DESIGNER'S TOOLKIT 2020: A VISION FOR THE PRACTICE

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ABSTRACT: Designer's toolkit is rapidly changing and design practices need a shared vision of what the short, medium and long term might be. With this in mind we interviewed twenty-four thought leaders in the design community worldwide.

Four big ideas emerged from the interviews: transferring technologies from other industries has provided great benefits, but it has also generated the need to transfer processes; changes in the way we build drives changes in the designer's desktop, including the representations that designers use to communicate; greater gains are achieved by focussing on the interplay of specialised algorithms; "just on time" design data improves design.

Four possible contexts for the designer's toolkit are described: the proprietor aimed at increasing productivity, the open-source aimed at increasing IT driven creativity, either more or less engaged with fabrication.

Finally, the paper concludes by proposing what designers ought to be doing today. Actions include educating specialist toolmakers, custodian and math modellers; integrating computer controlled machine workshops into designers' project spaces; the automation of repetitive design tasks; supporting communities around software tools and store project data according to geospatial co-ordinates.

1 INTRODUCTION

Most design research focuses on explorations of ever shifting design requirements instigated by dramatic changes in society based upon the assumption of unchanging tools and *making* processes. In contrast this study focuses on changing design tools and making tools and their effect on design.

Designer's Toolkit 2020 review study acknowledges the changes in tools and *making* process of the built environment as well as the seeming distraction of designers in industry and academia alike. The paper proposes as way forward one common vision to be shared by practice, industry and academia built upon observation of the status quo as one way to accelerate a much needed transformation of design practice.

Designer's Toolkit 2020 refers to the framework proposed in the National Research Council, (USA) study "Beyond productivity: IT and the creative practice"[2] with four level of risk-return for research and development:

- IT produces results that could not have been predicted
- IT enables otherwise impossible outcomes
- IT enhances the quality of results
- IT enhances productivity

Unusually for a review in this field, all four levels are taken into consideration.

Designer's Toolkit 2020 focuses on design research projects and individuals working on project-based research methodology. This methodology, as explained among others by Martin Fischer [3], is in contrast to lab-based research methodology.

Project-based research methods involve identifying a non-trivial challenge in a specific context in practice and solving the specific challenge within the project deadline with intuition. Researchers often make use of bespoke tools and protocols and in this sense their methods are not different from standard projects in practice. However, the next step involves revisiting the challenge, focusing on what is novel in the solution and generalizing it from the specific project, then rigorously testing the validity of the solution, confronting the findings within the research community and finally contributing to knowledge with the publication of the results. The proposed research method inherently guarantees the practical significance of the solution, a characteristic which is often questioned in much design research.

2 METHOD

Designer's Toolkit 2020 involved interviews in 2006, with twenty-four recognized thought leaders [1], ranging from PhD candidates to industry board members, from across the design world with contributions from designers outside the built environment profession. All interviews were conducted by the author, were – when possible - face-to-face, otherwise via video-conference. A handful of interviews were conducted by phone.

3 FINDINGS – FOUR BIG IDEAS

Four big ideas emerged from the interviews. The following observations often reverse an existing perception. They should however be seen as transitory changes that might revert back at the end of the next cycle:

1. Transferring technologies from other industries has provided great benefits, however it has generated the need to transfer processes; how other industries produce their design and make decisions.
2. Despite most of industry and academia focuses on development of designer's toolkit to increases efficiency, the main driver for its change are the new ways of *making*. Naturally the toolkit has developed faster and further in supporting changes at the bottom of the construction supply chain, however tools for early stages design are creating greater gains for designers.
3. The gains from the interaction and interplay of specialised algorithms are greater then the sophistication of the individual algorithms.
4. Designers are getting used to "just in time" information available anywhere, fast, recent and relevant and are now expecting design information to be just the same. Specialised staff identifies with the project more than with the employer, and similarly client focus on project teams more the single contributing design firms. The toolkit has a key role to play in enabling and enhancing this change.

3.1 *Process transfer not technology transfer*

"Our edge comes from us and the way we think, not just our tools"

Transferring technologies from other offices and/or other industries has provided great benefits; it has allowed the design and construction of building projects that couldn't be built otherwise; however those working with new technologies, including parametric relational modelling and building information modelling (BIM) point out the limitations of this approach [5] and the necessity of a whole new one.

"Our children in their bedroom are using more sophisticated technology to make decisions within games than we're using in the planning environment"

Process Transfer is the ability to learn from other offices and/or other industries how they go about producing their design, *making* decisions and the way they think with their tools, what their protocols of interaction are, whom they interact with and who has control. A bold example here might be the Toyota lean manufacturing methods:

"We used to have computer programmers and designers, now we have designers that can program. The ability to program what you want, when you want has already brought larger gains for the project, for the client and our challenge is to turn them into designer's gains"

Traditionally tools and methods have been selected by the master designer based on years of experience; however currently tools and methods have become disjointed with digital tools selected by apprentices and applied to the master designer traditional methods. Methods must also to be selected according to new tools.

"New graduates have no fear of programming, no use of primitives"

Traditionally the architect has taken control of the design; however in other industries the model managers hold all the design information and have eroded that control. The Master Modeller's role includes acting as gate keeper that gives information privileges, *making* sense of information coming in, knowing what information goes out to different teams at the time they need it. Possibly "just in time" design information could bring similar quakes to design and construction as "just in time" manufacturing did to its industry. In a similar way that manufacturers have seen warehouses full of components disappear, hopefully designers might experience servers full of unusable and redundant design data disappearing too.

However, designers have to ensure that in the long term, control will return to them, when interoperability, access control and versioning which are the current challenges in the industry will be overcome. The financial industry has automated access control methods already.

"When model managers are third parties, they take control. Project Management is the ideal place to find the lateral thinking and specific understanding necessary to be a custodian, or master-modeller or model manager. This might be a temporary role".

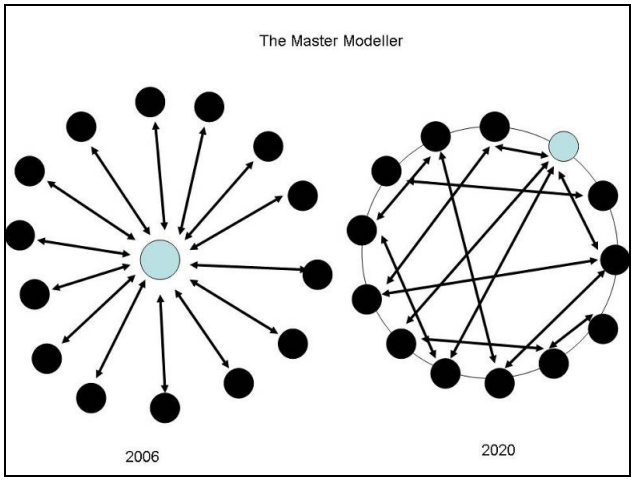


Figure 1. Diagram showing how Master Modeller role might evolve.

Master Modellers aren't the only emerging specialists.

"We will see a proliferation of experts, as the first rule of modelling "junk in, junk out" is still valid."

Computation is shifting the boundaries between disciplines, with the result that models from other disciplines are becoming of interest to designers. This is not new; what is new is that these models are explicit computational models that require set procedures to translate.

"I'm now involved with people in economics, in applied mathematics who have nothing to do with engineering, but who have little expertises that I don't have"

Designers might take notice of the role of the Math modeller in the automotive design industry. The electronic math modeller, also referred to as digital sculptor is the individual that takes a free form and then matches a mathematically driven form to it to create the computational representation.

3.2 *Design for new ways of making not design efficiency*

One of the greatest changes that is occurring to our industry is in the way we *make* (or build) things and specifically the increasing ability to produce unique and complex mass-customized designs at the same or even better speed, cost and quality of repetitive and simple mass-produced ones.

"We focus on novel designs not only measurable improvements."

Traditionally designers develop their abstract representation (scaled plan, section elevation) tailored to communicate their ideas and solutions to a number of audiences including, crucially, to fabricators and contractors. Now that design information feeds automatically into the Computer Numerically Controlled (CNC) machinery novel representations are required. These representations come in the form of spreadsheets of machine commands or databases, assembly instructions manuals as well as interactive visualizations that enable the fabricator to gain confidence that the script as well as the machine is doing the right thing.

The traditional representations of plan, section and elevation become redundant for the fabricator and the contractor. This might have profound implications for the designer that has used these representations as "tools to think with".

"Plan section and elevation will disappear as we know them today, however 2D schemes will grow"

There will be implications for other disciplines that have used the designer's drawings for example to extract quantities, provide planning advice, bring evidence in court and calculate fees. It is possible that all these disciplines will slowly adapt to the novel representations that are used to communicate between the designer and the fabricator. The following are just a few examples:

- The court used accurate representation of three-dimensional design geometry to support the case of a fatal accident on a building site.
- Channel Tunnel Rail Link (CTRL), the contractor used earthworks machinery driven by on board digital terrain models (DTM). This in turn is helping transforming the rail design industry from *vector to meshed representation*.

Steelwork fabrication quickly adopted *component based modelling* to improve their processes. This in turn is now rapidly transforming the designer's toolkit from lines, points and layers (which we inherited from the designer's hand drawings developed to communicate with the 19th century craftsman) to components and assemblies.

The Virtual prototype of the build environment, also named Building Information Modelling [5], or BEM Built Environment Modelling [6] is reducing the construction risk and waste. Designers have kept away from construction as it is a business with a different risk profile. However, reducing the risk has seen the proliferation of "garage contractors" who thrive on their green credentials because of the reduced waste and reliable delivery.

"There will be something of a pre-emptive modelling of the building process that will know exactly what's going to happen with the building. Today, if you go to have your appendix out, you don't hope you're going to come out alive. It's a near mathematical certainty that today you survive an appendix operation"

Conversely, the current limitation with Virtual Prototyping, which should be expected and it is common with all new forms of representation, is that it is unregulated and the practitioners are left with the challenge to select the appropriate level of detail and most importantly to communicate it to the team, so that everyone knows what the prototype represents and what it doesn't.

Designers should focus in developing tools to support the conceptual stage of the design process. First stage of the design process is arguably the most difficult stage of the whole process. It's much unstructured; it has no real algorithmic basis, at least not ones that can be readily perceived.

"We should enhance the front-end of the design process that's going on in all of the design offices. I think that many design offices miss out on a major possibility of increased productivity or an improved design the decisions made in the initial design stage, have an effect on 80% of what happens thereafter."

3.3 *Develop algorithms for integration not specialised knowledge*

There seems to be a cycle- we have had a twenty years of the development of algorithms that made explicit our industry's specialized knowledge, including finite element analysis modelling, and has greatly enhanced the development of performance based design in engineering. However, it was pointed out that there aren't many academic papers submitted in the past few years in this category. The current research focus is in enabling integration. Similarly in design practice, larger gains seem to occur in optimizing how disciplines interact than how they individually do our tasks.

Integration begins to emerge both vertically along the supply chain and horizontally across all design and engineering disciplines.

Traditionally the computational toolkit developed independently at a discreet level of the supply chain and in each of the disciplines. There is now considerable effort to get the tools to talk to each other, this area of research is referred to as interoperability.

"There'll be more ubiquitous footprints of operating systems that'll take more and more of the day to day drudgery out of writing software, so that software can get more specialised"

Initially links have been developed ad hoc and unidirectional. Such links allow the integration of results from discreet analysis within one single geometric model for review and demonstration purposes.

For example, simple visual checks includes assuring all analysis is conducted on the same version of the design or that Structural and Mechanical Services systems do not clash with each other.

"Holistic approach to sustainability drives multi-physics simulation? Absolutely, and with that will come a legal framework that will force you to do it. It's happening already in projects in Switzerland, also in Singapore and Finland."

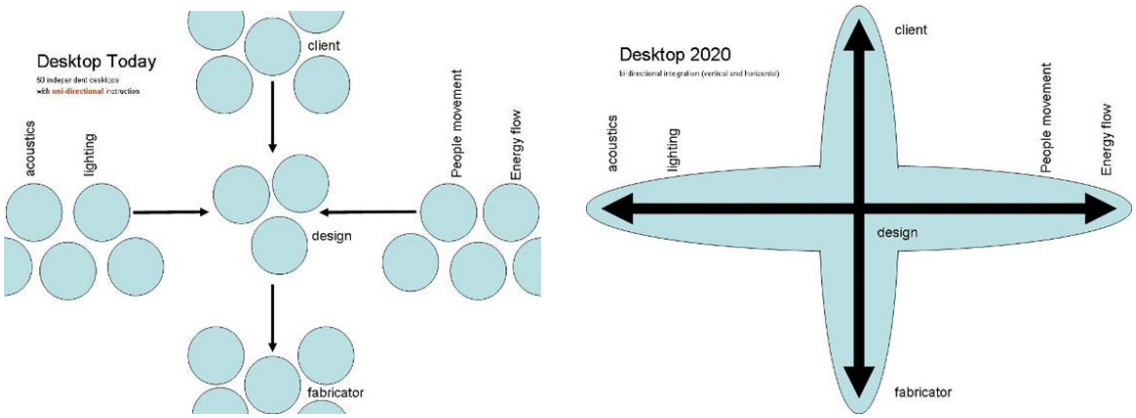


Figure 2. Diagrams showing current disintegrated tools and possibly integrated future tools.

"It's a multi-phase analysis; you need to do it at the conceptual design stage and at various stages all the way through. How to develop good evaluation technologies and requirements at each of these phases? It's a challenge to do that well and to be able to cross link across phases.

Horizontal bi-directional links between the analysis and geometrical model enables faster design cycles and allow for manual design optimization. In some projects, including stadium design, the geometry that is built might be the twenty-seventh design version. Bi-directional links between analysis and design also allow for computational design optimization [4]. For example in the design of space frames for long span steel roofs, CDO is being used to reduce the steel member size.

"The survivor will be the one that understands the need to connect"

The ultimate goal would be to take advantage of the interaction or interplay between discreet analysis as it occurs for example [8] in fire-structural analysis. The integration of the different discreet sub-models allows the designer to identify areas of overlap, interaction and feedback loops.

"The whole is more than the sum of its parts."

"The next drivers are going to be biology and I think it is biological modelling that is going to drive the next ten years."

Vertical integration already occurs in the automotive industry.

"Integration of CAD and PDM (Product Data Management) information containing vendor, product and consultant information, technology and industry research and CAD begins to provide automatic document writing and even specification writing (auto tailored to the customer and to the manufacturer)"

"Vertical integration provides feedback from top to bottom (Just in time?)"

3.4 *Where is the information? How fast, relevant and recent is it (rather than what is it)?*

Traditionally design information, whether drawings or three-dimensional digital models, was stored locally on the designer's PC. More recently designers had a single model environment where data is stored on a central server that is accessible by all the project team and sometimes its access is managed according to permissions.

Designers structured project information either according to folders and subfolders structures inherited from the time they had filing cabinets, or according to the way the project manager sees the world, the main goals being to retrieve the latest version of the relevant document without relying upon the designer that produced it.

However, with the continuous development of search engine technology, the ability to retrieve information based on key words has made redundant some of these organizations of information. Now, search engines have affirmed as the solution to organize and keep track of data.

Google Earth and others offer the opportunity to arrange information according to its spatial co-ordinates which provides an interesting alternative to the current naming convention based on chronological project number or the street address of the property. Imagine the situation in which you are working on a design for a holiday resort and you "see out of your window" the first three-dimensional sketch model of the feasibility study for the proposed wind farm.

"All project information now resides in one single environment that can be searched, so that the history of the design process and decisions can be simply tracked down. Relational database interface is visual and time dependent. Similar to Google Earth every bit of information retrieved will be presented in its context, both spatial and time (versioning) context"

Web-based tools have becoming increasingly popular for the one and two-dimensional creation of data, we are all becoming used to the fact that the latest version is on the web. Driven by a designer's increasingly dispersed team and the need for asynchronous working, three-dimensional modelling might become web-based and will have the security and reliability of today's banks.

"Completely ad hoc wireless technology where, the connectivity between you and the information you need is totally random and takes place just on the basis of where you are and what time of day you go about doing your business. The difficulty with wireless right now is distinguishing between multiple frequencies. It's all right if you want to get four people, but you've have to understand that there may be a thousand clusters of four or five people each, all within a half a mile of where you are, trying

to do their business, too. The only way to do that might be to make each human body be that determination of the frequency"

4 DESIGNER'S CONTEXT

The four big ideas described above will have different implications as they will occur within alternative context.

The designer's toolkit context might be unpredictable, but there are a few facts that everyone agrees upon and we know with reasonable certainty:

- Children that play computer games will be the designers of 2020
- Designers will not be attached to the desktop
- Designers will be more specialised
- There will be more collaboration between people with more diverse backgrounds (biologists, economists, applied mathematics)
- The virtual prototype is here to stay.

The matrix for the designer's toolkit in the figure below defines the possible contexts; the proprietor aimed at enhancing productivity and the open-source aimed at enhancing IT driven creativity. Either occurring in an environment more or less engaged with fabrication.

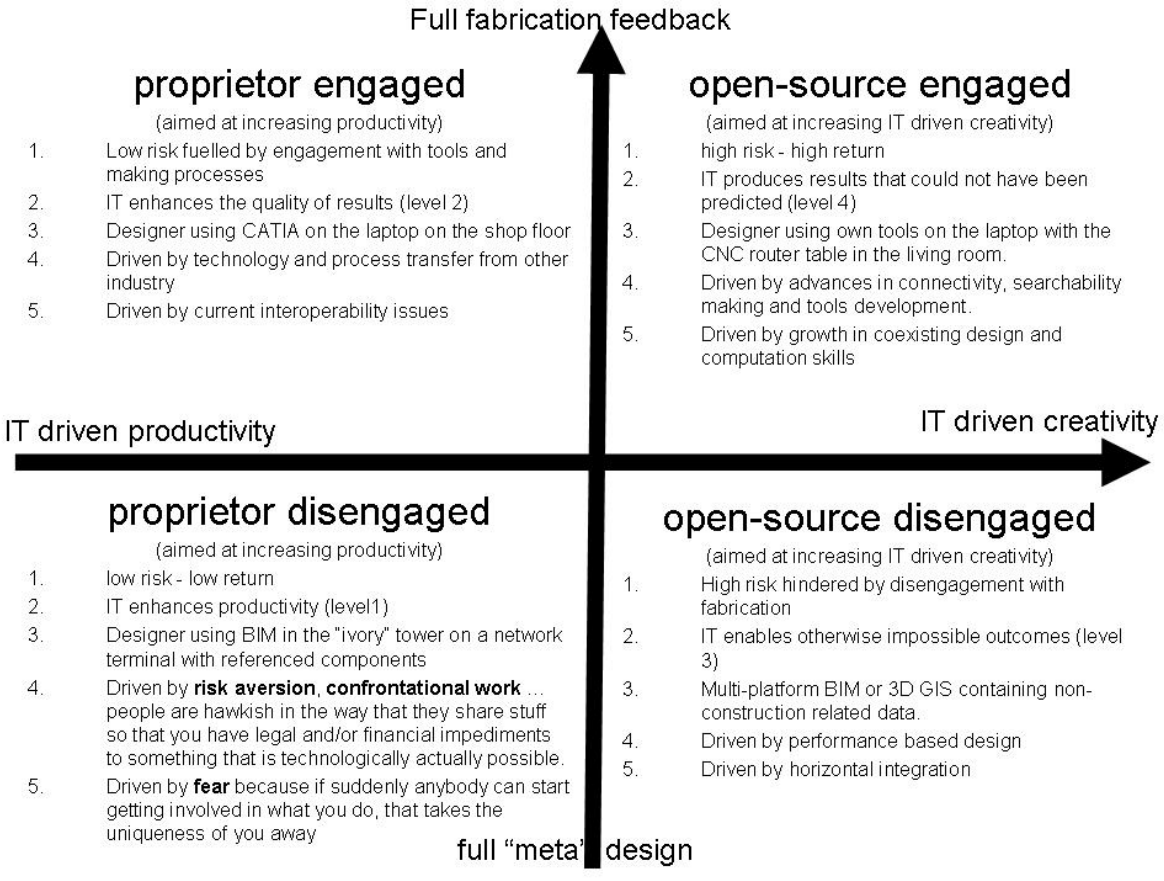
Additional perspectives are proposed in the following that might be relevant to measure the designer's toolkit 2020. These include:

- Production feedback versus richness of data transfer, currently limited to geometry and aspiring to include material, cost, assembly and user manuals etc.
- Employment model (fulltime to collaborator) versus mono to multi-disciplinary
- Dimensional representation (2D to 4D) versus *making* process (19th century craft to Computer Aided Manufacturing (CAM) and sequencing)
- Horizontal, multidisciplinary versus vertical integration along the supply chain (20% to 80%)
- Drafting to modelling versus architectural to multi-performance design
- Generative nature of design, from design instances to design rules optimization

All interviewees agreed with the importance of understanding the possible context within which the designer's toolkit will develop as well as of identifying measurable characteristics to be able to evaluate progress.

5 ONE POSSIBLE SCENARIO FOR THE DESIGNER'S TOOLKIT IN 2020

It is now June 2020, the firm designers are still at their headquarters building which they occupied since the firm begun. The building is now 20 years old and in need of refurbishment as it doesn't perform within the current energy consumption rules.



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More then 50% of staff are temporary both from outside the firm as well as from other offices. Their connectivity is completely ad hoc and wireless. The office has become a workshop for people to come and do their "performance", similar to downtown theatres or studios with a director and a small local staff to run the space and manage it.

More designers are tasked to look at other industries and domains to learn about their innovative processes. They are assessing how these novel processes can transfer to Arup, nas it happened with manufacturing method of "just on time" parts successfully transferred to "just on time" data for design.

Designers have learned tool making at University in a postgraduate course in addition to their formal education in first principle of design. Similarly, but more rarely, they might have learned by developing their professional careers in different industries and domains.

Fewer designers are looking at technologies, as it is not necessarily only the tools, but how designers use them that make the difference. For example, designers are not being given videoconference units, electronic white board, extranet, blogs etc…, instead they are given training on how to work remotely, 24/7 and non co-located, or how to choose between solutions according to the type of work, whether commercial and on the move or technical at the desktop.

Increased overall level of professional training, when compared to the beginning of the millennium, is occurring in the form of "learning by doing" in a highly controlled environment, running the complete technology solution and support, and where for example issues of culture are specifically addressed.

More designers have given up learning about innovative design processes from software re-sellers and are instead learning from other designer or researchers that are designing with different processes.

Designers are offering consultancy in design processes to selected designers at high value added prices, avoiding the direct competition. This creates tensions with other designers that are still offering instances of design.

Designers find their inspiration from new ways of *making*. All design teams have a workshop in their office where they can carry out physical prototyping of their ideas directly. The computer-generated-physical modeller will initially be a specialist role similar to the digital modeller, who has now become commoditized and disappeared as a specialist.

Design firms have begun to locate offices strategically near bigger workshops and to share with other industries, the likes of the movie industry.

Design firms are partnering with contractors, fabricators and owner-operators in demonstration and pilot projects to fast forward the adoption and exploitation of novel methods in the construction industry. Design firms have developed their own *making* activities aimed at developing designer's ability to innovate and rethink design from first principles rather than it being aimed at the business of fabrication or construction.

Sustainable design research has highlighted that high performance in buildings, including sustainability, can only be achieved with high performance operations and management of the building. This is why designers are now in the business of operating their building and using the feedback in the design process.

On a pilot project, designers have now been able to achieve something that was not possible because of the limitations of employing humans in the construction process.

Increased specialisation is a direct consequence of the first law of modelling: "junk in, junk out". As a result of increased specialisation and globalisation, the designer is now more multidisciplinary, multicultural and mobile. Culturally specific abstraction, for example written notes in English, or discipline-specific symbology, for example the arrows used by architects to indicate raising ramps on plan are not sufficient representation to assure an effective exchange of information when working with a Chinese Computational Optimization Programmer, logging onto the network to discuss the design at the fabricators shop in Germany. As a consequence designers are using full visual representation at all stages of design with 100% information from all disciplines.

Full virtual prototype has increased the understanding and value of the discipline specific modelling and has created a strong need for algorithms that consider the interplay of parameters from different disciplines. Following a period of slow development in algorithms, there is new activity in cross-disciplinary modelling, similar to the early 2000 evolution of fire-structure non-linear modelling.

Now all discipline modelling uses computational design optimisation, and current research is in multi-disciplinary optimization or project optimization.

Now all the issues of integration and interoperability of explicit three-dimensional models that occurred at the beginning of the century have been hammered out with the new "designer's platform". This reminds of the way "plug and play" operating systems have sorted out hardware incompatibility and painstaking searches for drivers.

Toolmakers, custodians and math modellers in every group are experiencing a commoditization of their specialities in the designer's community. Young designers joining the firm are already equipped with these skills; (ref: from Digital Design Media "and then in the end it will just be called design") however their skills have not become redundant, on the contrary they are now a requirement for any designer.

Office visitors from different firms or offices working on the project, using whichever operating system, whether Windows or Linux, are now able to connect with their laptop to a selected number of services including internet, project folder etc…without threatening the security of corporate firewalls.

At the front desk, offices now have a set of procedures, (or scripts) that can be run on visitors laptops when they check-in to configure local printers, local mailing lists, local outlooks, local favourites (way around town, local transport service etc…), local room booking, local profile etc.. Check-out procedures will run an uninstall script that will clean up and restore the original.

Since the early 90s we have seen commercial staff and design leadership travelling across offices, their visit was one day in average. If they were not travelling there was something wrong. Now design practitioners travel to other offices to apply their expertise for weeks at the time, their needs in terms of toolkit are dramatically different.

The office has been 100% laptop for some time. Every employee has the laptop(s) appropriate to her needs. With increased literacy, new starters are asked what laptop and software they need and only if unclear, they go through a series of interviews to determine what might be appropriate to their role.

Specialist designers, lonely in their specialties, belong to global communities of practice inside and outside the firm including for example the Virtual Design Network within Arup, Smart Geometry Group [9] or Radiance User Group [10]. Designers are loyal to those networks as much as to their employer.

All project information now resides in one single environment that can be searched, so that the history of the design process and decisions can be simply tracked down. Relational database interface is visual and time dependent. Similar to Google Earth every piece of information retrieved will be presented in its context, both its spatial and time (versioning) context.

Finally, creating digital tools is an activity that is encouraged and praised within the firm with "the most re-usable and generic tool" internal competition. Sharing of tools or toolkits is encouraged both between offices and outside the firm. The main value in creating tools is as an "object to think with" rather then the tool itself, similar to hand drawing for designers.

Each project utilizes more or less bespoke design tools according to its innovation ambition and budget. For example a project aiming at breakthrough innovation will use no middleware, similar to what it has been since the beginning of the millennium for games designers.

7 TEN ACTIONS FOR TODAY

Bearing in mind the finding outlined above and in view of the four possible scenarios what are the ten things that designers should be doing today?

1. Create the need for, not provision of technology. For example: increase understanding on how to conduct technical (not only commercial) work on the move, remotely, 24/7 and non co-located, or how to choose between solutions according to the type of work;
2. Convert meeting rooms into machining workshops to be able to "think with the new processes" and create informative scaled prototypes;
3. Create graduate professional degrees in M3D or Master of Information;
4. Develop a Virtual Prototyping standard that outlines what is included and what is not at every stage of the design process and might propose two or three type to choose from, (Light, Standard and fully Integrated Virtual Prototype) according to the integration ambitions of the project;
5. Praise and encourage the "thinking with new tools" in a highly controlled environment, fully equipped, fully supervised environment or "sandpit";
6. Enhance office front desk to support temporary practitioners on the move, with check-in and check-out procedures, concierge etc…;
7. Store all data online according to absolute spatial coordinates;
8. Reduce the teaching of software. Increase programming training and motivation, show what can be done;
9. Hire staff with computer science background to sit next to the designers to automate repetitive design tasks;
10. Assure that more than one person knows how to drive BIM.

ACKNOWLEDGEMENTS

The author would like to thank all participants to the interviews for their insight, colleagues within Arup for the informal discussions, Chris Luebkeman for leadership and encouragement throughout this study.

REFERENCES

[1] All comments in italic have been selected from the personal interviews by the author for Designer's Toolkit 2020 study with: Professor Mark Burry, RMIT, Melbourne; Reed Kram, Kram Design, Stockholm; Charles Walker, Arup; Jeffrey Yim, Swire Properties, Hong Kong; Martin Riese, Gehry Technologies, Hong Kong; Axel Killian, MIT, Boston; Jose Pinto Duarte, Lisbon University, Lisbon; Joe Burns, Thorn Tommasetti, Boston; Mark Sich, Ford Motor Company, Michigan; Phil Bernstein, Autodesk, Boston; Lars Hesselgren, KPF, London; Mikkel Kragh, Arup; Bernard Franken, Franken Architekten, Frankfurt; Martin Fischer, Stanford University, San Francisco; Tristram Carfree, Arup; Mike Glover, Arup; Duncan Wilkinson, Arup.

[2] Mitchell, William J.: et al eds., Beyond Productivity: Information Technology, Innovation, and Creativity. Washington, D.C.: The National Academies Press. 2003.

[3] Martin Fischer, Formalizing Construction Knowledge for Concurrent Performance-Based Design in Intelligent Computing in Engineering and Architecture 13th EG-ICE Workshop 2006, Ascona, Springer 2006

[4] |Chris Luebkeman, Kristi Shea, CDO: Computational Design + optimization in building practice. The Arup Journal 3/2005

[5] Building Information Modeling, white paper September 2002, Autodesk Inc. http://en.wikipedia.org/wiki/Building_Information_Modeling

[6] Tristram Carfrae, unpublished notes from Virtual Design Network Conference, June 2007.

[7] Chris Luebkeman, Alvise Simondetti, Practice 2006: toolkit 2020 in Intelligent Computing in Engineering and Architecture, 3th EG-ICE Workshop 2006, Ascona, Springer 2006

[8] Susan Lamont, Barbara Lane et al. Behavior of Structures in Fire and Real Design - A Case Study in Journal of Fire Protection Engineering, Vol. 16, No. 1, 5-35 (2006) Sage

[9] Architecture is fundamentally about relationships. Many of those relationships are geometric in nature or find a geometric expression. The SmartGeometry group has been created in the belief that Computer Aided Design lends itself to capturing the geometric relationships that form the foundation of architecture. www.smartgeometry.org/

[10] Greg Ward started developing Radiance in 1985 while at Lawrence Berkeley National Laboratory. The source code was distributed under a license forbidding further redistribution. In January 2002 Radiance 3.4 was relicensed under a less restrictive license. http://www.radiance-online.org/