Super Integration: A cross-disciplinary approach towards design

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Digitization signifies architectural opportunity driven by the rise of digital capabilities and competences, but it also means something more essential: an architect's longing for the agility, authority, and ability to predict and control the very nature of architectural design. Our practice has transformed significantly in the last decade. We have been exploring various tools that would inform an architectural outcome.

Architects today are expected to design and detail in a manner that uses fewer resources, while still innovating, adding value, and being sustainable. Deliverables must take less time and cost less money to produce, while not compromising on quality. Traditional linear thinking no longer works. We are moving towards an era of "Super-integration", which is marked by blurring of lines, disciplines, and roles brought about by interdisciplinary collaboration. Today, the architectural design has become a complex workflow in which geometric, spatial, and technical datasets are filtered through simulation, analysis, and optimization processes, with the aim to create integrated parametric models that can generate an array of outputs ranging from energy usage to production and management. Our design workflows are a means to increase efficiency, while focusing on exploring new design potentials, largely driven by parametric or associative modelling. This has enabled us to advance our office's philosophy of design and technology integration such that structure, material and production methods become the foundation of creative thinking.

ZJA, as a practice has always been keen in redefining the relationship of architecture to engineering and production. We have been advocates of cross-disciplinary collaborations to achieve outstanding levels of innovation Software interoperability among different disciplines continues to be one of the main causes of fragmented working environments.

Key words: Informed design, computational design, optimization, data, workflow, collaboration, fabrication, BIM, virtual, interoperability

1 Introduction

Architecture is a complex undertaking which requires input of many individuals with varying interests, backgrounds, and expertise. To meet today's demands for speed, affordability, and quality; engineers and architects are integrating their efforts to make decisions in real time. Ability to recognize and jointly develop solutions has greatly improved through technology, by minimizing the time between ideation, analysis, and team communication. The collaborative process is key.

We at ZJA began as architects and architectural engineers, we ventured into R&D, and have realized that the type of solutions and techniques found in our research are scalable to our projects. All of our projects inform and effect one another. It is ultimately about deepening the learning process and creating partnerships with people in other disciplines to help us continue to learn and evolve.

The current generation of construction process signifies cross-linking analogue and digital platforms, ideas, and approaches within a virtually open environment of digital planning. Cross-discipline knowledge of engineering, architecture, sustainability and management are some of the essential ingredients of AEC industry.

Architecture and design is an iterative process. Today, there are more variables, and it's more robust. Modelling is part of our design process and a powerful tool indeed. We need both the analog tools such as the physical prototyping, testing models and sketching with the digital tools. It's the combination of the two that's really powerful (Fig. 1).

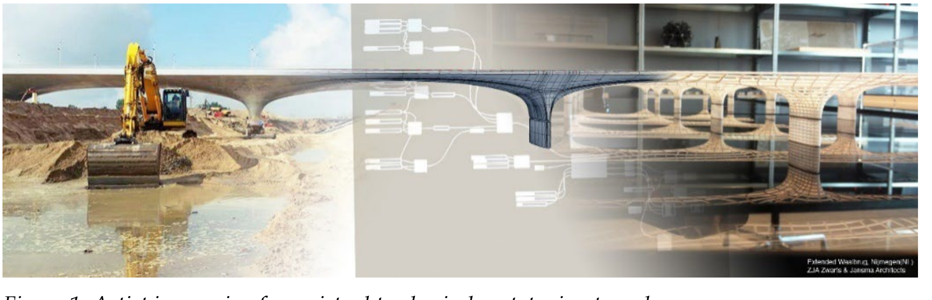

Figure 1. Artist impression from virtual to physical prototyping to real
Extended Waalbrug, Nijmegen (NL)

Architects don't design alone. The idea for a building is informed by experts at the table. The team conceives the idea. The architect's role then becomes to facilitate the process, and to refine the design until each stakeholder feels represented. Collaboration leads to the streamlining of conception to construction until completion.

Architecture always begins with an intuition. There's a mutual relationship between craft and technology. We don't want the technology alone to be pulling us along. We like to think that we are someone who can facilitate things. Architects need to know too much already. When in practice you rely on other people. You rely on other people's body of knowledge. As both an art and a science, architecture requires interdisciplinary and multidisciplinary participation. The people on the cross-functional team are there for a reason. They are specialists and have deeper knowledge and understanding in certain areas of the project than other people.

A sincere effort has been put in this regard to achieve an integrated parametric model that helps coordinate and achieve both the aesthetic/qualitative and the technical/quantitative

optimal sight to building *no sight*

Figure 2. Sightline analysis for Diamantbeurs, Amsterdam (NL); viewing percentages (high to low)

goals of the project, by fully understanding the impact that each would have on the other as shown in Figure 2. This has helped us to achieve integration of engineering expertise from third party specialists leading to file-to-factory manufacturing capabilities. Much of our recent works like extended Waalbrug, HSE, Diamantbeurs, Shaded Dome (Vrijheidsmusem Groesbeek), Amsterdam Central Station and Elevated Light rail System (South Korea) have been supported by access to computational technologies outside of traditional architectural boundaries

2 Cross-disciplinary collaboration

Architects and designers have insights into how something complex can be built, but also know how to make that process more efficient and economical. The concept and application of computational design has been there for a while. Within our office we observed something unique, small teams were able to more with less, delivering a design with a very high level of complexity in a short amount of time and with a very complex aesthetic to it. Our work goes through a multitude of cycles of development.

Structures such as the light rail station perform in terms of functionality, structural inventiveness and most important the precision in execution. The main eye-catcher of the station is the ensemble of the roofing, which consists of curved glass and bent steel that connects the metro station with the Hague Central Station as shown in Figure 3. The

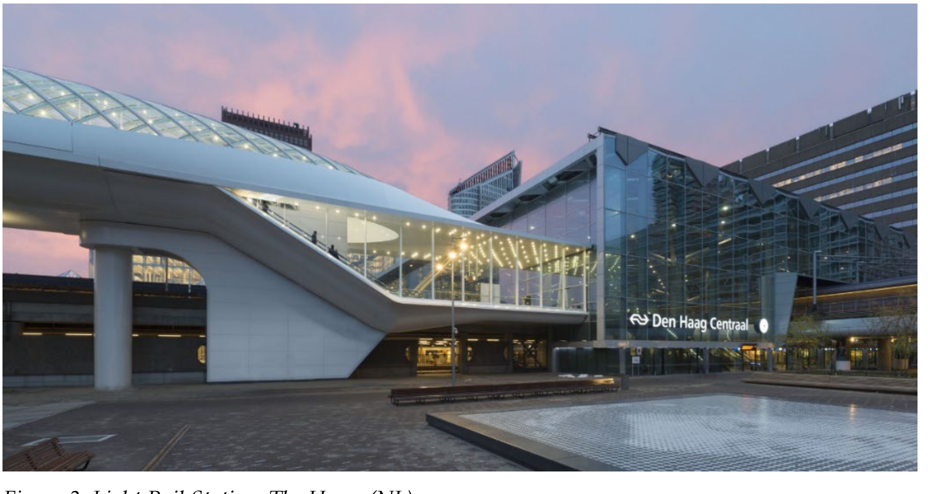

Figure 3. Light Rail Station, The Hague(NL)

geometry of the glazed roof structure is based on the principle of grid shell. Grid shells are naturally beautiful and efficient structures. It can transfer loads without bending, this is done by transmitting tension and compression forces solely within the grid (Fig. 4). They therefore require significantly less material than conventional structures under bending stress, as for instance beam or slab structures.

Figure 4. Physical prototyping of roof grid shell structure; Light Rail Station, The Hague(NL)

To assist with the structural design and optimization of the roof, Knippers Helbig advanced engineering based in Stuttgart Germany were invited to join our team. Knippers Helbig went back to our original architectural design and responded to the technical challenges. To design a transparent glazed shell, it was necessary to fragment the shell into a desirable grid sizes and curved twisted beams, thus creating a structure that offers maximum transparency [1]. From an engineer's perspective, they were equally involved in the development of the roof glazing details in collaboration with us. They used Genetic optimization solvers to reach the desired roof shape and avoid double curvature or limit it to minimum. So there is a significant involvement of engineers within architectural ambition as well. As architect's we made sure that the geometry accommodates functional aspects such as the clearances for trains, pedestrians, etc. (Fig. 5), the overall shape of the roof and the connection details. We collaborated in terms of exchanging Grasshopper script and vice-versa. We communicated the entire design range of what was possible and eventually reached the desired outcome.

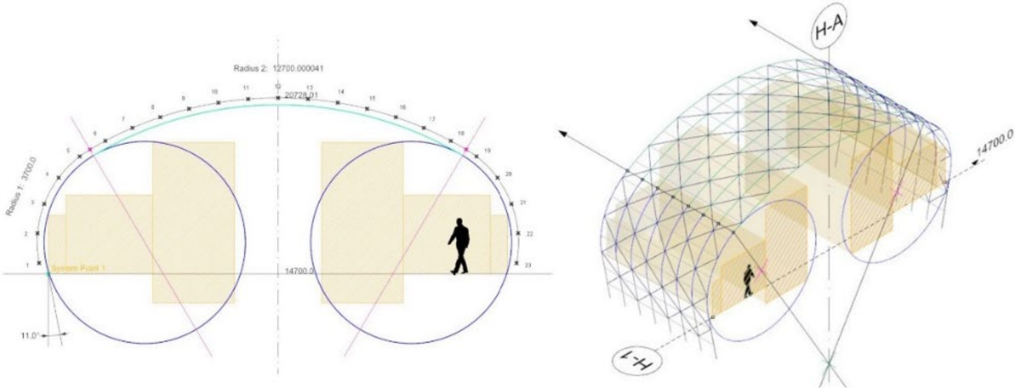

Figure 5. Generic cross section with diamond pattern; Light Rail Station, The Hague (NL)

Building information modeling (BIM) software enabled the creation of three-dimensional parametric models that included both geometry and non-geometric design and construction information. Any changes in the master file is reflected consistently across the model to keep other components, views and annotations consistent to one another. This ability assured increased coordination and decreased the likelihood of design or documentation errors, while easing collaboration between various teams. This coordination model (Figure 6) also ensured that when changes in the model are made, all information is updated both automatically and dynamically.

We have reached a point where we can insert everything in the model space. It consists of a design model, a structural model, various structural and geometric optimization

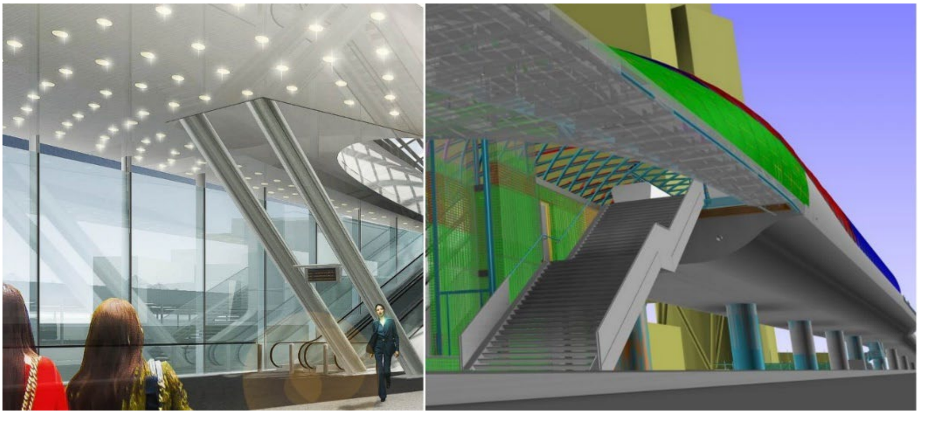

Figure 6. BIM Coordination model vs Artist Impression of Light Rail Station, The Hague (NL)

routines. There’s so many processes—planarization, rationalization, etc.—all of that in a single model. For the final assembly of the roof structure, total 375 steel segments needed to be bent and cut to prescribed sizes generated by our parametric scripts as shown in Figure 7. The station roof had 790 curved panel out of which 180 are unique at the irregular part with a total coverage of approximately 2640 m^2. Current workflows are making design and construction more efficient, and creating opportunities in terms of modularization, or automation of repetitive design actions. In general, an increasingly larger set of variables provides the designers an opportunity to evaluate the various possibilities and to edit out systematic useless alternatives. Being able to discard alternatives before iteratively acting on or testing them saves time and resources.

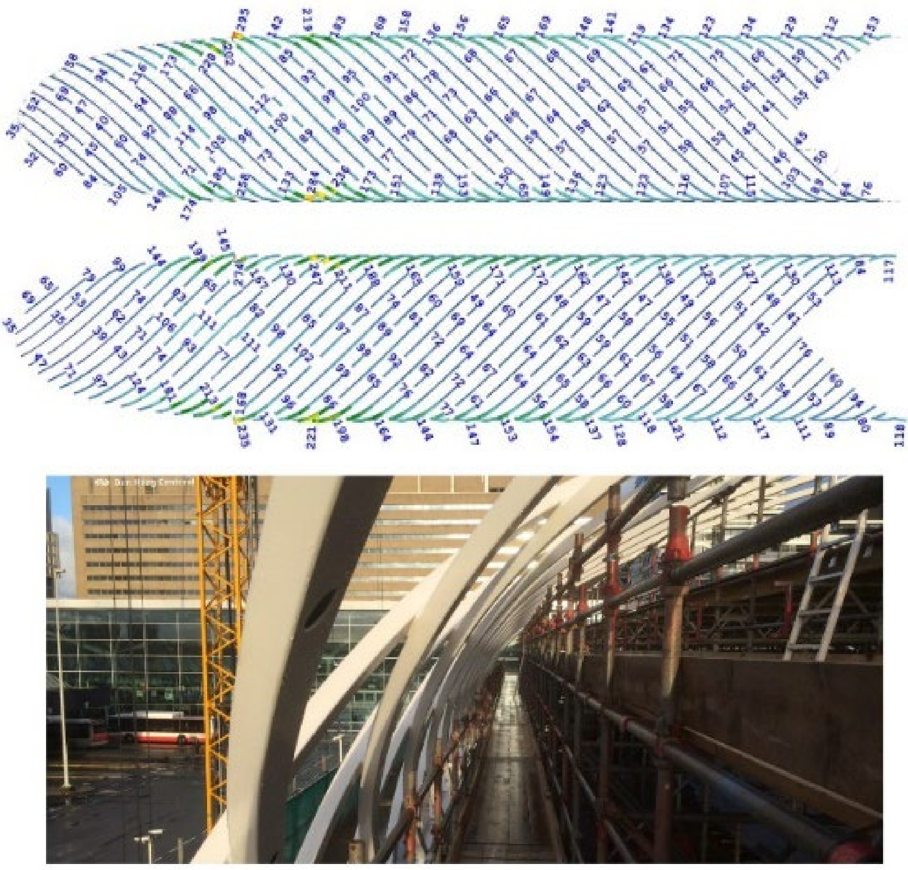

Figure 7. File-to-factory layout for production of curved steel members; Light Rail Station, The Hague (NL)

The construction and completion phases of a building's delivery has brought the production of design intent and the transmission of information closer than before. Much of this connection is due to the digitization of construction leading to increased coordination, collaboration, and communication, while reducing waste. Architect remains in charge of overseeing the design and build alongside the contractor so that the process remains transparent throughout. The renderings are helpful to convey to the trades and to the contractors and the people doing the work that there is a vision of what this building is going to be. The renderings are a great opportunity to do that, because they're about an outcome, and we want to inspire people to work toward that outcome.

3 Production and Fabrication

There is today a pronounced and accelerated cross-disciplinarity in architecture. It is occurring in building design, fabrication, and construction. We architects and other design professionals have been expected to design and construct in a manner that uses fewer resources while still innovating, adding value while reducing waste.

For a project like the Freedom Museum at Groesbeek (Figure 8), we as architects have to think beyond the linearity. This project is based on the principle of Shaded Dome which is a combination of air supported pneumatic structure with a tensile membrane structure on top. Although air-supported structures and tensile membrane structures are quite common, their combination into a hybrid structure like the Shaded Dome is unique and novel, and therefore, the design has been granted an European patent.

Figure 8. Freedom Museum, Groesbeek (NL)

For constructing such an unconventional building you need the right set of tools for the job. We at ZJA, worked out the geometric principles for the Shaded Dome Technologies and created computational design tools that makes it relatively easy for us to take the first steps towards architectural design. It allowed us architects to pull or push the geometry in order to assess most aesthetically acceptable and tentative stabilized form. The design requirements are the input for the parametric model and through generative computational algorithms, such as the positioning the entrances, optimizations in the sizes of the fabric patches, cable net and relaxation- inflation simulation, the shaded dome was generated in the virtual world as shown in Figure 9.

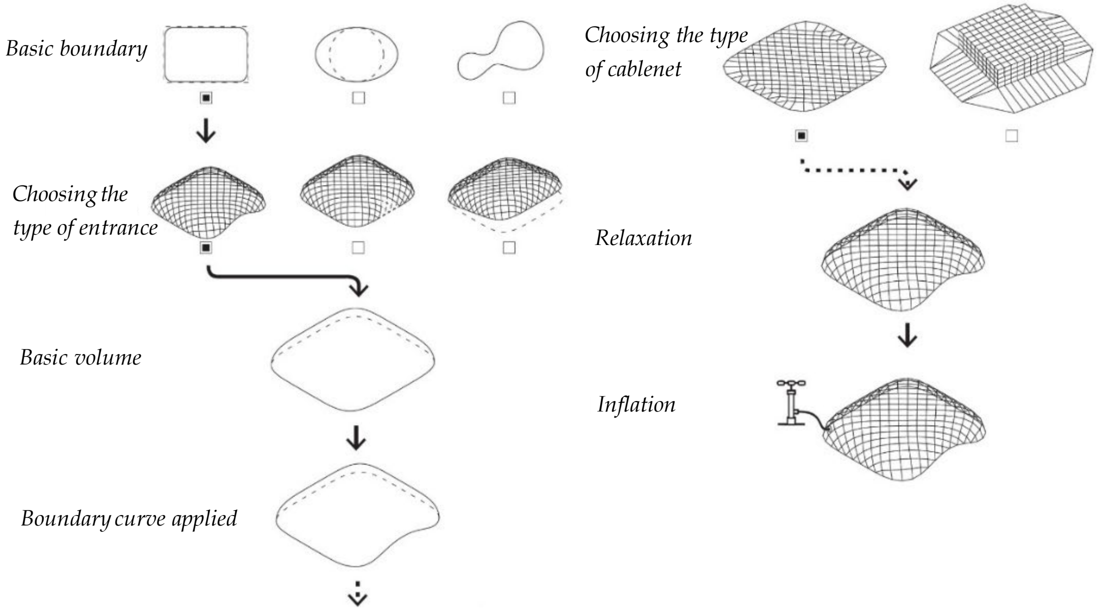

Figure 9. Computational Design workflow diagram for the dome generation

Our architectural decisions have very real consequences. The ability to foresee potential impacts and consequences of our architectural design decision increases with the introduction of feedback loop. A model that will turn into green when you are designing within predetermined parameters, constraints, and following the rules. As soon as what the model goes out of compliance and defies the rules, it turns red [2]. Based on that feedback, you can modify the design until it turns green again. It is an iterative process where you navigate the model, you start to anticipate and internalize the rules. Design computation provides more room for creativity because quick iterations and rapid prototyping provides faster outcomes. We can recognize faults, where it is occurring, more

readily adapt to and prepare for it, and anticipate where it is going to occur.
Along with analysis and automation, one of the key aspect of computational tools is providing simulation along with analysis to help design teams to make informed decisions. Simulation can be thought of as a form of construction: the construction of a model, usually a mathematical model, to reproduce the effects or behaviour of a phenomenon, system, or process (Figure 10) [3][4]. The exploration of solution spaces in simulation means that the project will be better, while optimization assures that it will be completed more cost-effectively.

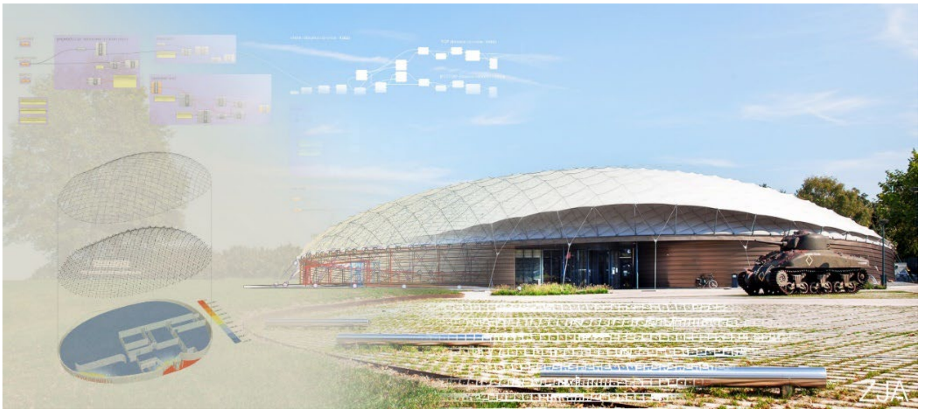

Figure 10. Energy simulation (Ladybug), Physics simulation (Kangaroo) representation, Groesbeek (NL)

Once the design was frozen. our algorithms then generated relevant files for all the components be it the Dome, Cable net, Struts, Shade, or the Suspension cables which are necessary for manufacturing and assembly. In our construction process we actually skipped the step where the fabricator generally is assigned to create his own set of working drawings which contributes to the extra time, money, redundancy and inefficiency. For the shade, we had to cut out about 438 patches separately and weld them together with an overlap of 40 mm. Each of these patches had to labelled in order to know which adjacent patch connects to which. This also provides a sense of organization to the scheme as shown in Figure 11.

Finally we are seeing the maturity and scalability of digital design-to-fabrication production methods whereby combining 2D-to-3D workflows. The industry is moving one big step away from the limitations of 2D CAD and moving closer to an integrated workflow. Design and fabrication workflow puts the power of making in the hands of design professionals.

Fundamentally, architects must also take into account constructability, and not leave it to contractors alone. Similarly contractors must take responsibility for the design implications of construction decisions. If contractors understand the motive behind each of the design intent, thus they will have a better understanding of how to construct the project.

What we managed to achieve here is a paradigm shift in itself when it comes to design and production workflows. Different parties involved shared their insights with the other partners. For instance Poly-Ned had to share their knowledge about the nuances of fabric's material properties with us, otherwise we would not have been able to make such an informed simulation (Fig. 11).

4 Data Analytics and workflow

Both engineers and architects are jointly coming up with solutions for large or complex projects that require a higher degree of expertise at the early stages. Both disciplines sitting around a table and jointly, collaboratively, working out those issues, in service of the holistic solution.

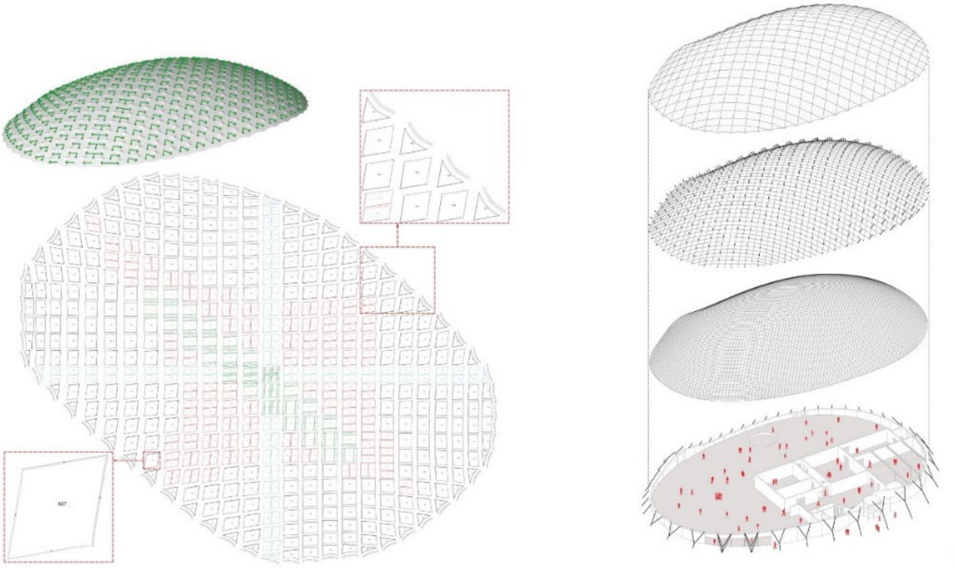

Figure 11. File-to-factory; shade fabric welding and production; Freedom Museum Groesbeek (NL)

For an ongoing project of such immense scale and complexity as the PHS Amsterdam Central Station (Fig. 12), using parametric software like BIM was the only way architectural design studio like ours could compete and deliver on time. It is a planning nightmare for a project which is built over an existing building. It becomes even more daunting task when you are not allowed to hinder the operations of a building in this case one of the most busiest multi modal transit interchange in Netherlands or probably Europe. The BIM largely contributed to the phasing of the design & execution which is very complex especially in a large scale project running for many years.

We are in some kind of renaissance if you think about how we leverage technology to deliver outstanding results. Technology is one of the foundations of our office. It is our conscious effort to treat technology as a toolkit. If we have an idea for something, we will research which technology best allows us to design, visualize and implement.

In this project, we are creating extra space for the proper functioning of Amsterdam Central Station. Apart from that the new design has to accommodate increasing frequency of travellers with a safe transfer, widening of platforms, relocation of stairways, optimal orientation and a valuable experience by utilizing and enhancing the monumental value of the station.

Figure 12. Artist impression of PHS Amsterdam Centraal (NL)

The data flows moves backwards and forwards from the database to the model, verifying that the design process and the people working on a particular piece of geometry are persistently working with live data. Key to the success of this workflow is giving the whole team access to the data within the modelled environment. This makes sure a stronger connection between what's designed, built, and how it operates.

Large complex projects and their accompanying processes generate more information than we really need, or that we effectively utilize, so we do have to filter information. That's the role of the architect to some degree because they are in a position to balance. As an architect we are getting input from a mechanical engineer, the contractor, structural, MEP and we have to make decisions that are balancing these different systems.

At its core, Amsterdam Central Station must serve civic and infrastructural purposes. We had to deal with lots of columns, staircases, elevators, train tracks, platforms lots of hallways, lots of pipes, lots of HVAC. We had to learn to negotiate among so many stakeholders, disciplines and parties. Out of troubleshooting systems for a civic infrastructure project, we developed a new system of working and cross-collaboration. In our practice, all the things we learned from our earliest projects have fed into the projects we are working on currently.

5 Interoperability

"Interoperability refers to the ability to make different systems talk to one another." [5] This is more than just a problem of 'conversion' or 'file format' and should be viewed as a critical project process. A lack of true software interoperability within the modelling and simulation ecosystem continues to limit the capability to fully leverage the power of collaboration. At present, computational tools and BIM platforms are merging, with Dynamo coming preloaded in Revit creating a new ecosystem where Rhino.inside, Rhino and Grasshopper are now interoperable. The combination of a parametric tool such as BIM with a computational tool in our opinion is natural.

Interoperability Tools, which provide seamless data exchange between Excel, Grasshopper, Dynamo, and many more tools via the Web have been used during the design exploration of the Amsterdam central station to generate the connection points between the platform and adjoining concourses tunnels underneath. Another tool used in this regard is

Rhino.inside, which is an open source project which allows Rhino and Grasshopper to run inside Revit. Tools such as Dynamo can connect tools in the design pipeline, improving the flow of data, such as BIM 360 cloud field data (Fig. 13). It lets designers create logic and adds behaviour to a BIM to explore parametric designs and automate tasks.

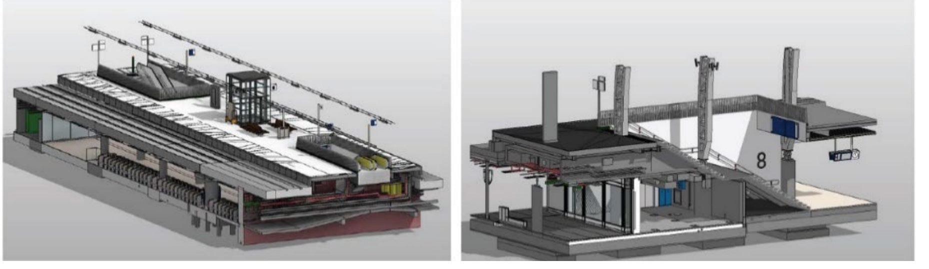

Figure 13. BIM360 coordination model snippets, PHS Amsterdam Centraal (NL)

6 Physical vs Virtual

To arrive at the project in its realized state, we architects today make use of the virtual, be it for laser scanning of the existing conditions, digitizing existing site surveys, analysing data for energy, daylighting, crowd control, and other means of performance—or just to see what it is like to experience a virtual environment walking right into it using various platforms such as VR,AR, First-person gaming development platform such as Unreal Engine, twinmotion and Enscape to name a few. These platforms are offspring of gaming, game mechanics, and game engines and they are on the verge of disrupting architectural practice and the way design professionals engage with project teammate, clients and project itself.

We are already designing in 3D, so it's a natural transition to create walkthrough based presentations. The Enscape model-to-walkthrough workflow directly from Revit as shown in Figure 14 represents opportunities for direct experience with a space or place, by eliminating steps or even phases in design workflows that requires the integration of client feedback into workable designs. It provides the ability to make decisions by engaging with the design in the midst of the larger project context. The valuable feedback that this explorative experience provides; and the interoperability of being able to move in, around, and through the building model is bringing a BIM model to another level.

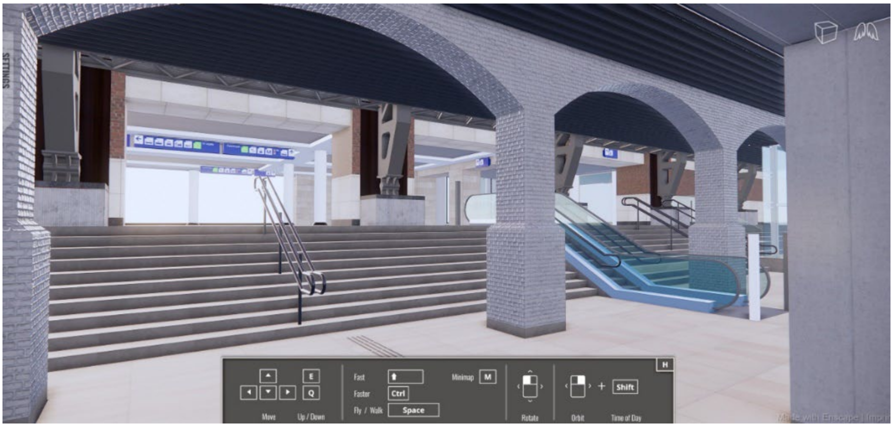

Figure 14. Enscape walkthrough, PHS Amsterdam Centraal (NL)

7 Epilogue

Parametric and BIM models are today aiding and improving the construction of the projects but they are fundamentally different from the hanging chain model used to find its shape and form from Sagrada Familia in Barcelona. In the hanging model, when Gaudi adjusted the weights, he received immediate feedback and this helped him built an intuition for the flowing forces through the structure. At present, with all the technology and computational simulation toolkits available to architects today, in a way we are trying to mimic this physical feedback that Gaudi enjoyed into our digital world giving us the freedom to explore our daring ideas without hesitation.

In any computational design workflow, we cannot leave out a great deal, which is the human element—creativity, intuition, insights and the human spirit. But we could put forward the creativity behind the computational rule-making. Architecture is a willingness to have conversations, to collaborate, to innovate. An informed architectural design requires the input of many individuals with varying interests, expertise and backgrounds. It is our hope, that the learning and exploration will continue, to the greatest benefit to those who are most in need of it.

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