KPF, J moved to ArupSport, Hugh to Foster + Partners, and Robert to Bentley Systems, but the friendship and the shared experience remained. In the car that day, the response from Robert was this: 'Sometimes I feel as though I have been to the future. I have seen it and I know that it works!'

But the question was, how could we get back to the future?

We held a conference in Cambridge, UK in 2003. The event attracted strong interest with many presentations. Two were particularly inspirational. Mark Burry described 15 years of decoding the designs of Antoni Gaudí (1852–1926) which enabled the completion of the Sagrada Família in Barcelona, and Chris Williams explained the generation of the geometry for the Great Court roof at the British Museum in London. Here were two people who had already delivered the kind of projects that we aspired to. They both combined a background in architecture and engineering with fluency in mathematics and scripting. This expertise was used to give expression to design ideas by developing custom workflows, which engaged a variety of applications. Mark described how he used Excel as a kind of blind CAD system to process data before exporting to graphics. Chris gave a live demonstration in which he showed how to 'sketch with code'.

We were delighted when Mark and Chris agreed to join us as tutors at the next SG workshop at the University of Waterloo, Ontario, Canada in 2004. With the addition of Axel Kilian from the Massachusetts Institute of Technology (MIT) and Robert Woodbury from Simon Fraser University (SFU), British Columbia, we had an international all-star team. The significance would only appear in retrospect as the community reached critical mass and gained momentum. So we approached the first workshop as a 'learn by doing' experiment, not just in design technology but also in design sociology, and this spirit continues.

If the future lay in integrated design then we needed a comprehensive platform that would support disparate activities