Beyond Architecture:
How Computation empowers the 21st Century Master Builder

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The presentation will cover works from both my office called Laboratory for Explorative Architecture & Design Ltd. (LEAD) and other the projects I have developed as Assistant Professor in Computational Design at The Chinese University of Hong Kong School of Architecture. What I'll be talking about today is how computational technologies are allowing for a different type of architectural practice to emerge.

I'm from Belgium originally, but I've been in Hong Kong for almost seven years now. I used to work for a while for Zaha Hadid Architects back in London before I decided to move to the other side of the world where we live in dense cities, maybe the most compact cities, depending on how one looks at it.

The city of Hong Kong was a radically different environment to arrive in for many reasons. When I was working for Zaha Hadid in Belgium and in London, as well as for other projects like this in Europe, what you draw is usually what you are going to end up getting. The clients we worked with, the consultants we worked with, the budget we had at our disposal, all formed an unique experience and it was great to be part of a team like that. At the same time as I was working on a project for Zaha in Belgium, her office worked on this competition implementation in China, just across the border from Hong Kong. This is the Guangzhou Opera House and, you may not be aware of it, but this project became a milestone for anybody who is operating in China—unfortunately for the wrong reasons.

This is from a news article published a year after the construction. People were lamenting the fact that the building was already falling apart. In a way this project became a stereotypical example of how things can be poorly made in China. There is even a book talking about product design suffering from a similar tendency (Poorly Made in China: an Insider's Account of the Tactics Behind China's Production Game).

I watched this project closely during its implementation and upon its completion and I don't think that the finger for this is to point at Zaha's architecture or at the Chinese construction industry. I think the result is entirely out of lack of a constructive dialogue, of authentic dialogue, between the people that implement buildings and the people that design them, and how designers work with the means that they have at their disposal. If there is such a lack of awareness, then disasters can quickly happen. Since I moved to Hong Kong this topic has been very much at the forefront of every piece of work I've been doing.

To give an example, these are the outlines of work as specified by the RIBA, the Royal Institute of British Architects, where you see all the phases that architects are supposedly involved with, going from conceptual design all the way to construction and post occupancy reports, etc. For the majority of the work this is not happening in Hong Kong and I think it is a trend that starts to spread world-wide: architects are very often separated from the entire format. Very often, especially if they work with developers, they are dealing with in-house design teams which are already put in place, and all they have to do is basically to provide concept design, maybe design development. Then your project is handed over to Local Design Institutes that develop and build it, and you're left with just the artistic supervision, meaning that in that process a lot of complexities of your project might become very problematic, unless you're building very generic architecture.

So, how can we, as young architectural designers, find a way to hack the system? How can we move around this reality?

That is where the centre of my research and my office work is based. One of the great things of doing this type of work today is that nowadays your washing machine has more computational power than they used to put people on the moon on the 1960s. That is a fact! Processors nowadays are so fast and so cheap to produce that they don't even produce the cheap ones or the slow ones that you need for the washing machines.

We have a redundancy of computational power at our disposal. That means that there is an opportunity for computational architectural design practice that engages with often non-digital or less digital cultures through strategic dialogue.

The talk today is centred on what it means to materialize architecture and what differences computation and digital design can potentially bring to it.

I'll be talking about three projects, from small scale to big scale, art projects to urban installation, from small to large structures, and the use of computation in various aspects of their design. The first one will frame the working methodology, the second one will talk about idiosyncrasies of the context in which we're working, and the final one will summarize and bring everything together.

The first project is the Dragon Skin Pavilion, a project that we did in 2012 for the Hong Kong Biennale, where we were working together with the Finnish University of Tampere where we had done a workshop (Fig.1). A Finnish wood manufacturer had approached us because they had a new type of wood available that included plastic inlays. Because of these, you don't need to steam bend the material to deform it. You just need to heat it up to 150 degrees and it will become supple, like leather. This means you can work with it in a much more sustainable way than what you would be able to do with plywood. But they had no immediate architectural use for it, they had not yet extensively experimented with it, so they gave us a pile and asked us to do something. We ended up making this pavilion with it—we called it The Dragon Skin Pavilion. What is important to know is that anything you see on this image, although it looks extremely decorative or very ornamental, that all these qualities are the by-product of an extremely rationalised and efficient fabrication and construction methodology that we had to devise as part of the project.

When we started the workshop, students were working with cardboard which can easily bend in a similar manner. Then, from these little physical models, we moved on to procedural models. Our team took on the concept that they came up with and digitised it inside our parametrically controlled environments. This is the work flow that we had set up: a normal eight by four feet wood sheet would be panellised and cut in exactly the same squares. Those then had slots CNC (computer numerically controlled) milled inside. Then they would be heated up and bent onto one single mould until all of the shells had exactly the same shape.

Fig.1 Dragon Skin Pavillion, internal view

All the complexity of the geometry lay in the exact precise position of each and every one of the slots. Here you see the milling patterns we used to cut the wood, and you can see that there is hardly any material loss and wastage. Then, these were brought into a little oven as you can see in here, and very quickly, very roughly, because we didn't have much time, they were stamped into these moulds that we had made in the workshop. We did this probably within a few millimetres or centimetres accuracy—we don't really know. The shape of the project was designed in such way that all panels would connect without glue, without screws, without anything, they would just slot into one another. Based on the number of interlocking points and overall equilibrium geometry of the shape, the whole thing would keep shape and come through.

Here you see the assembly. We were just following numbers, not even using plans. We had only one plan on the ground and from there we just puzzled pieces that would be brought together. We needed to figure out a little bit how to do it, so students volunteered to make a human scaffolding. In the end, we managed to basically lock everything into place.

Although this project was extremely "affectual", if that is a word I can even use, it is because of the very simple underlying procedural logic, the computer-controlled process that allowed us to very precisely define every slot and every interconnection, that we arrived at this very beautiful warm field of panels sliding across the space. Here you have a sense of the scale of it, you get a view from the inside where you can see the light under it playing with the transparency, by opening it up in certain areas and closing it off more towards the back, and here you can see the warm glow that comes out of it at night.

So, ornament can be part of architecture, but in this case here, it came at absolutely no cost. It was actually a by-product of a hyper efficient construction set up where there is no difference between skin, structure, lighting deflector, etc., etc.

The second project scales up from the first quite a bit. This was a year later when we won a competition in Hong Kong. We were asked to do a bigger intervention for the "Mid-Autumn Festival". I don't know about Japanese culture, but in Chinese culture this festival is one of the most important events of the year because it is celebrated on the day when families unite again and come together. There is a legend associated with it: the Moon Goddess was banished and only once a year she was allowed to see her husband. We entered the competition basically with a joke saying that when a young couple sees each other only once a year, then, from sheer passion and friction alone, the moon is going to get so hot it would catch fire and burn. We never thought we were going to win, but we did. The client said that we could do it under the condition that we change the moon from Burning Moon to Golden Moon (Fig.2), which was no problem for us. Here you see the competition images, where we just wanted to make a very aggressive statement in the city by creating this planetoid that would contrast heavily with the very generic building fabric surrounding it, all with a very bland pastel coloration. We created this environment where people can go inside and be transported to a different world.

Fig.2 Golden Moon Pavillion, external night view

We submitted exactly these competition drawings, where we said we were going to make a reflection pool on the ground, we're going to rent a geodesic dome, we're going to cover it with bamboo, we're going to cover it with stretch fabric that would have very simple details, we're going to put some LED lights, and that is it!

When they called us to say that we won, they also said we had to stick with this schedule. We had three weeks for design development before going for a public tender process of a month, in which we didn't know who we'd be working with. Then, we had three weeks for pre-fabrication, eleven days for construction, six days for the festival, and one day for demolition again. This is a six-storeys building, though, a twenty meters diameter steel structure that had to be built from scratch. Here you see the plan, which is basically a reflection pool and then this pathway that runs through it. From the section it is possible to get a sense of scale. The design was basically a steel platform that, because we couldn't put any foundations, was held down by a concrete slab. Then, we had a steel bent geodesic dome, that was cladded with two kilometres of bamboo, on top of which four hundred and seventy-five different flames were supposed to be placed to create the overall pattern.

For the design of this steel structure: if you want to make a big sphere, there are two ways to do it. One is to make it like a Bucky Dome (Buckminster Fuller's Montreal Biosphere), where you work with repetitive patterns. This is what footballs are made of. The problem with this geometry is that it doesn't allow people to enter it without breaking it. We used a different formula which is coming from Fibonacci and is a couple hundreds of years old. The formula basically allows you to throw objects at the sphere and populate it, creating a quasi-symmetry and repetition around the equator and a strong polarity on both ends. That polarity allowed us to basically create an entrance at the bottom left here and an oculus at the top that became a focal point for the geometry as well, as you can see here.

The steel structure fits inside this. We went to manufacture across the border in Guangzhou, where we went to a shipyard where normally per year they build around twenty two-hundred meter-long container ships. The construction drawings we made for them were exactly these. There were only two different types of members, because this is a geodesic dome. We had numbered them all specifically and had mapped where on the steel geodesic dome the intersections were going to be placed with the bamboo poles that were going to be on the top of it. This was made in the simplest way possible. In the back you can see a little induction coil, just basically a magnified microwave oven through which you squeeze this big metal pipes, and in front we see the rollers that can be manually controlled to bend these pipes into the accurate radius.

In a few days they managed to roll all of these out. Everything was nicely numbered according to our drawings, and all the markings were done on top of it. Then everything was painted black, and then the markings would be done again because of a communication problem. The steel structure was brought to site, and here you see that in a few days the structure was assembled.

Then, the more challenging part came. How do you map a three dimensional diagrid onto a steel structure without having an opportunity for people to read plans onsite? Here, we took the bamboo poles, we unrolled them, marked the intersection points on them. We asked the workers onsite to mark everything manually and use that as a guide to map them onto the steel structure. I don't know if you can see it exactly here, but the diagonal lines that are going up are part of the diagrid. The marks on the steel structure and bamboos will match and the diagrid will eventually appear.

This was done following a very typical Cantonese bamboo scaffolding making technique, where people would just by hand tie certain knots to fix bamboos together. Here you can see how at the very tip culms are coming together and the craftsmen are trying to figure it out how to finish the final tip there.

There was a question of extracting the right amount of information from digital models to allow this to be built.

Then the flames needed to go on top. Originally, we had white lanterns that were going to be coloured by the LED lights itself, but in Chinese culture white lanterns are only used for funerals, so the client demanded that we add colour to it. In the end, we had eight different colours of fabric on top of it. The resulting geometry was resolved by working with a paramorph. The idea of the paramorph is basically that of an object that can morph its geometry depending on which environment it is placed in. We took all the "flame" geometries we had, and we laid them out all next to each other. Then, we digitally grouped them into the eight most common denominators that we had in between them. We designed a very simple detail for a large stretch fabric flame that would be able to absorb and adopt all geometric forms that are necessary.

The complexity of all these frames was reduced to eight different shapes and eight different colours. Here you see how these were being put together just by using thin bamboo sticks and electrical tubing in order to cut the costs as much as possible and allow us to drill and make them easily on site. Details were done in such a way that in fifteen minutes a team of three or four people would be able to install flames by wrapping edges around and using zip ties and cables to put all things together. Here you see how the bamboo grid got absorbed into the flame geometry. Those lines you see coming down are the LED lights that were installed at the same time as well. Basically, we took a one-megapixel-screen and then wrapped it around our sphere and used data boxes around the equator to send the signals of a video mapping around to the whole structure.

Here is the day before the opening where all of that was still being positioned. All the flames were nicely positioned with simple metal wire coming down from the top. We positioned a few flames together with the contractors. Then, we asked them to just match these as much as possible to get the overall effect.

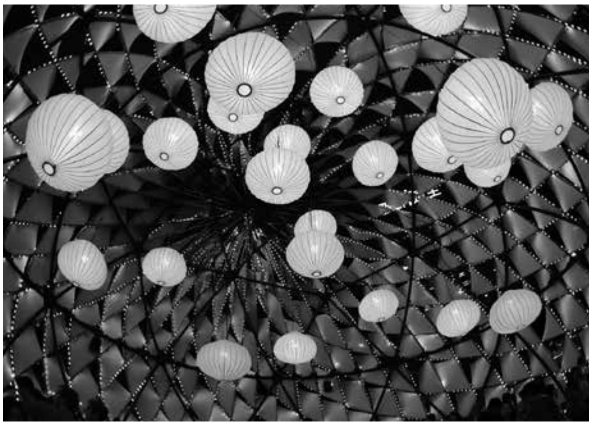

Fig.3 Golden Moon Pavillion, internal night view

This is the view from the inside (Fig.3). We had an animated light show running over the whole thing creating a sort of pattern going to the top with all these big lanterns hanging and swinging inside the winds. The combination of all of these effects meant you could really not focus your eyes the very minute you entered, because it is a very submersive environment where everything around you was spinning and twirling. It became a big success with about four hundred thousand visitors in six days. We had to cut the show in a half and extend the queuing area just so that people could get in.

Here you see the top of the scrambling geometry at the upper pole. Here you can see the colours it can get by night. And a very quick little video of it.

Basically, this thing went on, spreading out onto people's Facebook pages.

The final project, which is the ZCB Bamboo Pavilion, is a project we did with the Chinese University of Hong Kong in Hong Kong last year. Here, our client was the construction Industry Council, which is the Government Institute in charge of the construction industry and of the training of workers. They had this building and a square in front of it (Fig.4) (Fig.5). In Hong Kong, all the scaffoldings are made from bamboo and they had this difficulty that the craftsmanship is disappearing. Young people are no longer interested in that kind of industry. So, our job was to make bamboo "sexy" again.

Fig.4 ZCB Bamboo Pavillion, aerial day view

Fig.5 ZCB Bamboo Pavillion, aerial night view

We created an event space where several kinds of events could be held. So, in the wake of this project, I became a little bit specialised in bamboo. There are over twelve hundred species globally. The vast majority is growing in Asia, but this map shows where in the world you find bamboo. It is basically everywhere, except for Europe, North America and Australia. So, in all the areas where globalization is going on at a fast pace. Although this material is available for construction, it is very rare that people use it. In most countries, building codes do not allow bamboo to be used, which is a pity because it is the greatest carbon absorber that you can find! It grows much faster than wood and its fibre has strength similar to steel, so it's a very useful material. Most architects, if they are at all still using it, do so either for a symbolic cultural value, as we see in the project of Kengo Kuma & Associates made in Beijing. And here, in Brazil, you can see Leiko Motomura using it as a replacement for wood or steel in a normal space frame, using it for its light weight to create these nice triangulating roof structures.

Bamboo stands out because it is most flexible, because of its unique build-up of tubular elements with reinforced segments. Because of that, it becomes one of the strongest flexible materials you can build with. We wanted to work with that material property of bamboo. In Hong Kong, as I mentioned, all the scaffoldings are made by bamboo. Here you see how the craftsmen use body measures like leg lengths or shoulders heights. With very simple knots they can make, in a matter of hours, these massive scaffoldings. In a very short amount of time they can build two hundred meters high skyscrapers' scaffolds.

This craft is very unique to the Cantonese region. It is not only used for scaffoldings but also for the making of temporary Cantonese Opera buildings that look like this. Every year they make around fifty of these all over the town and they just take them down when finished.

This is a very flexible typology that allows to respond to very different terrains. But it has always similar sections and is always based on similar body measures. So, when we were asked to make an event space, we thought that it could be interesting if we could use the different properties of bamboo and a totally re-invented typology that they haven't been working with.

This is the final product. What we can do with digital techniques nowadays allowed this to become possible. These techniques allow us to perfectly simulate how a curve would behave if the curve itself tries to straighten itself out. We can simulate that physical behaviour and know exactly how the curve would behave when bent, or how a network of curves would behave. With these tools and physical prototyping at our disposal, we did a workshop with a group of students. The winning project could go through an iterative test processes until we arrived at the final structure—a system that is entirely made based on the material property. This is bamboo, split bamboo. From these physical prototypes we made a whole series of digital models until we arrived at the final construction. Because there are no building codes for building with bent bamboo, since nobody had ever built in a fashion like that, we had to re-invent everything from scratch.

The digital design started from the site. There we started by identifying the location for the foundations. From there, we extracted the diagrid that was fed into a physics simulation engine. Then, after that, we used trial and error to figure out all the parameters that we needed in order to manage to bend it digitally and fold that surface onto itself, aligning all the forces, which are stiffening forces and spring particle forces, to find an equilibrium within its shape. The shape was not drawn, the shape was generated using physical principles related to the material that we were working with. Then, later on, we had to again use a few simulations in order to figure out the installation sequences that would allow people on site to install this thing without the need for drawings or even understand what exactly they were doing at each point in time. Here, we see that all the bamboo poles are always laid up from top and then bent in place. You cannot weave them into one another because they are too strong.

This is the final top view of the design which spans thirty-seven metres. We have a space that 200 people can use. We use a membrane of a glass-fibre reinforced polymer to operate like a lantern screen. The structure's depth underneath basically creates a very nice shadow visible on the outside.

We worked mostly with Mao Zhu (毛竹), which is a type of bamboo, a giant species that is indigenous to China. We had to cross the border to Shaoxing in China where there is a bamboo factory organized in a very primitive way, very different from the nice bamboo forests that we have here in Kyoto, much messier. In a very primitive way, they cut the bamboos and centralised them. We had to quickly treat them, because you cannot use bamboo in permanent architecture if you do not protect it from UV light, water, rain, and biotic attack. We submerged it in a saline solution to prevent biotic attack and, while this was happening, onsite we prepared the tree foundations to be installed. To give a sense of scale, you've probably seen the Volvo Ocean Race where they have these massive boats? One of these boats is around 30 metres in height, weighs 12 tons and has a downwind sail of 578 square metres. Our structure spans 37 metres, weighs roughly half of the sailing boat, and has twice its size; so the lifting force on this thing is gigantic. One of the challenges was: how can we anchor this thing down to the ground?

The foundations themselves, these three slabs, weigh around 100 tons in total. Everything above them weighs around 6.7 tones. So, this is a hyper-lightweight structure. The air that is underneath the pavilion weighs around four and a half tones, so it is only 70% heavier than the air underneath. That ground connection was essential to hold this thing down. We borrowed a Colombian bamboo detail from Simon Velez, where he is working with rebar cast inside the bamboo. Similar to how we use the ripples on the rebar to anchor it inside of the concrete, here, we're using the interior profile of the bamboo to anchor the concrete inside of it. Thus, these details are supposed to pass on the force onto the concrete. Here you see the installation of the base, using very standard means. The first thing we had to deal with was the issue on how we communicate the exact info needed for. Then how do we bend all these rebars? The only tools available were paper printers, so we just printed triangles extracted directly from the digital models and, using steel pipes, we managed to bend them to roughly where we needed it to be. It was good enough. With all of the start positions in the right angles, we had to make a little plinth at the base to support the bamboo perpendicularly to each axis. We used plastics sewage pipes, cut according to data extracted from our models, to create the little foundation of the plinths; here we see the operation.

Then the bamboo arrived onsite. Everything was nicely cleaned, nicely sorted, and then we had the challenge of turning 473 poles into this doubly curved bending-active structure. Although we could digitally identify every single point of the structure itself, the challenging part was to decide which data we needed to take out and communicate with the people onsite, considering that we don't speak the same language. We started by unrolling each and every one of these members and numbering them. Here you see them taking the poles, following the numbers and dimensions, numbering each pole accurately. We made a 40 metre long table upon which we were tying each and every one of these individual members together using not the plastic wires they traditionally use, but metal wires for fire safety. Just connecting them into one giant member, and then, if you zoom into the construction drawings, we again marked up all the intersection points between different bamboo members. Using simple sheets of labels, all that the craftsmen needed to do was measuring exactly where the intersection points were and place the sticker on it. Then, since the temporary support scaffolding had gone up, they would hoist up the long interconnected members, bring them up the scaffolding, slide them over the starter bars, and gradually position them at the accurate height with numbers that were projected at the base. Gradually, as they were bringing more members, all they had to do was match the exact corresponding sticker labels. Then, bit by bit, you can see how the bamboo structure starts to emerge. Here are the first six members in place. We just bent parts by hand, so all poles are bent. Here you see how much they were curving. Then you see when they were trying to match the labels as closely as possible and ty them together. Gradually, similar to the physical models, the equilibrium surface started to emerge without any conventional architecture drawing necessary.

This is a view of one of these points. This is the top view, where we start to see that there is a 20 centimetre approximation happening there, so our exact simulation model basically was replaced by a cloud of approximation around each point with 20 centimetre diameter, which was fine. We could absorb all the exact measures of the bamboo. Here we see the foundation at the base where sometimes poles were too short, sometimes too long. We quickly anchored the foundation by squeezing concrete into the pole base until the whole thing was properly anchored.

This is the finished structure. We couldn't 3D scan it because of the scaffolding underneath. The point cloud would be too complex. So, instead of 3D scanning the whole structure, we used a different method for measuring the skin. If you know the software Pepakura (which is a simple software that you can use to make paper models of 3D objects, you just triangulate and fold everything); we did the opposite. Everybody had a smartphone in their pockets, so we shared a Google Doc spreadsheet and measured all the triangle edges onsite and made everybody punch the numbers into the shared spreadsheet. Then, from the spreadsheet, we could reverse engineer the strips that were necessary for the cutting. Then we went across the border into a fabric factory that was usually making circus tents. On this big CNC cutting table that you see here all the triangles were cut one by one. Then, by hand, using superglue, little edge strips were placed over matching edges and then fused into the fabric until it became one giant sock. That giant sock was lifted over the structure and rolled out and fixed to the bamboo. The whole thing was pulled under tension. Its seams were finished. That was the close-to-being-finished structure that just needed to be stretched. We see the buckles that tensed the whole piece. Then we installed the lights inside; up-lights shinning up and reflecting down from the structure (Fig.6).

Fig.6 ZCB Bamboo Pavillion, night view from pedestrian view point

The final piece in this very busy urban context became a shield that kind of blocked away the aggressive lighting that is all around it. Its high arches allowed the green form the park to come in whenever there were events underneath it. This is the view from the top, where you can see the pattern. Here is its use for all kinds of events. Then it was taken down after 9 months because it was a temporary site we could not use any longer.

So, to wrap up: "The future is already here; it is just not evenly distributed." Some labs may have robotic arms and CNC fabrication technology, but for most of the construction sites in parts of the world where most of the construction is happening it may be better to use an A3 printer as strategic choice to make construction documents. There is more computation power in your washing machine then they used to put a man on the moon, and a few years ago, they were selling smartphones in India for 40USD. How can you use that power if anybody has it free at their disposal? I think that there is opportunity for architects to become a 'fusionist'. That means you have control over that power, and if you're open to conversation with all people involved, you can play a central role in trying to make a type of architecture that can be radically different from anything you've seen so far. I'll leave you at that.