Practice 2006: Toolkit 2020

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Abstract. This paper discusses advances in computing applications as they affect the design of the built environment. It presents emergent applications selected from Arup's current projects, examines the changing nature of the profession, and concludes with a preview of research leading to Arup's vision of the designer's toolkit for 2020. Applications address in the first instance the vertical integration of the supply chain and secondly the horizontal integration across the different design disciplines. This paper further explores the link between three dimensional representation and analysis, automated generation of representation, computational design optimization and Realtime synthetic environments. Of integral importance to the continuing innovation in computational applications are of course the people who use the tools. We describe four emergent specialists: toolmakers, custodians, math modellers and PhD candidates embedded in the practice. The vision of Toolkit 2020 ranges from persisting hardware limitations for near-realtime design regeneration, to the emergence of open source freeware.

1 Introduction

Arup is a firm of some seven thousand designers spread across the world. The firm has been traditionally known in the built environment for its structural consultancy work from the Sydney Opera House onward. However, Sir Ove Arup in 1970 was quick to point out that innovation in design occurs in a multidisciplinary practice [1]. In 2006, forty years from the date when Sir Ove Arup founded it, the firm employs specialists consultant in many design disciplines including acoustics, lighting, fire, flow of air and water, flow of people through spaces and during evacuation, flow of goods through airports, manufacturing plants and hospitals, traffic and vehicle movement. Professor William Mitchell[1] points out that research in computing applications is most successful when experiments occur in non-trivial scenarios. Advances in computing applications as they affect the design have consistently occurred at the confluence between information technology and creative practices [2], [3]. Both authors made a conscious decision to move to consultancy, accepting the challenges of putting invention and innovation into practice, on the assumption that the real world challenges are seldom trivial [4]. The focus of this paper is on work occurring in

[1] William J. Mitchell, Professor of Architecture and Media Arts and Sciences at MIT. Mitchell is currently chair of The National Academies Committee on Information Technology and Creativity.

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between the practice of architecture and engineering, in between academia and practice and finally between implicit design intuition and the explicit rule-based generation of design [5], [6].

2 Computing Applications in Practice at Arup

The first series of applications address the vertical integration of information in the supply chain with the contractor and fabricators at one end, and the clients and building owner at the other. Contemporary examples of the application are driven by the client aspiration to improve their asset management, to counteract the time restrictions of market forces and minimise the risk of human error.

A second area of application addresses the horizontal integration across the different design disciplines (or physics of a building) to create multi-performance simulation environments. Current Arup projects include an urban environment, a highway widening and a transport interchange where natural light reaches the platform level thirty five metres below ground. The openness necessary to allow the penetration of light through the building creates a design challenge for both the intelligibility of public announcement as well as fire and smoke propagation.

Further reference is made to the link between three dimensional design representation and analysis beyond its application in structural steel design. Presented are applications in construction programming (4D) of complex construction sites.

Most generation and iteration of three-dimensional design representation occurs manually, whereas here we focus on emergent automated (not automatic) applications. Parametric relational modelling has already been used in the design of sport venues, characterised by geometrical complexity and a fixed opening date.

Regenerative modelling with Visual Basic scripting was applied for example to the design and documentation of an Olympic swimming centre so that the 3D representation and documentation becomes a by-product of three thousand lines of script. Computational optimisation has also been applied to projects that include panelization and rationalization of curved surfaces, optimization of building envelope, and sizing of structural members. Automated design methods such as computational optimisation for the sizing of structural members, present the need for Realtime synthetic environments to enable us to understand results which, through static images, alone would remain unreadable.

Immersive Environments was used to demonstrate design to non-specialist project stakeholders. Realtime[2] synthetic environments is applied to operationally driven design facilities such as healthcare facilities and infrastructure design with a large number of stakeholders; SoundLab[3] is applied in the design of performance venues.

2.1 Vertical Integration of the Supply Chain

The Building Information Model (BIM) are becoming the integrator of the supply chain all the way along the line from the client to the fabricator. Such geometrical

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[2] Realtime is an interactive environment, is an innovative design tool developed by Tristan Simmonds at Arup, based on cutting edge computer graphics technology.

[3] SoundLab, with 12 channel ambisonic 3D sound system, is an innovative design tool developed by Arup to give an auralization of sound in performance spaces and other building types remote from the spaces themselves.

models have become the interface for the complete database of project information. Although they are already commonplace in the aerospace and automotive industry, they are just emerging in the construction industry where they often challange the standard contractual arrangement of the supply chain.

As an example, we will introduce three projects, each of which integrates a different portion of the supply chain. The Sydney Opera House Opera Theatre Refurbishment integrates design representation with facilities management, Westland Road Tower integrates architectural, structural, mechanical and quantity surveyor disciplines in a single model during the schematic design phase of the project; Serpentine Pavilion 2005 integrates design and fabrication.

Sydney Opera House – Opera Theatre Refurbishment. For this project, Arup developed a 3D model of the existing structure of the Sydney Opera House, Opera Theatre Refurbishment [7] using Bentley software. Each entity in the model contains the complete set of the original information, with some three thousand architectural drawings, one thousand structural, and several hundred services and associated subcontractor drawings.

Each entity in the model, in addition to geometrical modeling information, holds a description of where the drawing information for that entity originated. Tags containing the entity’s unique number from the original drawings, list all the structural and architectural drawings used to create that entity (the list can contain as many as 10 different drawings). All existing drawings are in TIFF format and can be retrieved by double clicking on the entity in the 3D model.

In addition, each entity in the 3Dmodel is directly linked to the Opera House Facilities Management database. By double clicking on an entity in the 3D model, using its unique entity number, the Facilities Management master spreadsheet opens. This spreadsheet in turn is then hyperlinked to all other spreadsheets that are used for the daily running of the building. Similarly, by double clicking the entity number in the spreadsheet, it will open Bentley Structural, create a report, find the tag within the 3D model and show the location of the entity in one view.

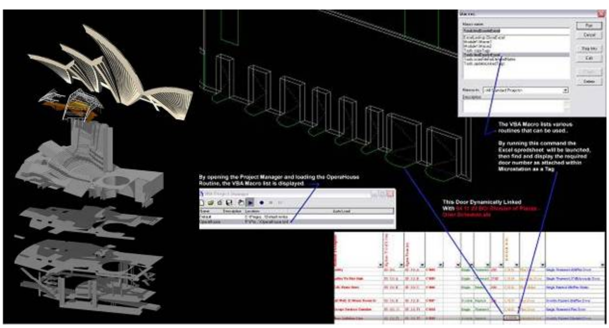

Fig. 1. Sydney Opera House, Opera Theatre Refurbishment linked to the facility management spreadsheets

This BIM, directly linked with the Building Management System (BMS), is currently being used by the building owner. The long-term purpose of this 3D model is to assist the team responsible for the proposed internal Opera Theatre refurbishment in attempting to realize the architect Jorn Utzon's original concepts.

Westland Road Tower. Arup participated in the creation of a BIM for Westland Road Tower in Hong Kong. Here the BIM was used for co-ordination and clash detection, within a project that was constrained by a very short timeframe. The tower is three hundred meters tall, seventy nine floors, and the client allocated a short six month design development period to produce Structural Tender Drawings. The tower client, Swire Properties [8], decided to use Digital Project[4] software.

Approximately twenty-five team members including the client's project manager, Quantity Surveyor, Architect, Structural, Mechanical, Electrical and Public Health (MEP) engineer and a 3D consultant were trained by the software supplier, Gehry Technologies [9]. A Model Coordinator was resident in the project office.

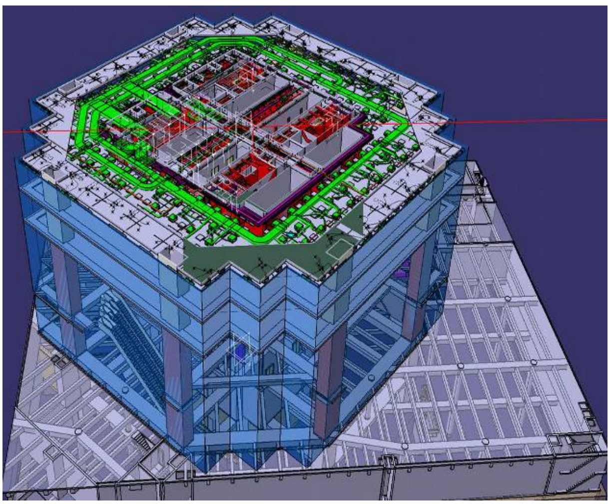

Fig. 2. BIM Westland Road Tower in Hong Kong (courtesy of Gehry Technologies)

This represents a pilot project for the client and for the industry as a whole. We are waiting for this tower to be completed and a few other applications before we can measure the full scale of the success.

Serpentine Pavilion 2005. Arup used Visual Basic (VB) scripting language and AutoCAD software for the twelve week Design Development phase of the Serpentine Pavilion 2005 [10] in London's Hyde Park. The driver for this method of working was to reduce the risk of mistakes in this project with a short time frame. The 3D geometrical model was a graphical instance of the script, the design rules evolved during the design development. This process insured that at least 80% of the model had no risk of mistakes. Doors and special edge conditions were added manually. The

[4] Digital Project software is the customization of Dassault's CATIA for the construction industry by Gehry Technologies.

success of the project was to build the pavilion with zero mistakes that were unacceptable to the client. To communicate with the fabricator, Arup used the geometrical model along with a text file containing the joint number and coordinates. Based on Arup's rules and joint information, the German fabricator rebuilt their model and checked it against the Arup three-dimensional model. When they started assembly on site, Arup produced a 2D drawing upon request.

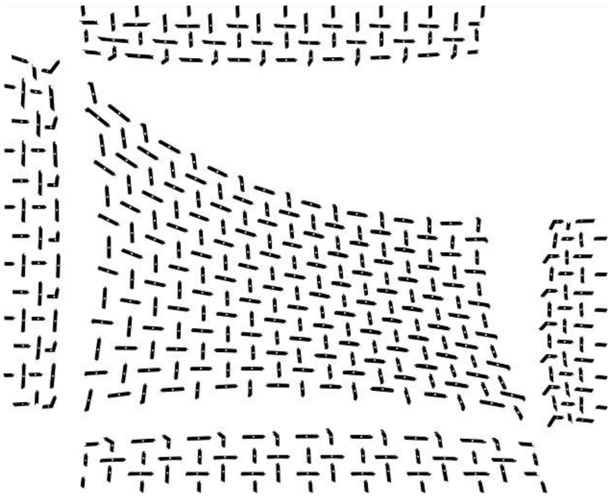

Fig. 3. Serpentine Pavilion 2005

Serpentine Pavilion 2005 proves the success of this methodology for a temporary pavilion. Now, the industry has to apply these techniques to the realm of permanent buildings.

2.2 Horizontal Integration of Disciplines

This section refers to 3D models which are used to integrate the results of the analysis of different design disciplines contributing to the design development of a project. These models are used to achieve a higher level of integration of the individual design disciplines and to communicate performance based designs to the public, the client and the regulatory authorities.

Three projects are highlighted here, each of which has been used to communicate with different bodies: *Florence High Speed Train Station* simulations were used to communicate with regulatory authorities, *Ancoats Village* urban digital prototype has been used for seven years by the client, a regeneration agency, to communicate with stakeholders, and *M1 Widening* was used in the project's public exhibition and public consultation.

Florence High Speed Train Station. Together with architect Norman Foster and Partners five disciplines at Arup [11] completed distinct design analysis of the Florence High Speed Train Station. The station box is some thirty five metres underground and some four hundred metres in length, dictated by the length of the new Pendolino high speed train. The design of the project was driven by the aim of bringing natural light thirty-five metres underground to the platform level via holes in the slabs.

Designers focussed mainly on two operational conditions of the building: one under standard conditions and another in the case of an extreme event. The worst case scenario was exemplified by the coach of a train arriving at the station on fire, aligned with the hole in the slab, with the doors open, some smoke coming out, a loud speaker announcement that the whole station must be evacuated, and finally with the windows of the coach exploding and more smoke invading the station.

The architect produced a geometrical model of the architectural surfaces that incorporated the bare-faced concrete structural model and the complex geometry of the steel roof. This three-dimensional model, evolving at each design iteration, was then used as a basis to create a RADIANCE[5] three-dimensional computational lighting simulation to demonstrate and refine the natural lighting levels at platform level. The same models were also used as a basis for a Computational Fluid Dynamics analysis, using STAR CD[6] to map the smoke propagation during the extreme event described above, and as the basis for a STEPS[7] people evacuation model of the entire station to support communications with the Italian Regulatory Authorities. Finally, the same model was used as the basis for a three-dimensional computational acoustical simulation, or auralization, of the station which demonstrated to the client and the authorities the intelligibility of emergency announcements with alternative acoustical insulation and public address systems.

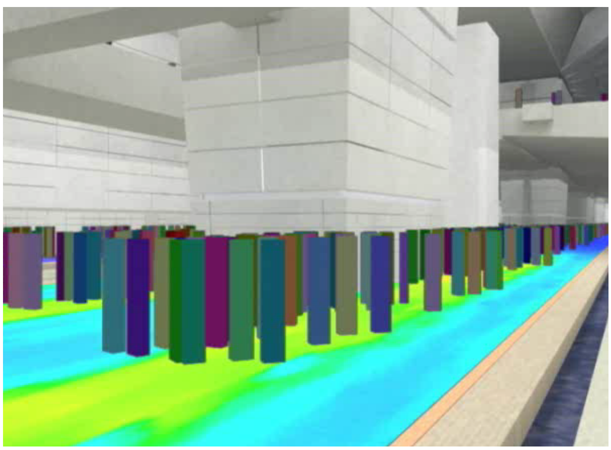

Fig. 4. Florence High Speed Train Station multidisciplinary simulation

[5] The Radiance open source software is a distributed raytracing package developed by Greg Ward Larson, then at the Lawrence Berkeley National Laboratory (LBNL) in Berkeley, California.

[6] The computer program STAR CD by cd-adapco.

[7] The computer program STEPS (Simulation of Transient Evacuation and Pedestrian movementS) has been developed by Mott MacDonald to simulate the movement of people during emergency evacuation scenarios.

Upon completion of this discreet simulation, Arup produced a multidisciplinary simulation that integrated the results of all discrete disciplines described above in one specific extreme event condition. To produce this multidisciplinary model, all analysis results were extracted directly from the different analysis models and were then manipulated in spreadsheets and imported into a common modelling environment, using 3D Studio MAX[8], via custom-made scripts. The model explicitly demonstrated the co-ordination of disciplines to the client; for example, no passengers evacuating the space were still on the mezzanine bridge by the time the smoke engulfed that level.

Ancoats Village Urban Regeneration. Arup has created and maintained an integrated area wide ICT information system for Ancoats Village Urban Regeneration [12], which, for the past seven years, has remained continuously accessible on the internet to all stakeholders (planners, developers, politicians, designers, engineers, transport and utility service providers and individual citizens). This has enabled more inclusive decision-making and has supported a more sustainable practice. The urban prototype, based on a live accurate geometrical model, has been used as a basis for visual assessment studies, transport modeling, pedestrian simulation, noise studies, wind loading, lighting simulation, and remote sensing technology studies.

Fig. 5. Ancoats, Manchester, City Modelling

M1 widening. Motorway design has changed since the M1, Britain's north to south motorway, was built in the mid 1960s. Designers now have to make sure that local communities are protected from over-development and that measures to minimise any impact on the surrounding environment are carried out. This is a process known as 'mitigation'. Arup [13] has created a synthetic environment to introduce the public and the project stakeholders to the key issues related to the M1 widening project:

[8] 3D Studio MAX by Discreet, Autodesk.

visual and acoustical performance of the noise barriers; new road surface to mitigate noise; retaining structures to mitigate impact on existing mature vegetation and light spillage mitigation.

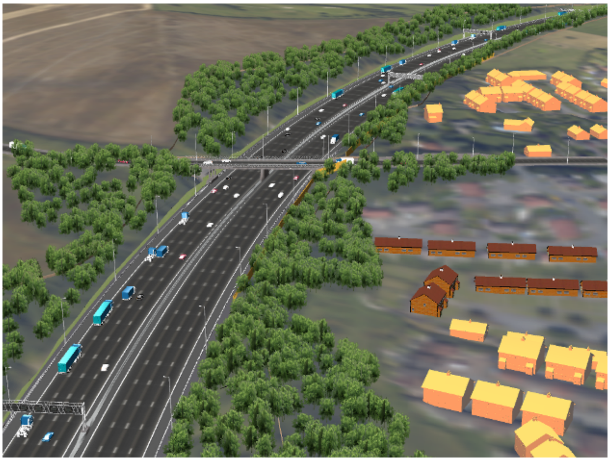

Fig. 6. M1 Widening for Public Consultation

The two km^2 synthetic environment, represented a stretch of motorway that was eighty-three kilometres in length which had been earmarked for widening. The synthetic environment was created from: three-dimensional design data of the proposed widening design, Ordinance Survey maps, LiDAR[9] data pre-processed for the ground surface building outlines and tops of trees, three types of aerial photography to create the models texture, accurate acoustical and lighting surveys, accurate lighting simulation, accurate auralization and indicative traffic flow. Three-dimensional tool InRoads[10] design data, in turn integrated several design disciplines including bridges, civil and geotechnical engineering.

With a large number of disciplines coming together for the first time in one environment, despite a virtual one, the challenge was to integrate different stages of design development and different entities which would have otherwise looked awkward in a single visual representation. For example the DTM captured by an aircraft flying overhead necessarily wouldn't include data under the existing motorway overbridges; however in the M1 synthetic environment it would have looked awkward to leave an empty gap in the model.

2.3 Construction Programming

Construction programming is undergoing a rapid transformation where a project program is linked two-ways with the three-dimensional geometrical model to create an

[9] Light Detection and Ranging (LIDAR) is an airborne mapping technique which uses a laser to measure the distance between the aircraft and the ground. This technique results in the production of a cost-effective digital terrain model (DTM).

[10] InRoads software by Bentley.

interactive graphical simulation of the construction process. Also referred to as four-dimensional modeling, this form of representation improves the analysis and communication of a proposed construction sequence or construction program and enables all stakeholders to contribute with greater understanding and confidence.

Linking three-dimensional representation with the construction program is possible in object based modeling and was not in the traditional layer based modeling. This idea is emerging most evidently in structural steel, but also in electrical design and it will probably spread to the other design disciplines.

Channel Tunnel Rail Link. For the Channel Tunnel Rail Link project, Arup piloted the use of four-dimensional models for the new St Pancras International Terminal using Timeliner[11] software. The pilot project included the modeling of over six-thousand activities in worksite areas and construction elements. This provided an accurate overview of the trade contractors planned works on the project, months in advance, and was used to identify contractor interfaces and generate time related clash reports.

Heathrow Terminal 5. At Heathrow Terminal 5 Arup piloted four-dimensional modeling of the Control Tower. The model was developed off the critical path of the project. Arup is currently using four-dimensional modeling on the T5 Interchange which is in the pre-construction phase. The interchange model is reputed to have been very successful in bringing groups of planners from different contractors closer together, proving to be a major aid in facilitating improvement in the program.

Fig. 7. Heathrow T5 Construction Programming

2.4 Regenerative Modeling

Arup uses two techniques for regenerative modelling: parametric relational modelling, and automated modelling.

Parametric relational modelling, also referred to as "live intelligent modelling" is a three-dimensional model that contains information about entities as well as their

[11] Timeliner by NavisWorks.

relationships or dependencies. This differs from the large majority of three-dimensional modelling where entities are independent. Early results from Arup pilot projects have demonstrated dramatic improvements in the design cycle latency, which drops sometimes from weeks to seconds. To create them, the math modeller, an emergent professional specialist, needs to develop the skills necessary to be able to extract hierarchies and entities for the design and define them in terms of parameters, dependencies and constrains. It is common with beginners to observe an iterative process of identification of parameters and dependencies, where the over-constrained model grinds to a halt and has to be rebuilt from scratch several times.

Arup conducted a post-mortem study on Selfridges Birmingham Pedestrian Bridge with RMIT[12] university [14]. The bridge's three-dimensional parametric relational models with architectural and structural dependencies and constraints were built using CATIA[13], thereby reducing the interdisciplinary design cycle latency. Construction constraints, including the maximum available tube diameter that changed during fabrication, were introduced in the model thus demonstrating that such a radical change in the diameter value dramatically reduce the design cycle time.

Arup also used parametric relational model methods on live projects, using Digital Project[14] software, in the structural design studies for critical portions of the Beijing National Stadium for the 2008 Olympics. On more recent stadium roof designs, once the parameters and constraints were defined, Arup used computational design optimization techniques to improve the selected parameters.

For the concept design of complex geometry, high-rise building façades, Arup has implemented the "user feature" tool within the software, which allows the definition of the design principles of a detail to be automatically adapted at each instance within the design.

Finally, automated modeling defines a technique that is becoming popular with designers, architects and engineers alike whereby the three-dimensional model becomes a by-product of the design process. The technique involves the identification of a set of rules that define the geometry. The rules are then scripted in a simple program that takes the values of the parameter as input and automatically generates a three-dimensional model in near real-time. The ability to adjust the defining parameters and rules for the dependencies of the entities and automatically update the entire three-dimensional data design model allows for radical changes at a late stage in the design process.

This technique was used, for example, to develop the design and eventually automatically produce the structural tender drawings for the superstructure of the Beijing National Swimming Centre[15]. Close to three thousand lines of VB script automatically regenerated approximately eighty percent of the roof's cellular moment frame geometries in 3D, which included some twenty-five thousand beams. In this design, cells are twelve-sided and fourteen-sided polyhedrons according to Weaire-Phelan foam theory. The three-dimensional model was generated using Microstation[16] software.

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[12] Royal Melbourne Institute off Technology (RMIT) SIAL.

[13] CATIA, by Dassault is a standard software of Aerospace industry.

[14] Digital Project is a parametric relational modeling software , by Gehry Technologies.

[15] Beijing National Swimming Centre by PTW Architects of Melbourne and Arup with China State Construction International Design. Under Construction. May 2006.

[16] Microstaion by Bentley.

One can imagine that this design technique will be more suitable to some designers then others, however it will become necessary in all those instances were a manual design process will take too long or it will carry too much risk of human error.

2.5 Interactive Synthetic Environment

Arup has developed an interactive synthetic environment called Realtime, which gives users the possibility of exploring their designs in three dimensions by roaming through them at will without the limitation of a pre-set path. All the project stakeholders have access to a preview of the project, avoiding expensive delays, misunderstanding or design mistakes. Realtime brings this capability to the projects quickly, reliably and without the need for expensive equipment. Successful applications have included a diverse range of time-critical projects.

Realtime synthetic environments are a development of cutting edge 3D graphics technology that fit the needs of clients, designers, planners and other professionals involved in the built environment. Three-dimensional models are brought to life with surface texturing, lighting and other visual detailing. Realtime environments can run on current specification computers with operation by a simple intuitive game console.

Realtime enhances the communication between the client technical team and the user and support staff by providing a realistic experience on the innovative proposed spatial design that affects current practice.

Arup's Realtime simulation provides three general modes of navigation: fly-around mode allows the user to go anywhere in the three-dimensional model, including through walls and slabs; first-person mode uses gravity and collision detection to give a 'human' dimension to the space. The user experiences the space with a view at head height moving along the floor or up stairs, with a pre-programmed natural walking bounce effect, constrained to accurate walking speed. Finally, a third-person mode adds an avatar to the first person experience. The avatar, male or female, allows the user to understand the scale of the design.

Realtime has, for example, been used by the firm to demonstrate the development of St Helens and Knowsley hospitals near Liverpool with architect Capita Symmonds to a group of stakeholders including patients and nurses, doctors and local council. The project includes a one million square foot newly built acute care hospital. It will be one of the largest building in town and the first of such buildings to be built within the community in this generation. An accurate understanding of the spatial relationship between the building and the surrounding community was crucial in order to reach a consensus among those present. All stakeholders in a project benefit from using Realtime, as it accurately represents and co-ordinates proposed three-dimensional geometry.

Similarly, Realtime was used to demonstrate a proposed design for the M1 Widening of a section of motorway near Nottingham described above. Here, Realtime took centre stage at the public consultation where people were encouraged to explore the proposed motorway widening design. Not surprisingly, the accurate and explicit demonstration of such a highly controversial project proved popular when presented to the public.

Fig. 8. St Helens and Knowsley hospitals screen-shot from Realtime

Finally, Realtime has become a necessity to a design team when the design is automated following a set of rules. This proved to be the case with the Beijing National Swimming Centre described above. The design team used Realtime to double check the geometry generated by the script. The interactive synthetic environment became a powerful tool for debugging the script and developing the design itself.

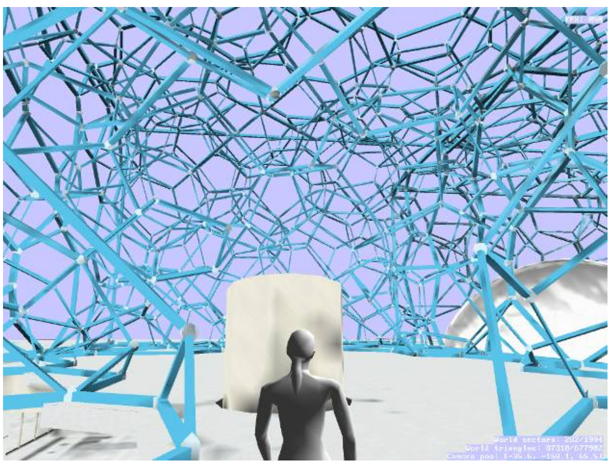

Fig. 9. Beijing National Swimming Centre screen shot from Realtime

Arup has also developed an interactive synthetic environment called SoundLab, used in design development and in the demonstration of three-dimensional audio material or auralization. The purpose of the SoundLab environment is primarily for the direct communication of acoustic concepts to other members of a design team, and for the acoustic design of performing arts venues and auditoria, but it touches on all aspects of the project. By recreating the spatial acoustic field of existing venues, and by comparing this directly to new design options developed out of three-dimensional geometric models, we are now able to immerse clients and project colleagues in the project during the design phase. SoundLab for example has been used for the design of public announcement systems for the Florence Station project mentioned above.

3 Preliminary Findings – The Designer's Desktop 2020

Within the context of current Arup practice described above, we carried out an international survey as part of an ongoing study on the changing nature of the practice. We interviewed two dozen colleagues from around the world, including clients, automotive designers, architects, engineers, software manufacturers and academics. The study will also include interviews with those who are more cynical about future developments, in order to present a balanced view. It must be reinforced here that purpose of the study is not to predict what the future of practice might be in 2020, which nobody knows, but to develop a map of possible futures. Such foresight studies are common for example in government.

This paper moves on to examine the changing nature of the profession; the toolmakers and custodians as emergent specialists in the digital design landscape; and the roles people are playing across academic disciplines and commercial practice.

To conclude we present a discussion of the social, technological, economic, environmental and political implications of designer's desktop 2020. Mention is made of hardware limitations for near-Realtime design regeneration, as well as the emergence of open source freeware and of the various initiatives used to create a (minimum) common denominator for exchanging data.

We began our interviews by presenting our colleagues with the following diagram, and by describing four arbitrary contexts in which designers might operate in 2020. We asked the participants to position their practice today with a dot on the diagram and to draw an arrow representing their perception of the context in which their practice might operate in 2020.

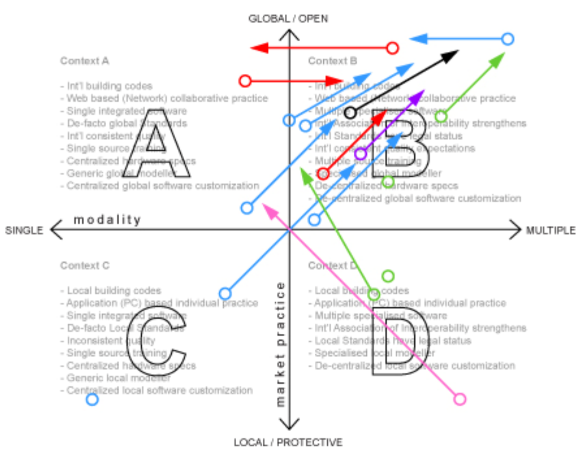

Fig. 10. Four contexts of practice range from the local and protective market with a single mode of practice *(Context C)* to the global and open market with a multiple mode of practice *(Context A)*

Developers appear to be pushing towards a design environment based on a single tool as a measure to reduce interoperability costs. Aerospace managers, who opted for a single tool design environment a while back in order to improve the quality of their life-dependent products, appear now to be grappling with a designer-led mini-revolution, driven by efficiency. Designers, on the other hand, are breaking away from the well-established single tool design environment towards an environment based on whatever tool does the job.

To canvas general perceptions of the designer's desktop 2020 we used a straw poll method. We asked our colleagues to rate, on a four point scale (from strongly disagree to strongly agree), the following ten arbitrary scenarios "I believe that by 2020 …". The table below shows the scenarios and the mean response. The preliminary sample was seventeen.

Table 1. Scenario Straw Poll

I believe that by 2020 … [sample of 17]	Strongly disagree 0% Strongly agree 100%
we will work digitally directly from bldg site	82%
we will be designing design systems	73%
2D Documentation will disappear	41%
Multidisciplinary BIM will be commonplace	78%
we will all work in open source	36%
we will use programs to stimulate versus simulate	76%
algorithms will learn from their user	72%
we will regularly simulate a dozen physics at once	81%
Modeling animated architecture will be commonplace	71%
Immersive environments will be used for design reviews	69%

These preliminary results, often conflicting and inconclusive, nevertheless highlight the highest level of agreement for a 2020 practice commonly using multidisciplinary integrated modelling which is accessible on the out of the office. This is in contrast with the current two-dimensional line drawing stored on individual computers. In addition, very much like the paperless office myth, it is suggested that 2D documentation will not disappear, immersive environments will have to wait even longer to get out of the university labs and unexpectedly for us, open source software will not be taking over.

Further recurring views were that tools will be assembled by project; we will be playing parameters in real-time; there will be an easier entry level to software, nobody will be teaching it; designers will be doing more programming and the motivation will be in seeing what can be done.

To assess the world around us we used the STEEP framework to ask colleagues "what do you envision lies ahead?". The driving forces and implications that resulted from these questions allowed us to focus on the factors which might influence our future, some of which are extrapolations and some of which are speculation. The following table shows the key excerpts gained from the interviews.

Table 2. Desktop 2020 drivers and implications STEEP framework

	Drivers/ Implications
Social	It's not just a matter of learning AutoCAD.., but more a way of transforming the idea of the design office, so that it is intimately connected with crafting these tools themselves. The quality of products in Aircraft engineering is so much higher than the quality of buildings. It may well be that we need to turn to alternative sources other than the traditional civil engineering department or architecture department. Transitory employment between employers will become a real challenge for employers
Technological	Search and access of knowledge will become a bit easier. The viewer will be on the web somewhere. You are going to have access to pretty much anything, anywhere you are. Biological modeling is going to drive the next ten years.
Economical	All sectors at all levels of the industry always must necessarily remain incentivised. Reducing waste in the construction industry can easily pay for the enhanced work at the front end. If the value proposition gets redefined, then the fee structures will change. Project insurance will be like decennial insurance, so none of the designers indemnify themselves, the client will actually indemnify the project
Environment	Buildings need to be designed in such a way as to diminish energy consumption. Green architecture is probably as big a force for design integration as all the other stuff.
Political	A more open, co-operative agreement, rather than an adversarial type of contract. It's embedded in the American psyche that every state gets to do whatever it wants. It is all depending on trust between the designer, the contractors and the clients. The openness of European countries will drive change. In New Orleans to replace three hundred thousand housing units the traditional design bid is not going to work. Three-dimensional objects are required by planners

4 Conclusions – The Changing Profession

Having described what we are designing across Arup, and having interviewed some two dozen professionals we conclude as follows.

The industry needs new specialists, and if academia doesn't provide them, the industry will have to resort to setting up private academies. This has already occurred in the past, for example in the mid 1960s, the Istituto Europeo di Design was set up in Milan when the Italian Academic community couldn't meet the demands for emerging specialists including the Industrial Designers. Similarly, a few years back, the Interactive Institute in Ivrea was set up by Telecom Italia outside Turin, when once again Italian Academia failed to address the need for multidisciplinary design education based on advances in computation.

Don't be mistaken, the blame is not only to be placed on academia, our professional practices will also have to develop attractive careers for these new specialists if we are to reduce the current outflow of highly valuable professionals towards setting up their own shop. A trend that would not be negative for the industry as a whole if it wasn't for the inevitable consequence that the specialist, once on their own, are forced to manage the process as opposed to practising it, generally with the result that they interrupt their research.

We identified four new emergent specialists in our profession: the tool maker, the math modeller, the custodian and the embedded PhD. What follows is an attempt to profile each of them.

Toolmakers might be individuals that create programs or scripts to generate geometry and could have a fundamental understanding of first principles of design as well as a solid background in computer science or graphics programming. They would be a central resource to the office or the region and would spend short and sharp periods of time (from 2 weeks to a month) with each project team. Tool making is a part-time activity that combines very well, but not necessarily, with design itself. When not helping the project team, toolmakers would be given time to reprogram relevant code written for specific projects in a more generic way for re-use throughout the firm. These individuals would also be given time to connect with the programming community outside the firm, and would regularly present their novel work at technical conferences.

The BIM Custodian, also known as the BIM Master, or BIM Co-ordinator, would be an individual with solid experience in 3D modelling, preferably in several different software packages. He or she would have an understanding of how to set up modelling protocols with a broad grounding in construction techniques and a good understanding of multiple design disciplines.

The BIM co-ordinator is a fulltime position working on one or a few projects depending on size. Similar to the current Project Manager, the BIM co-ordinator is one of the foremost specialists dealing with the client and public relations. He/she would be on the move and work with a powerful graphics laptop. Because of the nature of the work the BIM co-ordinator would also have exceptional interpersonal and team management skills.

Regenerative modelling requires an individual with formal education in design and in computation or equivalent experience. The Math Modeller work involves the abstraction of mathematical rules that determine geometry; the ability and design experience to foresee architectural, engineering and/or construction constraints that might occur during the design of the project. These individuals would have an interest in the emerging field of explicit capturing of geometrically engineered detailing knowledge for reuse on other projects. This is an emerging area that promises to transform the engineering practice and these individuals would need to be given the time and resources to interact with the software developer, university and external communities.

The Embedded PhD would involve a PhD candidate sitting within the professional practice. The PhD thesis topic would be determined through discussion with the host practitioner. The financial structure of the mechanism would be designed to maximise the relevance of the candidate's research work in conjunction with the new professional practice. His or her PhD advisor would provide research methods, protocols and computational software and hardware tools to support the work. This is in striking contrast with other more common mechanisms, like many of the engineering doctorates, where a PhD candidate sits in the professional practice and uses the workplace as a test-bed for his or her PhD research – research whose topic is determined in discussion with an academic advisor. One practical implication of this one mechanism versus the other is the employability of the individual in the professional practice at the conclusion of their PhD; where in one case the work is relevant to the professional practice, in the other case it might not be.

Object based modelling is very rapidly taking over line drafting. Currently, the main remaining obstacles seem to be hardware computational power and a large stock of outdated training courses and software boxes filling the firm's IT asset depreciation lists.

Based on the evidence presented, interoperability, currently heralded as the number one enemy of the profession, shall largely sort itself out with more of the general functions of the software moving to the operating system. Interoperability issues related to the specialist functions of the software might be dealt with by a network of people, including the toolmakers, as opposed to standards.

Following in the footsteps of the one-dimensional world of text, the preferred viewing platform for the databases of three-dimensional information might also be the Web, accessible anywhere and searchable in a "Google Earth" style.

Based on our synthetic environment experience, one of the implications will be the ability of these individuals to work towards targets and overcome the drive to resolve too many design details, too early in the project, a tendency that appears more common in three dimensional modelling when compared to two-dimensional drawing and drafting. By 2020 most of us will have retired and necessarily, in the developed world at least, we will be replaced by those that today spend hours playing computer games. As highlighted by Harvard Business Review's study, these individuals will make better managers as they develop faster at decision making skills. Explicit representation of the design process, together with the enhanced ability to make many small and fast decisions will change the way we design.

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