# 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.

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# HUGH WHITEHEAD

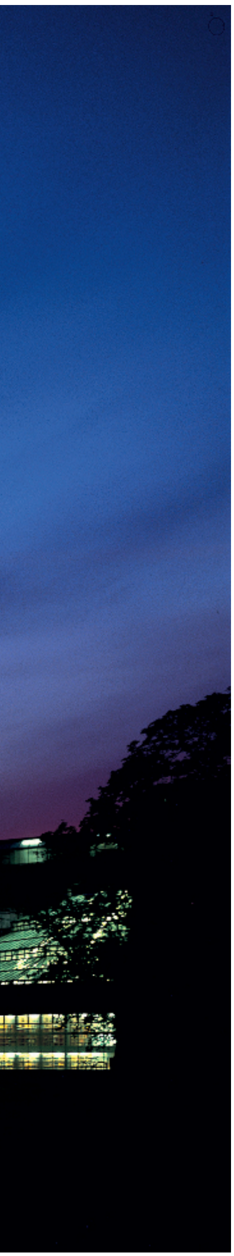
## BACK TO THE FUTURE

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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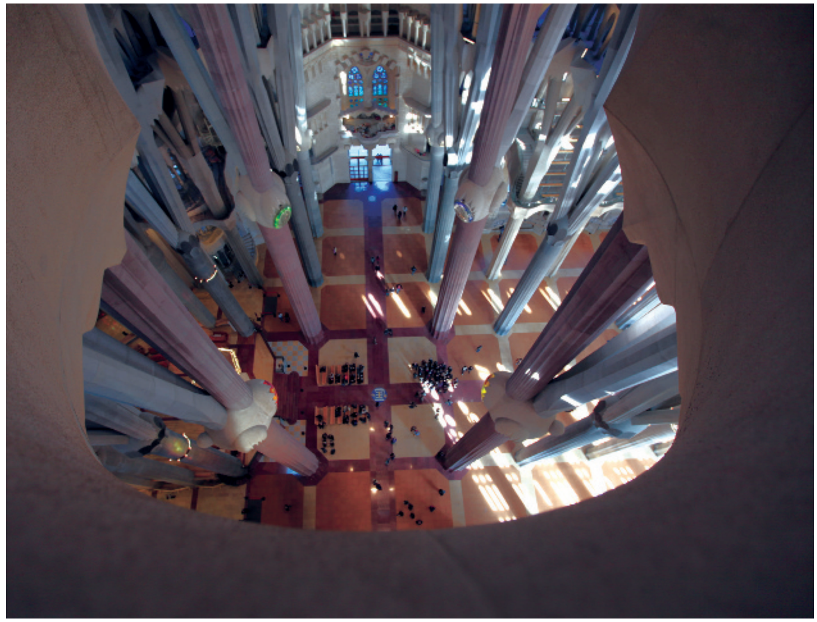

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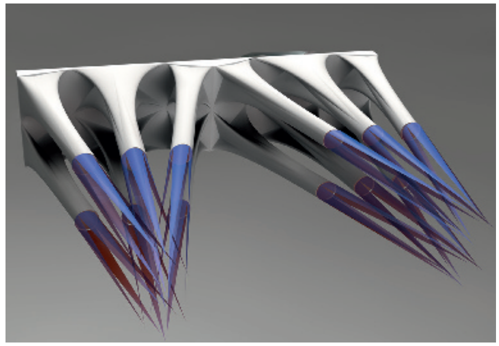

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So what happened in that decade between the introduction of VDS to YRM and the car ride to Exton? How was parametric design lost to architecture in those 10 years? The1980s bubble burst: YRM went down, Intergraph went down, Lars moved to KPF, J moved 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

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.

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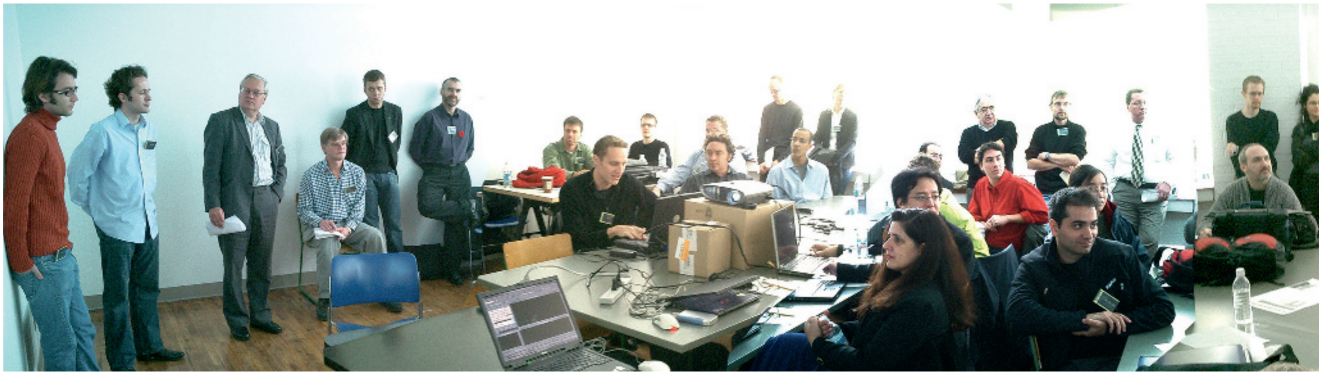

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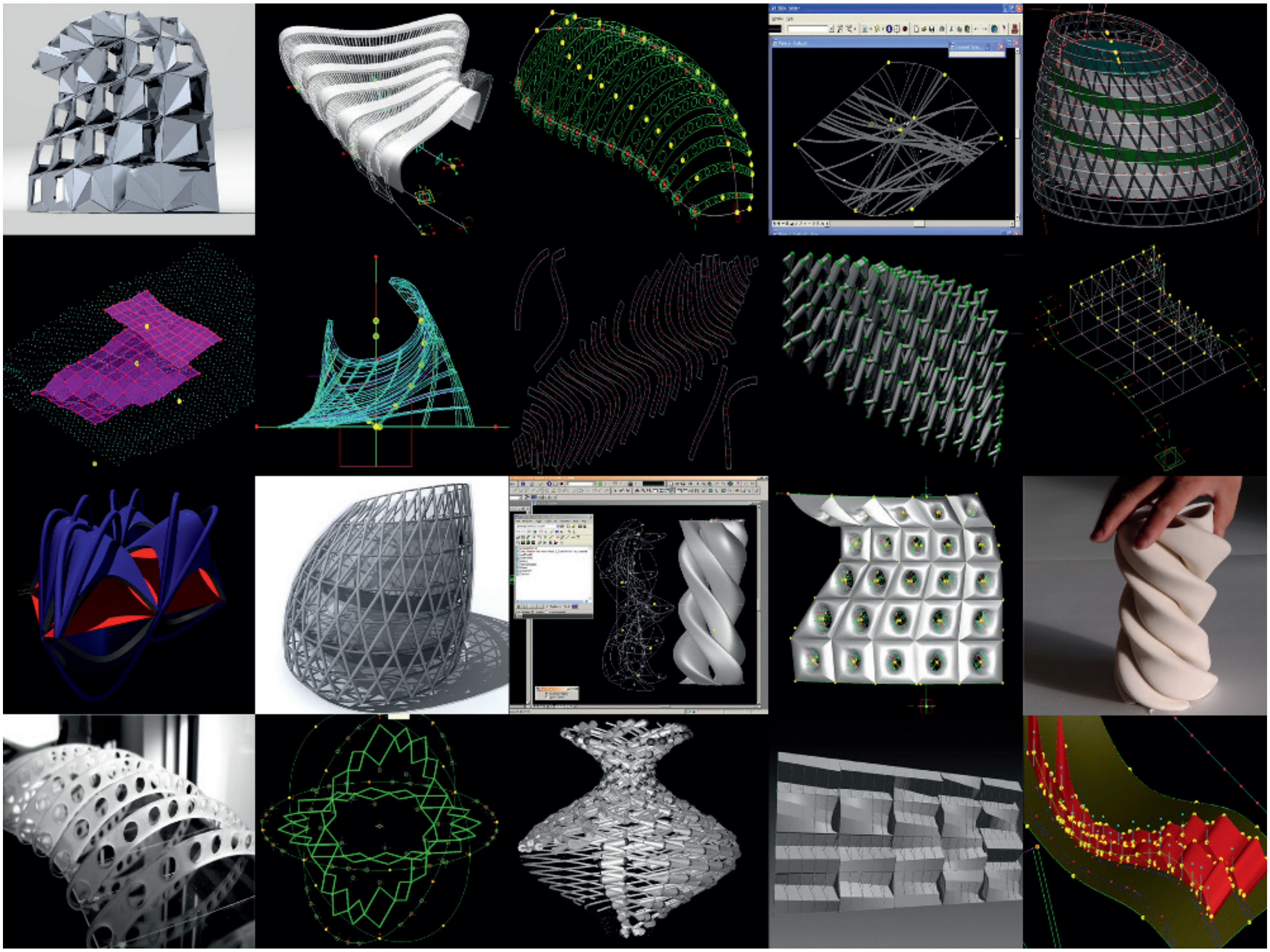

6 The SG 2004 workshop briefing at the University of Waterloo, Ontario, Canada. Tutors gave a brief description of their background and special interests. Participants then formed groups around their chosen tutor to discuss their projects before moving off to rooms to begin the workshop. We became a self-organising community.

7 Design explorations at SG 2004, University of Waterloo, Ontario, Canada.

and promote collaboration between different specialists. To give the workshop an experimental focus, we then invited Robert Aish to join and asked Bentley Systems if they would agree to let us trial their new object-based system, GenerativeComponents (GC). Never before had a group of designers experienced a raw development platform in the early stages of specification while the author of the software looked over their shoulders. It was a rough and bumpy ride, but a rare privilege and everyone was captivated by Robert's tireless enthusiasm. Often he would work through the night to address issues that arose and emerge in the morning with a 'crisis build' which he distributed on a memory stick.

Almost by accident, SG became a design process laboratory with a unique characteristic. It became a community of people drawn from competing organisations, but the bonds that were formed crossed all known boundaries. Instinctively the tutors led from the front and the participants followed their example and competed to share knowledge, ideas and experience, and even tools, techniques and concepts. This special synergy was well appreciated by Bentley, who gave Robert the opportunity to pursue his vision. They have continued to support SG in what became a series of annual events that have spanned the last 10 years. But those early workshops were all high-risk ventures with an edgy quality, and so we would treat each one as if it might be the last.

Not everything went according to plan and 'the great pizza disaster' has now passed into SG folklore. We had no experience of event management on this scale and there was so much to organise – tutors, participants, admission, registration, venues, accommodation, travel, facilities, equipment etc. We forgot about food! At the end of a totally exhausting first day we suddenly realised that we had 40 starving people out on a university campus miles away from civilisation. If everyone just left in search of sustenance the event would lose all momentum and we would lose their goodwill. At an emergency meeting the SG Directors agreed to put their hands in their pockets and send out for a pizza delivery, but could we afford a few beers? Fortunately we could, because the pizza was late and cold, but at the sound of popping cans the spirits revived and the intense discussions flowed again.

When we related the story of this near-disaster to Greg Bentley the next day, he kindly offered to pick up the tab and bail us out, but added a stern warning that we had to become more businesslike because 'altruism is not commercially viable'. However, it could be said that Bentley have spent the last 10 years proving that with the right community it can be. During this period the SG workshops helped to specify and test four different versions of GC, which demanded extreme patience and perseverance from all concerned. The concepts that were being prototyped proved to require a new type of development language with advanced capabilities. Perhaps, if the SG Directors had not sent out for the pizza, GC might never have happened!


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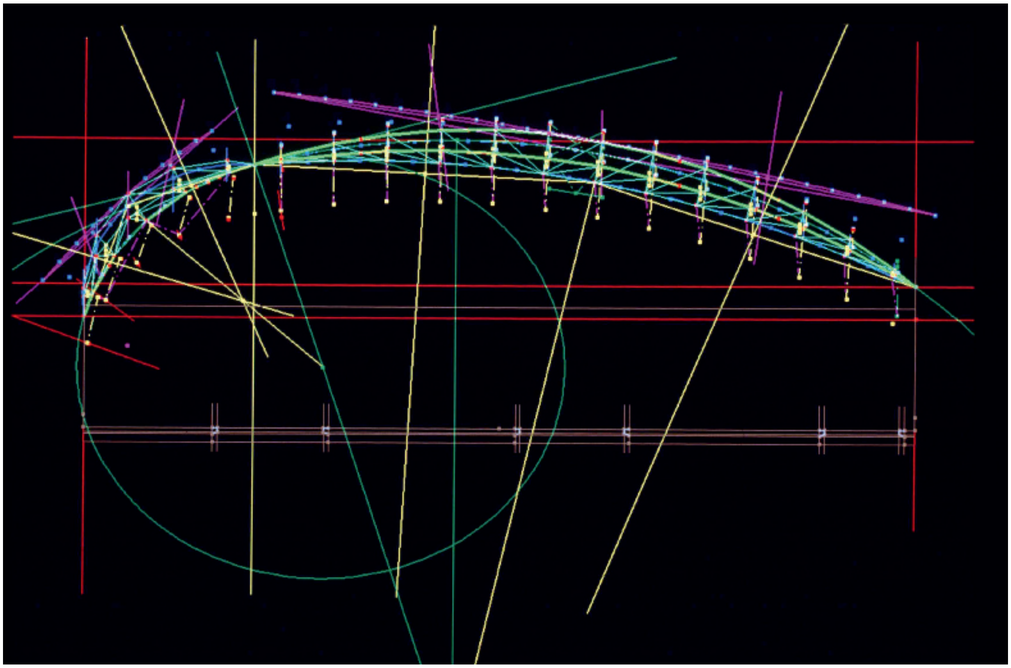
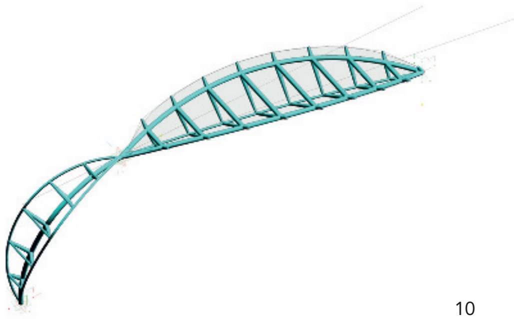


Some participants look back on those early workshops as a life-changing experience, which launched a whole new career – and it is comments like these that provide our motivation. Now, with the addition of a ShopTalk day and a public conference, SG provides not just a forum but also a stage, which many people regard as a window on the future. The original founders can only look back and marvel at the culture that grew from a cold pizza in Cambridge!



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## LARS HESSELGREN

### APPLIED PARAMETRIC DESIGN

In 1982 I was a fully-fledged computer addict with an early-generation Sinclair computer to my name. I was working at Halcrow where we were trying to convince them that CAD was the future. At the time, we spent a lot of time stencilling notes onto contract drawings. I was a port architect and Halcrow was designing all the new ports during this first Middle Eastern building boom: Jubail, Jeddah, Dubai, and Jebel Ali. I made a change after seeing a lecture at the RIBA where YRM showed off its new technology, the fabulous Intergraph system. I joined YRM to play with the new toy; it was so fabulously expensive we worked the machines in shifts. Hugh Whitehead joined YRM soon after as we graduated from 2D in black and white to 3D in colour.

Hugh and I were both sent to the conference in Huntsville, Alabama every year and here we got to know the cutting-edge CAD scene. As a result of connections made there, we had the opportunity to alpha test Intergraph's 'Master Architect' software and one of the developers was Robert Aish. Master Architect was sitting on top of a mechanical modelling system that was very advanced and had parametric modules. When Master Architect was cancelled, Hugh and I persuaded YRM to employ Robert to continue with our parametric work. One summer Grimshaw came along with the Waterloo Station International Terminal project. I grabbed the model, cross-examined the project architect on the setting-out principles behind the design and built a parametric model of it.

A contemporary example of the need for 3D parametric technology in practice was the Pinnacle Tower by KPF. This tower at Bishopsgate in London has a unique cascading rooftop with a viewing gallery and restaurant, and was designed to be the tallest building in London, exactly in line with the Shard. The design team were hard at work but found it difficult to come up with a rational geometry to realise their design goals. The geometry of the tower is based on inclined planes in 3D, and on plan, circular arcs which get smaller to form a sheared cone. The top is mapped as a curve. This is then remapped back onto the inclined planes and sheared cones. The design of the project was carried out on the new GC software developed by Bentley and used at SG.

### THE FUTURE OF SOFTWARE

SG emerged at a time of great opportunities in computational

8 Architect: Grimshaw (architects), YRM Anthony Hunt Associates (engineers), International Terminal, Waterloo Station, London, UK, 1993.

9 Parametric model by Lars Hesselgren of the International Terminal, Waterloo Station, London, UK, 1980s.
The original parametric model of Waterloo Station by Lars Hesselgren while at YRM Anthony Hunt Associates for Grimshaw using I/EMS mechanical modelling software.

10 Parametric model by Lars Hesselgren of the International Terminal, Waterloo Station, London, UK, 1980s.
Rebuilt parametric model of the Waterloo Station arches, architects Grimshaw, structural engineers YRM Anthony Hunt Associates. The original model used Intergraph I/EMS software, the rebuild is done with Bentley GC software.

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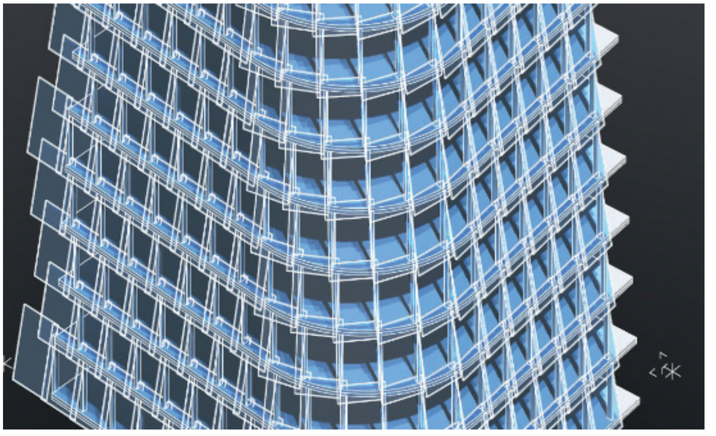

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tools and developments in computer hardware. This has meant that, far from being an elitist pursuit, anybody could join in. A new product category in architecture, 'parametric design', was born. It seems likely that this will soon disappear as it is increasingly clear that parametric design will become embedded into mainstream CAD software, just as it has in the mechanical arena. In order to use parametric software well, a user needs to have an underlying mental model of a process. This is often geometric in nature, but it increasingly encompasses other aspects such as performance, cost and end-user enjoyment. The digital age is changing our perceptions as designers and for myself this is where the future of architectural design lies. How do we use digital technology to inform, survive and entertain ourselves?

## J PARRISH

### THE FUTURE SEEMED SO CLEAR

The late 1960s and early 1970s were exciting times – as students we felt we could do anything, and Concorde and the Jumbo's first flights and the first moon landing helped convince us even the sky wasn't the limit!

My 'eureka moment' came with a final-year visit to architect John Lansdown of Turner, Lansdown & Holt. We'd already been introduced to CAD by our Systematic Design department at Bristol University, but in his dimly lit London office we were amazed by parametric design tools that calculated, designed, modelled and documented stairs, lifts and other building elements in 2D and 3D and provided neatly tabulated performance data. John had even written a program for specifying planting for different climates and locations with an interface that responded to questions typed as normal English sentences, just because it was an interesting challenge.

### I'D SEEN THE FUTURE OF ARCHITECTURAL DESIGN!

1975 was not a good year for Part II architectural students entering the job market, and I was extremely lucky when the RIBA's Appointment Service directed me to a successful interview with Howard V Lobb & Partners in London's Tottenham Court Road. Two years later I found myself with the plum job of project architect working for leading UK expert Jim Cutlack on the redevelopment of Cheltenham Racecourse. I didn't realise at the time, but the direction of my architectural career and the roles to be played by sport and computational design were set.

> *In 1975 most architects had not even heard of parametric design. Even thirty years later few understood its potential and would have considered it the future of their profession.*

### JIM'S RULE OF THUMB

Developing a new masterplan and designing the first section of a new grandstand for the Racecourse in a short time and to a

11 GC model of Kohn Pedersen Fox (architects), The Pinnacle, London, UK, under construction.
The sheared cones concept was used in the Pinnacle building designed by the current PLP partners while at KPF. This image, which illustrates the sheared cones and the overlapping sets of inclined snakeskin facade components, is drawn from a new GC model built by Lars Hesselgren in 2012 while at PLP.

12 Kohn Pedersen Fox (architects), The Pinnacle, London, UK, under construction.
The Pinnacle in Bishopsgate, located between Tower 42 and St Mary Axe, will form a prominent landmark on the London skyline when completed. It is a project of Kohn Pedersen Fox (International) PA in which the following people at PLP Architecture were involved: Lee Polisano was Partner-in-Charge; Karen Cook, Design Partner; Lars Hesselgren, Head – Computational Geometry. (Lee Polisano and Karen Cook are partners of PLP Architecture.)

very tight budget was challenging and we relied heavily on Jim's knowledge and experience. To create the section through the grandstand, we needed to know the height of the steps in the lower and upper tiers that would give each spectator a good view over the heads of spectators in front. As usual, I asked Jim.

He examined the sketch drawings and dimensions closely and, after checking a few key distances with a scale rule, recommended an appropriate constant riser height for each tier. When asked how he determined the required riser heights, he admitted it was basically a rule of thumb and, yes, he did get a bit nervous when making the first site visit after the steppings had been installed. He explained his routine was to 'have a nice lunch and a couple of glasses of wine before attending the key site meeting and it has always worked so far'!

> *As a young architect who believed in computational design, I knew there had to be a better way to design spectator seating tiers.*

### ARCHITECTS DON'T INVEST IN RESEARCH

The project structural engineers, Jan Bobrowski & Partners, clearly did understand sightlines, and an article they'd written for *New Civil Engineer* set out the principles clearly and succinctly. It revealed that sightlines were not rocket science. The only slight complication was that for a properly optimised viewing tier, the riser for each row needed to be calculated from the preceding row – a simple iterative process for a computer. The practice needed a computer; or, more accurately, J Parrish wanted a computer so he could develop a program for working out sightlines, and he thought it only reasonable the practice should pay for it.

Mini computers were unfortunately far too expensive in 1976, and the Apple II (1978) and IBM PC (1982) had yet to be developed, but the Texas Instruments TI-52 (1976) card programmable scientific calculator was available and, although expensive, just about affordable. My pitch to the partners for a TI-52 was turned down – investment in technology has never been a construction industry strong point – so I bought one myself and started programming. The result appears to have been the world's first sightlines program. The highly unreliable TI-52 was eventually replaced by the excellent TI-59 which was used for all the subsequent Lobb sports projects for the next five or six years including Goodwood Racecourse's main grandstand, Cheltenham's new parade ring and Twickenham's South Stand.

> *Others often don't understand or appreciate the potential benefits of developing software – ignore them and develop your own in your own time, based on your own expertise.*

### DESIGNING IN 3D FROM FIRST PRINCIPLES FROM DAY ONE

After a hiatus from sports architecture I moved back to Lobb in 1989, tempted in part by the offer of a proper CAD system. The architectural world was waking up to CAD at long last. Pioneers, led by YRM, were investing heavily in sophisticated multi-user systems and developing highly skilled user teams. Our investment was much more modest, a basic version of the gold-standard Intergraph system, plotter and software but still nearly £25,000, probably equivalent to 10 far more powerful workstations today. While other practices developed plans for implementation, we adopted a much simpler approach – start immediately on live work and learn on the job. It worked; and we also avoided falling into the trap of giving the expensive computers to technicians, or to architects who were then treated like technicians, with inevitable consequences. Instead, we gave each new machine we bought to the next most skilled architect. Our team embraced computers with enthusiasm and never looked back.

> *Always give the most powerful tools to the most able.*

After a brief but intense dabble with 'Project Architect', which repaid me by deleting every element in a highly complex ground-floor plan for a large hotel on the eve of the first site meeting, I was convinced the best way to design great buildings was to design as many aspects as possible from first principles and in 3D. I learned complex, underdeveloped software should be avoided.

> *Microstation became my working environment. All my projects from then on were designed from first principles, in three dimensions, from day one.*

**SIGHTLINES MARK II**

Microstation's User Commands provided a platform for computational design with direct CAD output, and the development of tools for creating complete seating bowl sections was straightforward. Anyone in the office could use my simple User Command to create a properly calculated multi-tier seating bowl section for any stadium from local club to Olympic venue. It soon became clear there were potential problems with releasing software for general use.

> *Providing system-wide software tools for use by any designer carries risks – garbage in and garbage out is just as relevant to architects and engineers as to any other computer users. Automated systems can be appropriate for tasks requiring minimal designer involvement; but designing major spectator venues well, even with the most sophisticated computational design tools, still requires great skills and experience. Using software based on expert knowledge does not in itself create a great design or an expert designer.*

**STADIUM FOR THE '90S**

The stadiums being developed for the Italia 90 World Cup were a revelation to UK sports architects used to a diet of tight budgets and low aspirations. Stadiums really could be fun, adventurous, dramatic and iconic. My Lobb colleague Rod Sheard and Geraint John of the Sports Council were determined England should

13 J Parrish for Lobb Partnership (architects), YRM Anthony Hunt Associates (engineers), Stadium for the '90s, concept design shown at Interbuild, Birmingham, UK, 1990.
The stadium roof was modelled in I/VDS by Hugh Whitehead for J Parrish and YRM Anthony Hunt Associates. The technique of populating a structure with rule-based variational geometry was to become a prototype for GenerativeComponents.

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compete in stadium design as well as on the football pitch, and hatched a plan. We'd develop a prototype of an affordable 25,000-seat English stadium that could be constructed in stages, would provide excellent views, comfortable seats with safe access and egress, excellent revenue-generating facilities and be fun, adventurous, dramatic and iconic. And for good measure it could also be built with a closing roof.

An ultra-efficient stadium clearly warranted an ultra-efficient (minimal-cost) architectural design team of one. We also needed a highly talented structural engineer and, at Geraint John's suggestion, Stephen Morley of YRM Anthony Hunt Associates joined the team. It was my ideal project: to design a stadium for the future with a multidisciplinary team, from first principles, in three dimensions, from day one. The design process proved a great success and the stadium was developed in record time. We worked directly on computer in 3D, with the architect and engineer communicating by phone and exchanging drawing files, albeit frustratingly slowly, using dial-up modem links. Just five sheets of paper were used and only because affordable computer projectors had yet to be invented. Having a great design is one thing, but we needed to show our creation to the world. We needed computer renders and a state-of-the-art animation and we needed them in time for the Interbuild exhibition. Stadium for the '90s was shown at Interbuild 1990 in Birmingham. It attracted much attention and was a great success. In developed form it became the McAlpine Stadium in Huddersfield and was awarded the UK's highest architectural prize, the RIBA Building of the Year award, in 1995.

> *We turned again to YRM Anthony Hunt Associates and to Hugh Whitehead, Lars Hesselgren and Robert Aish. It had taken 15 years to find colleagues and friends that shared my vision of the future.*