STUDIEVERENIGING KOers
CONSTRUCTIEF ONTWERPEN

Kersief

EDITION 113
July 2021

The Digital Era

VeriCon

constructeurs & 3D-engineers

Dé innovatieve partner voor constructief advies en engineering

Variatie
Beton, staal of hout; woonhuizen, hoogbouw of specials, we gaan geen uitdaging uit de weg.
Variatie, daar houden we van!

Totaalengineering
Wij geloven in de kracht van totaalengineering: alle vlakken van constructieontwerp en -engineering. Als integraal ontwerpend constructeur en als engineer voor de uitwerking van alle deelconstructies. Door het verzorgen van constructieve coördinatie voorkomen we fouten en ontstaat een gestroomlijnd en zorgeloos ontwerp- en engineeringsproces.

Parametrisch ontwerpen
Onze parametrische manier van ontwerpen resulteert in snellere, kosteneffectievere en optimale oplossingen voor projecten. Een mooi voorbeeld van een project waarin we parametrische tools hebben toegepast is de 1,5 km lange golvende betonnen gevel met achterliggende staalconstructie van Mall of the Netherlands.

Innovatie
Wij geloven dat innovatie nodig is om samen, efficiënter, betere, goedkopere en beheersbaardere gebouwen te maken.
Modelleren doen we dan ook uitsluitend in 3D. We werken met een uitgebreid pakket aan geavanceerde rekensoftware zoals Grasshopper. Kan er hier iets beter? Dan zorgt ons team van ontwikkelaars daarvoor.

Samenwerken
Met een enthousiast team van ruim negentig betrokken collega's zetten we in een open en zelfstandige werksfeer onze kennis en expertise in voor bouwkundige projecten. Samenwerken is daarbij een van onze belangrijkste waardes.

Kom ons team nu al versterken
Als innovatief bureau heeft VeriCon een nauwe band met de ingenieurs van morgen. We werken veel samen met studenten. Meewerkstages, afstuderen, werkstudenten en duaal-studenten, zowel hbo als universitair. Bij VeriCon doe je praktische ervaring op, waarbij je begeleid wordt door de besten in jouw vak.

Ons DNA
- samenwerken
- ambitieus
- innovatief

Onze expertises
- constructief ontwerp en advies
- civiel ontwerp en engineering
- bouwkundige uitwerking
- BIM-management
- prefabbeton-engineering
- woningbouw
- HSB en CLT
- file to factory

meer weten?
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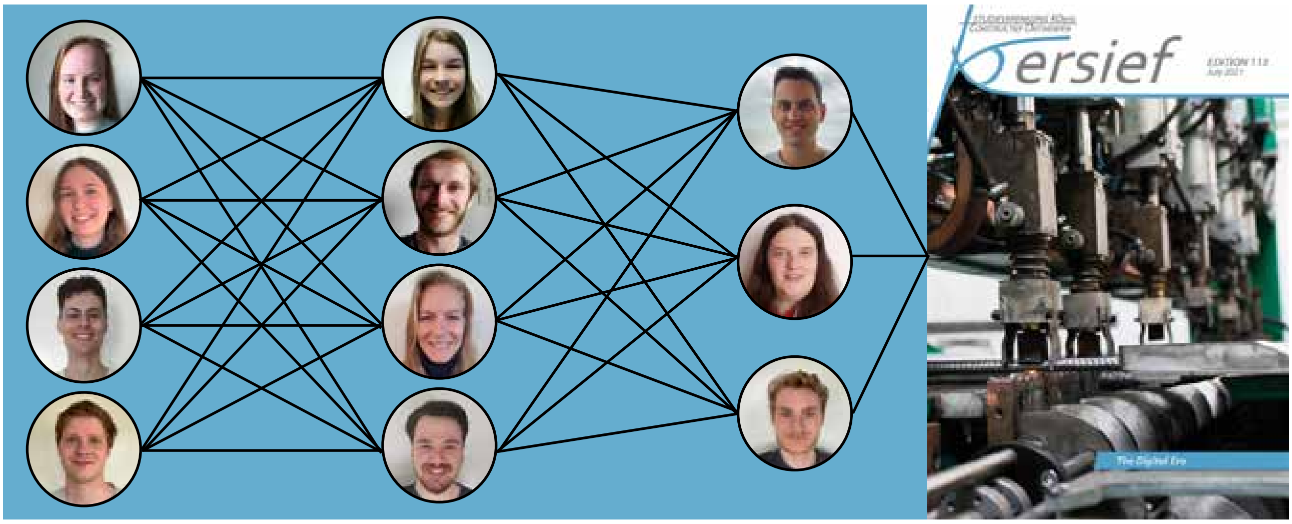
Editorial



Dear reader,

For over a year, the pandemic has dominated our lifestyle. Social activities, as well as work, have largely been moved online. Our committee has not been able to meet in real life for this edition either. Luckily, we live in the 21st century and the digital era is well established. Who knows how we would have kept in touch, had this pandemic struck two decades earlier.

Despite the apparent restrictions, many engaging initiatives have been introduced in the past year. Even the KOersief itself got a digital spinoff; the 'Kunnen wij het maken' podcast. We also solidified our online presence with the weekly Instagram polls and interesting facts. In short, the digital era facilitated the possibility to stay active and relevant in this year of social distancing and remote working.

As the cover already revealed, the theme of this edition is The Digital Era, a suitable theme for our current situation. In this edition, you will read how Artificial Intelligence (AI) can aid structural engineers, how our industry benefits from parametric design and robotic manufacturing, the role of the structural engineer in this digital era, and much more. The photo of the editorial board above is a nod to the structure of neural networks. In the left column, you will find Femke, Laura, Maikel, and Tom. The middle column contains Marijke, Pieter, Evelien, and Olaf. In the right column, you will find the layout team consisting of Jordy, Leonie, and Lucas. Finally, the network results in the KOersief, fully packed with many interesting articles.

On behalf of the editorial board,

Pieter van Loon
Editor-in-chief KOersief 113

abt adviseurs in bouwtechniek

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Building ambitions

Do you want to work on leading projects in a professional organization? Together with our coustomers we develop the buildings of the future!

We work on projects that matter. Think of the Boijmans van Beuningen Depot, where we calculated the optimal technical shape of the reflective facade. For House of Delft our Integral team was able to realize a solid, preliminary design in three months' time.

Knowledge development

What characterizes us is our curiosity, our eagerness to learn and our passion for technology. ABT invests in knowledge development and innovation. Building envelope engineering, BIM, concept development, computational design, refurbishment, parametric design and AR: we apply it all in our projects.

Building zero impact

With all the engineering disciplines under one roof, ABT can offer - through our integrated design approach - an optimal mix of sustainability measures in the field of energy, water and materials. The result is a healthy building for the user.

Are you looking for an internship or graduation assignment? Let us know your ultimate challenge! We are happy to get to know you and are curious to see if you are the perfect fit for our team in Delft, Enschede or Velp (Gld).

On werkenbijabt.eu you can find our current intership- and graduation topics and vacancies. We look forward to seeing your application.

Chairman's Note

Dear KOers members and relations,

Almost a year has passed already, and the end of my chairmanship of the 51st board of KOers is in sight. However, as I am writing this, there are still many great activities ahead, like the Batavierenrace, many lunch lectures, drinks, and of course, the end of the year BBQ. The KIST to Gothenburg and Helsinki is also scheduled for the summer, but at the time of writing, I do not know if we will be able to travel there. Still, I hope that by the time this KOersief comes out, we will be able to read it on the plane to Göteborg.

Taking a look back at the past year, I admire how we as KOers and all its different committees have stayed active and tried to make the best out of this strange year. Having to deal with all the regulations of the government and the TU/e due to the well-known Coronavirus has made us creative to find new ways to stay connected with all our members. We have explored many of the great digital possibilities to learn, to have fun, to exercise, or just to have a coffee together at a KOKO.

Speaking of the great digital possibilities which we have explored. The theme of this KOersief is digitalization and artificial intelligence. The past year has shown us that the digital world is bigger and more important than we thought and that we can all do so much more with it. This also naturally applies to the world of construction, so I am very curious to read more about these possibilities of digitalization and artificial intelligence in this new KOersief.

Despite all the regulations, the lockdown, and the possible loneliness, all the members of KOers have made it a great year to never forget. We had many successful online activities and even a

few real-life activities at the beginning of the year. And now, the future is looking very bright, at the time of writing we are allowed to organize real-life lunch lectures and outside drinks again!

Finally, I would like to thank my board for making this a great year with many activities, even though it was very different from previous years. I wish the next board the very best for the upcoming academic year. I would also like to thank the editorial board for this edition of the KOersief, and I hope you will all enjoy reading this new edition in the summer!

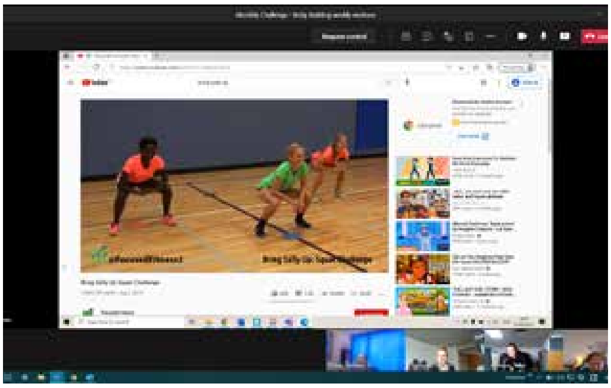
Yours sincerely,
On behalf of the 51st board of KOers,

Monica Suijs
Chairman of the 51st board of KOers ◀

In the spring of 2022 KOers will attempt to break the world record of longest beer crate bridge again!

Agenda

KOers Bake-off *January 2021*



Body Building *March 2021*

Easter Egg Hunt *April 2021*

Crazy 51 *May 2021*

KOers Challenges
To keep connecting our members even in Corona times, KOers has been setting up challenges for them. These challenges range from exercising to cooking and from doing crafts to searching for easter eggs.

MOVEmber
November 2020
During November, we challenged ourselves with a walking challenge: taking 51000 steps per week. This is 7285.7 steps per day, just above the recommended 6000 steps per day! During this month, we also did an online workout together every week.

Veggiecember
December 2020
During December, the aim was to eat meals containing no meat and fish for at least three days a week. Every participant also sent their best recipes, which were then collected in a fantastic vegetarian KOersKOokBOek.

KOers Bake-off
January 2021
We started the new year with a baking challenge, where we performed three technical assignments with chocolate, caramel, and buttercream. These were then combined to form one larger cake.

KOers Knutselclub
February 2021
In February, we did some crafts and constructed bridges with papier-mâché!

Body Building
March 2021
In March, we built our bodies and health with a weekly workout challenge accompanied by some good music tunes.

Easter Egg Hunt
April 2021
During April, we hid many Easter eggs all over KOers' social media pages. The goal was to find as many Easter eggs as possible. The total number of hidden eggs was 97!

Crazy 51
May 2021
A month full of mini-challenges! A list of 51 tasks that you have to complete during the month was made. Tasks included hugging a tree, kissing concrete, building beer crate bridges, or going to an online KOers drink. Participants made photos or videos if they completed the tasks. ◄

A Glance at The Digital Era for The Structural Engineer

By: Maikel Brinkhoff and Tom Diks
Editors KOersief

In 1943, McCulloch and Pitts, in their paper "A Logical Calculus of the Immanent in Nervous Activity," proposed the very first mathematical model describing an artificial neuron [1]. This is widely considered to be the start of Artificial Intelligence (AI). Since then, AI has come a long way and has been used in many industries, ranging from transport and finance to healthcare. AI's problem-solving and pattern recognition capabilities often exceed human capabilities. Especially when it comes to complex problems. Due to these feats, AI also will have an increasingly prominent role in structural engineering [2].

As with most emerging technologies, AI is accompanied by big promises and consequentially a tremendous hype. Each year, the Gartner Hype Cycle takes an inventory of how the expectations of these emerging technologies change over time, as can be seen in *Figure 1*. The list is dominated by AI technologies. As structural engineers, what do we need to know about AI?

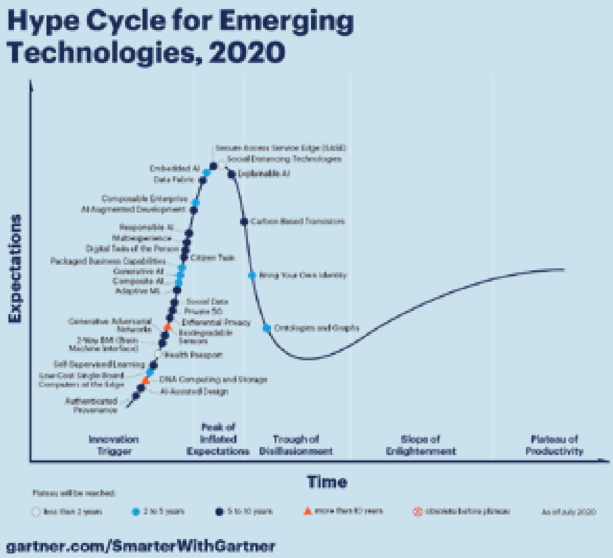


Figure 1: Gartner Hype Cycle for 2020 [3]

Fundamentals
AI in itself is a broad research field. The scope of this article, therefore, limits itself to the most used techniques within structural engineering: Machine Learning (ML) and Deep Learning (DL) [2]. As the name implies, ML refers to a system that automatically improves with experience. ML uses a so-called learning algorithm that uses training data to achieve a particular outcome. DL is a tool to enable ML. DL uses Artificial Neural Networks (ANNs), with multiple hidden layers, to simulate a human brain processing information, as seen in *Figure 2*.

One can distinguish three categories to train an algorithm: supervised-, unsupervised-, and reinforcement learning. Training an algorithm with data containing labeled input is called supervised learning. The input represents a specific situation and labels the corresponding action. The aim is to react correctly to data outside of the training set. Unsupervised learning uses unlabeled data to examine underlying patterns in the data. This method is ideal when

Figure 2: Overview of AI, Machine- and Deep Learning [4]

dealing with complex data or when one is unsure what one wants to / can gain with the data. Like unsupervised learning, reinforcement learning does not give explicit instructions on what to do. The difference is that reinforcement learning is not focused on finding underlying patterns but instead tries to maximize rewards by predicting the best consecutive moves [5].

To better understand DL, we will briefly cover its principles. As mentioned, ANNs are at the base of DL and represent biological neural networks. Therefore, the essential components consist of inputs (neurons) xi, weighted channels, hidden layers with biases, activation functions, and output y. The process is visualized in *Figure 3*, where a 4-5-1 ANN is shown. One can interpret the naming as follows: four inputs, one hidden layer with five components, and one output.

The process can be mathematically written as:

$$y_k = \varphi\left(\sum_{i=1}^{N}(x_i w_{ki}) + b\right) \qquad (1)$$

where *w* is the weights, *b* is the bias, and *φ* is the activation function. The latter limits activation of the neuron to a predetermined range [5]. Note that this shows the process in its simplest form. One can only speak of DL when multiple hidden layers are used. The most used training method of an ANN uses backpropagation, where an error value gets offset

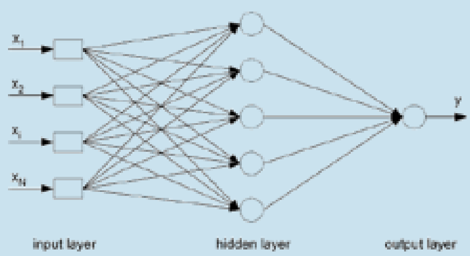


Figure 3: Artificial Neural Network structure [6]

against a weight value. Using gradient descent, one can find the weight with the minimal error where the derivative approaches zero; see *Figure 4*.

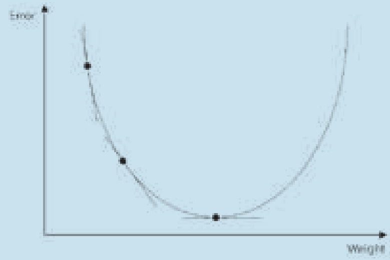


Figure 4: Method of gradient Descent

Practical application

AI approaches can help predict material properties, including compressive-, flexural-, and shear strength. Besides regular concrete, one can also use AI for more advanced types such as fiber reinforced concrete, (ultra) high-performance concrete. Deng et al. [7] compared a 4-9-1 backpropagation ANN, Support Vector Machine (ML system) (see *Figure 5*), and Convolutional Neural Network (and DL system). The Support Vector Machine (SVM) is a supervised learning algorithm that draws a decision boundary (hyperplane) near the extreme data points in the data set, segregating the data [8].

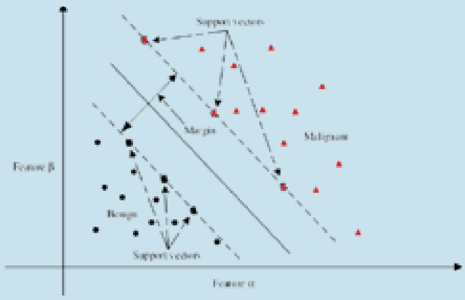


Figure 5: Example Support Vector Machine [8]

The Convolutional Neural Network uses convolution (producing a third function out of two existing functions) in the hidden layers. The paper's aim was to determine which of the three most accurately predicts the compressive strength of recycled concrete. Of the three, the DL system (RE 3.65%) provided the most accurate predictive capabilities, followed by the ML system (RE 4.35%) and, lastly, the ANN (RE 6.63%).

We need to get rid of the magic

At first, with little understanding of what AI entails, one soon gets excited about it. As you learn to understand it better and better, the enthusiasm turns into a certain realism. Precisely upon learning the limitations due to that realism, it is important not to let go of the initial enthusiasm.

A common misconception is that one needs to know exactly how an AI system works to use it. For scientists, this holds, as a deep understanding of AI allows the researcher to get a grip on the system and thus on the results. Users of AI do not need this in-depth knowledge. For instance, knowing how a computer or smartphone processes your input on a binary level is not required when writing a text.

Then you may be wondering: what do I need to know to use it? What you need when you work with an AI system is to ask specific questions about that system. How do I process the (training / verification) data? How do I interpret these results? Is applying an AI algorithm actually the best option (sometimes deterministic/statistical methods are qualitatively better, e.g., a regression algorithm)? How do I strip data of noise? What variable am I going to test? Questions like these do not require knowledge about underlying AI principles but do allow you to use it.

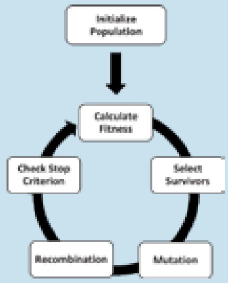


Figure 6: Visualization of Evolutionary Algorithm [9]

Optimization ≠ AI

AI excels in providing answers to complex questions. Of course, AI is not the sole solution method for complex issues. It is not always clear whether one is dealing with AI. For instance, a particular solver in a FEM program is, in most cases, not an AI algorithm. These solvers are often hard-scripted algorithms that do not adapt or learn.

Another commonly used optimization tool is Galapagos within Grasshopper. With this tool, a user-defined value is minimized or maximized based on several input parameters. Again, there is no mention of AI. Galapagos is a form of Evolutionary Algorithms; see *Figure 6*. Here, a population of possibilities is initialized, and the best combinations are calculated and selected. By repeating this process many times, a local or global optimum emerges. So, if you want to optimize something, ask yourself if an AI tool is useful because there are more possibilities to optimize. ◀

References:

[1] *McCulloch, W. S., & Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. The bulletin of mathematical biophysics, 5(4), 115-133.*

[2] *Salehi, H., & Burgueno, R. (2018). Emerging artificial intelligence methods in structural engineering. Engineering structures, 171, 170-189.*

[3] *Panetta, K. (2020). 5 Trends Drive the Gartner Hype Cycle for Emerging Technologies, 2020. Retrieved from https://www.gartner.com/smarterwithgartner/5-trends-drive-the-gartner-hype-cycle-for-emerging-technologies-2020/*

[4] *Srivastav, S. (2020). Artificial Intelligence, Machine Learning, and Deep Learning. What's the Real Difference? Retrieved from https://medium.com/swlh/artificial-intelligence-machine-learning-and-deep-learning-whats-the-real-difference-94fe7e528097*

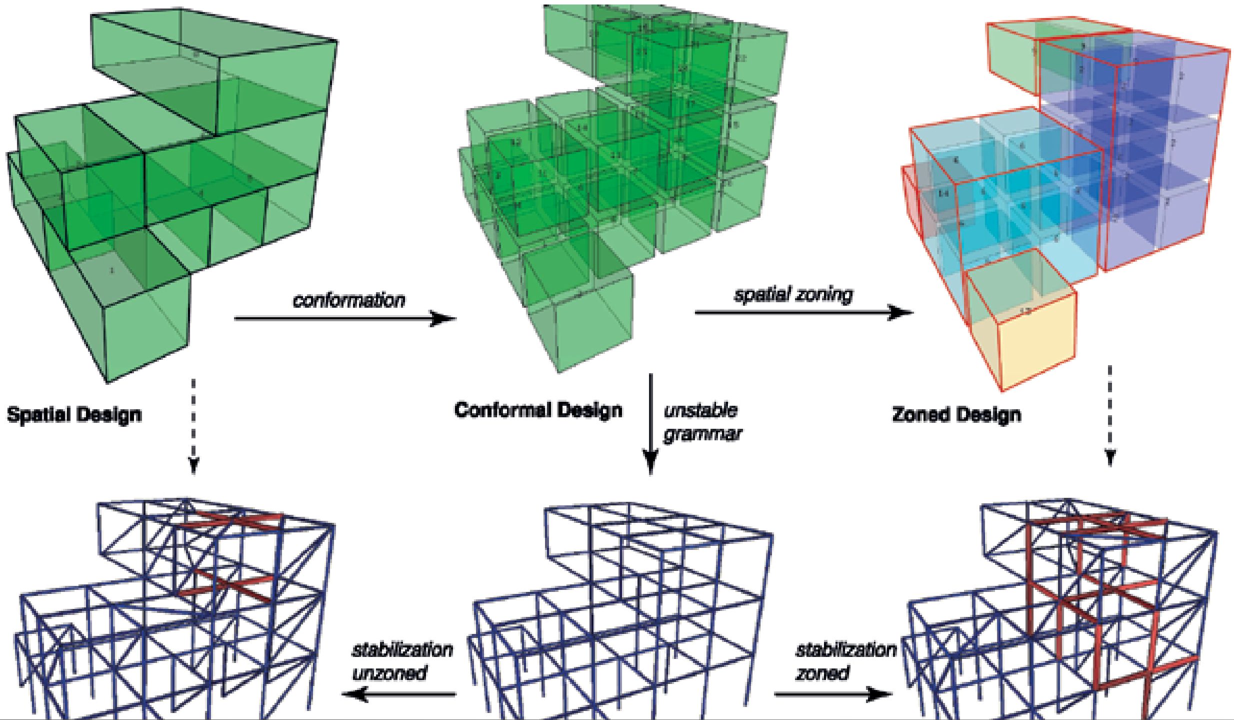
[5] *Hoła, J., & Schabowicz, K. (2005). New technique of non-destructive assessment of concrete strength using artificial intelligence. NDT & E International, 38(4), 251-259.*

[6] *Sutton, R. S., & Barto, A. G. (2018). Reinforcement learning: An introduction. MIT press.*

[7] *Deng, F., He, Y., Zhou, S., Yu, Y., Cheng, H., & Wu, X. (2018). Compressive strength prediction of recycled concrete based on deep learning. Construction and Building Materials, 175, 562-569.*

[8] *Wang, H., Zheng, B., Yoon, S. W., & Ko, H. S. (2018). A support vector machine-based ensemble algorithm for breast cancer diagnosis. European Journal of Operational Research, 267(2), 687-699.*

[9] *Lerch, F., Ultsch, A., & Lötsch, J. (2020). Distribution Optimization: An evolutionary algorithm to separate Gaussian mixtures. Scientific reports, 10(1), 1-10.*



Simulating the iterative, multidisciplinary design process

The (Artificially) Intelligent Design Team

By: Pieter van Loon
Editor KOersief

The article '*AI for Structural Engineers*' discusses how neural networks can aid the structural engineer in predicting material properties and in making other decisions. However, determining material properties is just a small part of the work of a structural engineer. The main task of a structural engineer is generating a structural design and validating it with calculations. What happens when - besides giving the engineer AI tools to aid his decision making - an AI agent will perform these core tasks?

It is well known that the Architecture, Engineering, and Construction (AEC) industry is a multidisciplinary industry where many parties work on the same design. Design teams consisting of different specialists need to collaborate constantly. Every discipline has its own objectives for which it is responsible and which it wants to optimize. In meetings the specialists come together, compare designs, and update the whole. Iteratively, the design gets better and better until, at some point, the due date has arrived or the design is 'finished'. But what if this iterative multidisciplinary process could be improved by simulations? At the TU/e, Hèrm Hofmeyer and PhD and MSc students have carried out research on how to simulate the design process and how to create design agents; an AI designer, geared to optimize the design towards a specific discipline.

The structural design bot

In the 2020 paper *"Spatial zoning for better structural topology design and performance"* [1] principles for a structural design (SD) agent are laid out. The SD agent can generate a 3D structural design, based on a spatial design. The AI agent basically functions

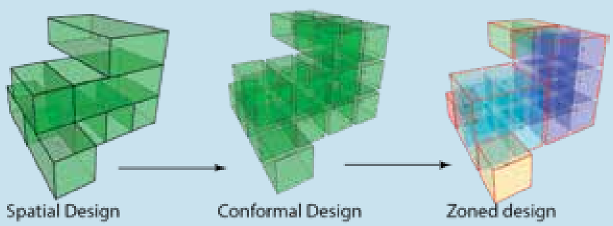


Figure 1: Example of zoning procedure [1]

as a human engineer; it analyzes the spatial design, concludes where structural elements could be placed, makes zones where stability elements are required, and designs and optimizes a structure. This previous sentence that casually summarizes what the agent does, actually contains a lot of complicated steps. Some steps require typical AI features, whereas other steps can be performed using more straight-forward algorithms and calculations.

First of all, how do you decide where a structural element can be placed? How do you determine which walls can, or should, be used for stability? What do you do when no such wall is available? People do this intuitively, based on experience. We look at the plans, or talk to the architect, we understand spatial relations, and that it might not be desired to put a column in the middle of the hallway. Furthermore, we can make structural zones within the spatial design; we look for continuous walls for stability, logical span directions, and we improvise when needed.

For the SD agent, a component analyzes the spatial design, divides it into cubes, and recognizes the larger patterns of these cubes for more efficient structural zones. *Figure 1* is an example of one of these zoned designs. Note that the zones do not necessarily comply with the spaces. When the zones are established, two 'grammars' get to work to generate the structural design. A grammar is a set of rules related to an algorithm so a design will be generated with a specific logic behind it. In this case, a stable grammar and an unstable grammar are applied. The first grammar will always result in stable configurations, whereas the second grammar generates unstable configurations by only generating unbraced truss frames. These unstable configurations are subsequently made stable by another AI technique: an expert system operating FEM analyses and adding structural elements.

With the zoning procedure and the grammars in place, the work of a structural engineer can basically be simulated. At the start, the SD agent is provided with a spatial design from which it analyzes the shape, makes structural zones and generates a design. *Figure 2* provides a visual overview of the global procedure. In this example, it was found that the zoned solution indeed yielded a more efficient structural design.

The artificial design team

Of course, the design of a building is more complex than inserting a structural system in a spatial design. Obviously, there are more disciplines that influence a building's design than just the structural design. Furthermore, as mention earlier, real life building design is an iterative process. Similarly to the 'Structural design bot' explained above, Boonstra et al. [2] describe in their 2021 paper the simulation of a multidisciplinary team. Besides a structural design agent, a building physics agent and a spatial design agent were created as well. The three agents work together in a loop to perform a co-evolutionary design process.

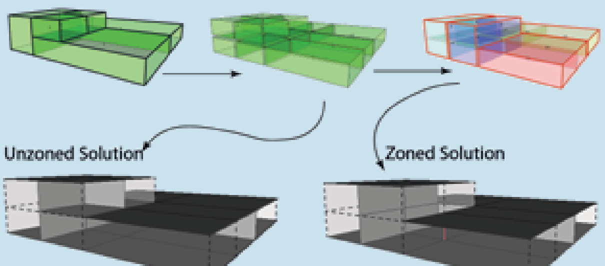


Figure 2: Generated structural design - the zoned design has 10.7 percent less strain energy, and 5.2 percent less structural volume

Figure 3 illustrates this co-evolutionary design process. It starts with an initial spatial design, then an agent analyzes the design and converts it to a discipline specific model which it can optimize. When the optimization is performed, it gets translated back into the spatial design model and the next agent can get to work. Because the agents translate the model to their specific discipline related model, large changes and optimizations can be made. These changes do not necessarily conform with the boundary conditions of the other agents, but that is not unlike real people working in multidisciplinary teams. Because of the cyclic iteration, every agent gets the chance to restore the model to its discipline's specific requirements.

The advantage of this co-evolutionary design process based on design agents, is that a huge optimization can be realized with relatively few steps. The downside, however, is that it is not too good at finding *the global optimum*. For that, the paper shows the implementation of a phase in which a more conventional evolutionary optimization is applied. Such an evolutionary algorithm – in contrast to the co-evolutionary design process – only makes small variations and calculates whether or not these are beneficial or not. It requires way more steps to make significant optimizations, but it does cover a

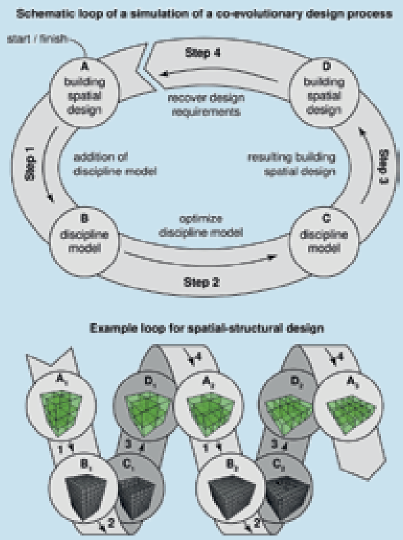


Figure 3: Visual representation of a co-evolutionary design process

larger range of possibilities. It is therefore more suited to tweak the optimization, and to find global optima.

By alternating the two evolutionary systems, the best of both worlds is achieved. This hybrid approach yields better optimized designs in the same time span as a conventional evolutionary algorithm. While at the same time, it explores a broader set of options, and finds the global optimum, resulting in a more confident conversion.

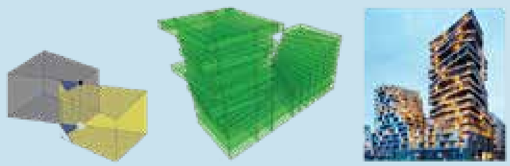


Figure 4: Analysis of a design agent on non-rectangular shapes

Outlook

Design agents can quickly generate solutions and explore options for us engineers. The co-evolutionary design process, combined with traditional evolutionary algorithms, might be a good basis in the future for the kick-off of any multidisciplinary project. Every discipline could be represented by an agent, and variations could quickly be made. At the moment, PhD student Tessa Ezendam extends the rectangular shapes to non-rectangular shapes, see *Figure 4*. She will also extend the disciplines with lighting, and will cooperate with Leiden university to make the tools really useful for designer, possibly including interfaces for e.g. Rhino and Grasshopper. If these 'artificial design teams' become more interactive, human design teams could greatly benefit from their artificial counterparts. Quickly exploring new ideas could kickstart more creative, clever, and optimal solutions. ◀

References:

[1] *Claessens, D. P. H., Boonstra, S., & Hofmeyer, H. (2020). Spatial zoning for better structural topology design and performance. Advanced Engineering Informatics, 46, 1-16. [101162]. https://doi.org/10.1016/j.aei.2020.101162*

[2] *Boonstra, S., van der Blom, K., Hofmeyer, H., & Emmerich, M. T. (2021). Hybridization of an evolutionary algorithm and simulations of co-evolutionary design processes for early-stage building spatial design optimization. Automation in Construction, 124, 103522. https://doi.org/10.1016/j.autcon.2020.103522*

Figures:

Header, 1 ,2 — Cleassens et al. (2020) [1]

3 — Boonstra et al. (2021) [2]

Artificial intelligence and augmented reality

Digital Innovations on the Construction Site

By: Tom Diks and Olaf Vens
Editors KOersief

The digital era is on the rise in the built environment. Allrounder BAM, which covers many disciplines in the construction industry, gives insights into the innovative applications they are currently working on. These new developments are both on-site as well as on the office floor.

Using AI for building applications

By: Wouter Jaspers, Pierre Hendrix (translation)
Structural Engineer at BAM Bouw en Techniek

New developments that use Artificial Intelligence (AI) are currently in preparation. This is done in combination with students and the market. Some applications are further elaborated.

Application of Artificial Intelligence during pre-qualifications
BAM participates in different tender procedures on a daily basis. For these tenders, it is common practice for contractors to pre-qualify. Based on a history of projects and results, a customer decides whether a contractor has sufficient experience and references to apply for the tender.

For our pre-qualification team, it is a time-consuming job to keep track of experiences and references of the past years. Together with students from Hogeschool van Amsterdam we took the first step to accelerate this procedure with the help of AI. The developed algorithm scans the required qualifications of a tender on the one hand and combines it with a database of reference projects based on text recognition. This is a good development. Since the pre-qualification team now needs a few days to search for references, we hope to speed up this process to reduce it to hours.

The algorithm is still in the prototype phase and needs more training in order to perform better. However, we see great potential. Hopefully, the algorithm will be able to predict our chance of success in upcoming tenders based on past references and help us with strategic choices. The power of AI is to strengthen mankind and enrich our choices where possible.

Application of Artificial Intelligence in market prediction
We are proactive in the preparations for upcoming projects. Especially for larger projects that are bound for the market, the preparation starts years in advance. The right people, partners, and available sources are assigned to reply as complete as possible on upcoming tenders.

However, it is a great challenge to predict when a project will come to the market. Projects are subject to great uncertainties and can be delayed due to multiple reasons

To mitigate as many of the risks as possible, a qualitative study was conducted together with students of TU Delft on how AI can assist in this process. We tested different AI models on reliability in predicting the starting date of historical projects. To do this, we combined data from different data sources such as news, route decisions, and government programs.

For the time being, our commercial managers have the lead on the predictions of AI. However, as we start training the algorithm and adding more data sources, this will soon turn. We believe this is a good example of how the use of AI and big data can strengthen the position of our commercial managers.

Using AR on site

By: Arnoud van der Heijden, BIM-Director at BAM Bouw en Techniek
Project: Accelerator, Utrecht Science Park

Digital Construction is the standard at BAM; from design until maintenance, digital construction is the way of working. The technology goes fast, more is possible and the demand from our people to apply digital construction is high. BIM models are being used on every construction site, but the use of digital construction ends when you leave the site office and walk towards the site. How do you get a step further and use the BIM-models actually at the construction site? This question was asked by the project team Accelerator in Utrecht and there is only one correct answer: **Augmented Reality (AR)**

Figure 1: Accelerator, a project in which AR is used

With the introduction of the Microsoft HoloLens three years ago, the construction industry came into contact with AR. This was tested at the time, and several work instructions were programmed onto it. Think about a work instruction to maintain a sprinkler installation, for example. However, the HoloLens was not safe to use at the construction site because, at that point, it was not possible to integrate this with a certified construction helmet. The accuracy in combination with the technology was not good enough to use for plotting measures at the construction site.

Now 3 years later, AR is back. Not as a question of what the possibilities are, but as an answer to the question *"how can I see at the construction pit and what need to be built?"*. For this, BAM uses Gamma AR in combination with BIM360. Our models are managed in BIM360 and being pushed to the AR environment of Gamma AR.

How is AR used at the construction site?
The mechanics or site personnel go outside with their iPad (the device we use is the new iPad Pro 2020 because this one has a Lidar sensor, which results in a better AR user experience on site.). When the mechanics or site personnel are outside, they start the Gamma AR app, select a model to align with and then align with a wall from the model. After that, they append per level different aspect models, for example, mechanical, electrical, or plumbing (MEP) models. Now the digital models are combined and outlined with the actual image of the camera. The virtual image can be set transparent to overlay the actual image. Hereby the virtual and real world are combined.

Figure 2: Overlay of the virtual image over the real world

Added value
Only the projecting itself is an added value because a mechanic can see how certain issues are engineered. The projection is also being used for checking what kind of objects intersect with a recess, and if it is located in the right position. Furthermore, projection is used to determine whether objects are in the correct position.

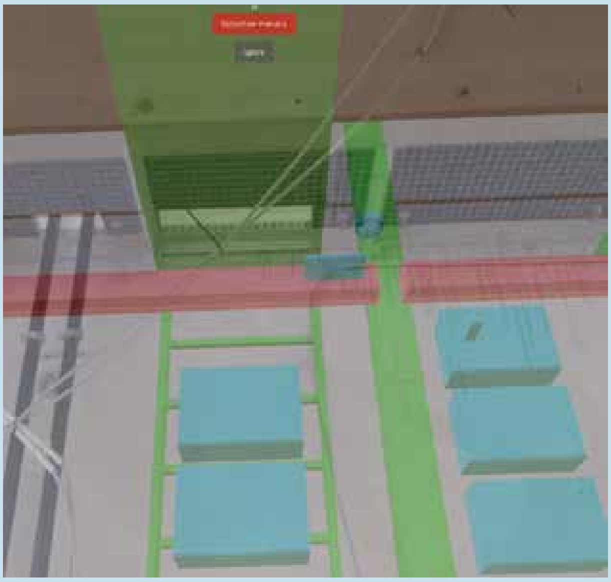


Figure 3: Overlay showing difficult issues with multiple services

The technology is now at a point that it can be used for everyday work. There are some technical points of improvement (such as aligning a model with certain points projected from a coordinate system). But the biggest challenge is not the technical side but the human side. People are not used to walking on the construction site with a (charged) tablet to check recesses or objects. Also, the users must be trained and supported correctly so this can be implemented successfully. It is a success when the users see this as a process improvement rather than a new tool. The key to success is training & support. ◄

Towards predictive twins and AI as a supportive tool for structural engineers

Interview on Predictive Twins

Interview with: Joep Paulissen and Árpád Rózsás
(civil) structural engineers TNO

By: Femke Hermans and Marijke Veenstra
Editors KOersief

This article describes an interview that was conducted with Joep Paulissen and Árpád Rózsás, who are both (civil) structural engineers by training and now work at TNO. Joep started at TNO within a researcher role on the topic of the combination of monitoring and models to assess mainly steel bridges. Now, he fulfills a consultancy role, in which he focuses on initiating relevant research on the topic of monitoring and smart infrastructure. Árpád works as a researcher at TNO. His expertise is probabilistic assessment of structures using statistics, recently also exploring and using AI techniques. Both Joep and Árpád are involved in the TNO Early research Program Predictive Twin for Structural Integrity.

What is a predictive twin and what are the fields of application?
Joep: In a few words, it can be described as a digital copy of a structure or a system that can effectively say something about a future condition or a future situation. The term predictive twin came up to give a bit more emphasis to the term digital twin. It is called a predictive twin because we emphasize more on its predictive capability.

Árpád: In general, a predictive twin consists of some sort of mathematical model, either physics-based or not, and an algorithm that is used to fit the mathematical model to measurement data. Thus, data is needed to calibrate the model. The calibrated, more accurate model can then be used to make predictions of a structure's lifetime, which can be interpreted by decision-makers. In the case of the IJsselbridge (used as a proof-of-principle test case in the TNO knowledge program), there is a finite element model, a neural network, and measurements of the structure. Then, an optimization problem is solved to fit the model to the data. The test case showed that the optimized finite element model allowed a reduction of 15% of the partial safety factor for fatigue loading while maintaining the required reliability index from assessment standards. This is a significant and promising result of the proof-of-principle phase.

Joep: There are plenty of application areas for predictive twins. For bridges, we are researching the possibilities to make an accurate predictive copy of a bridge structure, with which we can predict the remaining service life. Also, a scenario analysis could be performed. Other application areas are, for example, building physics and traffic flow.

How do you decide the required complexity of a predictive twin?
Árpád: if you asked a structural engineer how to make a decision on the complexity of a finite element model, you would get a similar answer. Sometimes, a simple model can capture the most important aspects, while this will not be sufficient in other situations. For predictive twins, the same principle holds. In some cases, building a 3D model can be avoided and replaced by a very simple 2D model of a beam, combined with a neural network. However, this is only possible if enough data is available to fit the model to the actual situation.

Figure 1: IJsselbridge

Joep: The downside is the need for data. The effort is shifting a bit from modeling to acquiring data, and, eventually, there will be some trade-off, depending on the specific case. Currently, we are in the exploration stage. The next stage will be a cost-benefit analysis to determine the best strategy for acquiring data and constructing a predictive twin.

What data is being collected and how?
Árpád: For the assessment of steel bridges, typically strain gauges are used. So far, the used measurements correspond to controlled loading conditions, where we have full knowledge of the loads on a bridge. To obtain such data, a bridge is usually closed for one or two nights. The decision on the location of the sensors is based on engineering judgment while taking into account the costs of putting a sensor somewhere and the expected benefit. For the IJsselbridge, the sensors were placed on the main girder and the crossbeams. Around ten strain gauges were used to capture the global behavior.

Joep: For the Van Brienenoordbridge, the focus was on the fatigue life of the bridge deck. A fracture mechanics model was constructed of a specific type of crack. Thirty-two strain gauges were placed on the bridge deck to capture the local, complex fatigue behavior. Eventually, 15 of them were used for the analysis.

Figure 2: Van Brienenoordbridge

Which AI principle is used?
Árpád: The focus is on obtaining models that can predict the mechanical behavior accurately. In the case of the IJsselbridge, this is done by combining a computational physics model (finite element model) with a neural network. Neural networks are used for two reasons. The first reason is a theoretical one. Relatively simple neural networks are already so-called universal approximators, which means that they can accurately approximate arbitrary complex "well-behaving" functions. The neural network is used in the whole model chain to model the parts that we do not have sufficient knowledge and understanding about to actually use physics-based models. The second reason is an empirical one. In all other fields, neural networks have proven to be extremely successful in capturing high-dimensional non-linear functions. Also, in our field, neural networks seem to work very well.

Figure 3: Van Brienenoordbridge and corresponding model

How do you see the future of predictive twins? What will be the main challenge?
Árpád: The first challenge regarding predictive twins is related to having the tools and algorithms ready in such a way that they are robust and easy to use. Then, people can start to use them and explore the added value. Currently, the effort is definitely too high, and hence the added value is not yet clear. My impression is that the future of predictive twins (at least those that combine physics and AI) is exciting and promising, probably even more so outside of civil engineering.

A disadvantage of predictive twins that involves AI models is that there are no guarantees that such models will always provide reasonable predictions. While in purely physics-based models, equilibrium is always maintained, the uncertainties increase when putting in more and more AI. Therefore, some reluctance is expected for using predictive twins. Since the consequences of failure are significant, I would never rely on a purely data-driven model. These models can only be used with confidence if a neural network represents a component in a model that has some physical meaning, such that the machine learning model itself is interpretable from a physical point of view. In that way, we can look at it with our engineering "eyes" and perform a post-processing check. Therefore, the eventual reliability of the predictive twin is a property that actually depends on our own knowledge.

Joep: As for the development of FE methods, a new development starts, grows, and becomes common practice. This will happen to predictive twins as well, but it should not be forgotten that it requires something to feed this very promising technique. Gaining good quality data is a profession. Choices must be made regarding the type of sensors to use, where to put the sensors and how to maintain the systems. The role of measuring data will increase, no doubt about that. Engineering knowledge and experience will always be needed to make senseful predictive twins and AI applications. Engineers will have to learn to work with it, to embrace it and to adopt it as a new tool. It is an extension of the toolkit of engineers. ◀

Figures:

Header,	*Shutterstock*
1, 2,	*Rijkswaterstaat*
3,	*TNO*

The Voorbij factory driven by the BIM model

“What you BIM is what you get”

By: ir. L. Rooijakkers
Production Manager Voorbij Prefab

In the Western Docklands of Amsterdam, on the North Sea Canal's quay, stands the green concrete factory of Voorbij Prefab. In the summer of 2015, this factory was converted into the most modern precast concrete factory in the world. Robots are used to produce eight homes a day, controlled directly by data from the client. It is not without reasons that one hears in the corridors: What you BIM is what you get.

Those who visited the factory before 2015 encountered about 180 employees here. They were busy carpentering wooden molds to make houses, among other things. On average, it took two days to prepare the mold. That image has now changed completely. The two days have become six minutes, and the chaos and bustle have transformed into tranquility, purity, and regularity. Large steel tables are driven past workstations and robots in a carousel arrangement, each adding their part. An empty table is built up into a concrete wall, ready with electrical cables, frames, and insulation. After a hardening time of eight hours, the wall is ready to be placed on the transport carriage. After five days, the walls are assembled on the building site, and the house shell is ready.

Figure 1: Prefab walls

The basis for production in the plant is data; the process starts with the BIM file. 2D drawings that were previously edited into production drawings by a team of modelers have been replaced by BIM files that the customer provides. In this way, the client can be sure that he receives what he has modeled. The structural model, the window frame model, and the electrical model are combined into one file. Finally, some product-specific elements are generated, such as the facilities for lifting the walls. A preparation time of five weeks has thus changed into a preparation time of five days. By standardizing the process, unique walls are generated efficiently and without errors.

The data from the complete BIM file is exported to the production system. Each robot in the process extracts the data from the file that applies to that particular robot. For example, the formwork robot reads where to place magnetic formwork, and in six minutes, builds a wall including window recesses. It also places magnets for sockets so that they are placed in the wall with millimeter accuracy. Finally, the robot indicates with paint where human action is required on the table, such as the laying of an electrical conduit. Once the formwork robot is ready, it signals the rebar robot as seen in *Figure 3*, and it gets to work. The robot cuts the appropriate amount of steel from large rolls and welds the bars together to form a reinforcement mesh. This method results in zero waste when producing the mesh. When the table passes this station, it lowers the mesh into the wall, and the wall is ready to be concreted.

Since the summer of 2020, the walls have already been prefabricated with PIR insulation, allowing higher insulation values to be achieved than with soft insulation, such as glass wool. This is done, of course, with a robot controlled by data from the BIM file. The optimal distribution of insulation boards, which are then nested by specially developed software, ensures less than five percent cutting waste. The insulation is accurately cut to size by a water jet cutter *(see Figure 4)*, and the boards are placed in the right place on the wall using a laser. Instead of sizeable logistical insulation deliveries and waste on the building site, the walls are now delivered entirely with insulation.

Figure 2: Formwork robot

Figure 3: Rebar robot

Voorbij Prefab strives to deliver an increasingly sustainable concrete shell . This is done not only by prefabricating the casco and reducing waste but also by developing new, sustainable concrete. One of the significant challenges here is that this mixture must be applied according to the production process's preconditions. This means, for example, that the concrete must remain workable enough to allow it to be poured and insulation to be applied but must harden quickly enough for it to be removed from the formwork within the specified eight hours. Voorbij's concrete technologists, in collaboration with the engineering firm ABT, have developed a recipe that saves up to 44% of CO_2 compared with our standard concrete, which is currently used in the cascos. Compared with the concrete in the National Environmental Database, even up to 67% CO_2 is being saved.

Voorbij Prefab is also looking ahead to new developments in the future. A digital twin of the production process is being developed. The process is being rebuilt digitally, and by digitally modifying or inserting process steps, one can see what the change in output from the factory will be. The real-life production process no longer needs to

Figure 4: Water jet cutter

be disturbed in order to assess the impact of a particular change. The digital twin can then see whether, for example, a five percent increase in the speed of the reinforcement robot will result in five percent more walls in a day and can then base investment choices on this.

From 05:45 in the morning to 23:15 in the evening, tables with walls drive around at Voorbij, with each table and wall having its own processing time at each station. This data is also logged and used. With historical production data for each wall and each production station, the production process's bottleneck can be determined for each production run. This gained knowledge can also be applied to future production runs. In this way, one can find the ideal production sequence in order to use the employees and robots as efficiently as possible.

Since every production worker has access to the 3D model of the wall that is currently at their workstation, paper production drawings are already obsolete in the entire process from customer to delivery. The next step is to visualize the wall at a workstation with a HoloLens. The wall is projected directly from the BIM model onto the table, and the employee sees in 3D which elements he still needs to add. Using the 3D model as an overlay on the actual wall is a final quality check.

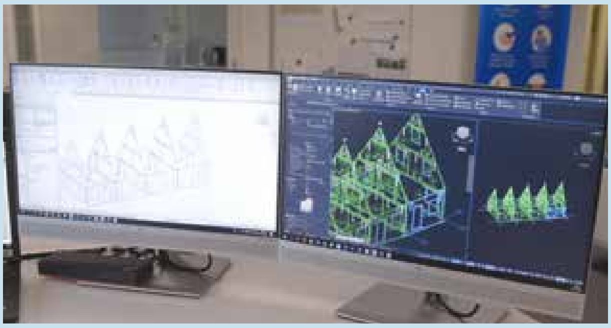


Figure 5: Digital workflow using BIM

At Voorbij Prefab, data is vital throughout the entire process: from the client's data at the start of the process to the data used to organize the production process as efficiently as possible. Efficiently producing affordable and sustainable homes is the goal, and automation and digitization are the means to achieve it. ◀

A summary of Vertico's projects and achievements

Three Dimensional Concrete Printing

By: Hidde van Wezel
KOers member

After graduating in Philosophy, Volker Ruitinga became intrigued by three-dimensional printing and decided to start up Vertico, a company focusing on three-dimensional concrete printing (3DCP). After a couple of years and some nice projects as a startup in Amersfoort, he decided to move his company to Eindhoven where technical engineering and innovation come together. Here, he has the space and the contacts, such as Study Association KOers, to let his company grow into success. In this article, an overview of some of the projects Vertico has worked on so far is presented. [1]

Green facade 2016

The green facade is a pioneer project in which a collaboration between multiple parties, such as Saxion Hogeschool and, project Konkreter, led to a wall that could be filled with plants. The walls design is based on the Voronoi-diagram, which exists out of multiple polygons. Each polygon is unique, and therefore simple production with frameworks would become expensive and labor-intensive. The solution is 3DCP, since no framework is needed. In addition, there is a good collaboration between parametric design and the printer. The individual polygons were made to fit on a pallet and should not have a higher weight than 50 kilograms. This ensures that two persons are able to stack the polygons, which eventually will form the wall.

Figure 1: Result of the Green facade project

The Voronoi-diagram is a mathematical principle in which a grid of points is created. Each point x lies in a cell that is created out of points closest to the point x. This principle is also used to, for example, determine to which hospital people live the closest. In this project, it is used to create a sort of random design like the Green Facade.

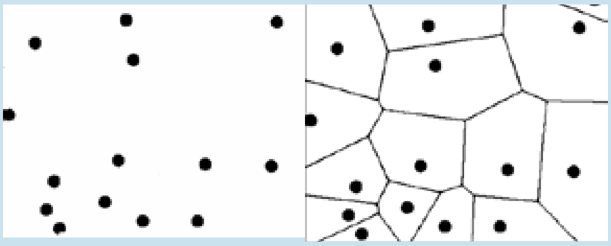


Figure 2: Example of the Voronoi-diagram

Topology bridge

Together with the Gent University and Technion – Israel Institute of Technology, Vertico has designed a fully printed concrete girder of four meters long that could function as a bridge, see *Figure 3*. The girder is designed using topology optimization, which made the girder 20 percent more material-efficient than a standard beam with a span of four meters. [2]

Using topology optimization usually generates complex geometries; therefore, it is natural to combine it with adaptive manufacturing. 3DCP is a suitable manufacturing option,

Figure 3: Concrete printed girder

even though it was impossible to print the girder as a whole. Therefore, the girder was cut into parts and connected together with post-tensioning strands; one strand at the top and one at the bottom. In addition to the strands, reinforcement was applied for additional tensile strength.

As mentioned earlier, the girder was divided into several parts, 18 to be specific, and all printed separately. The 18 girder parts were placed between two end blocks. These end blocks are casted in the traditional ways. In additions to holding the girder in place, the end blocks are also used as anchors for the post-tensioning strands.

In order to divide the girder into elements, multiple parameters had to be taken into account. For example, the elements could only have a maximum height of 400 millimeters and a self-weight of 30 kilograms. Another parameter that the designer had to keep in mind is the maximum allowable overhang. The elements were printed with the perspective that the overhang was kept to a minimum. When printing an element, the designer has to make a print path; this is done by slicing the elements virtually. Vertico has made their own slicing algorithm using Rhinoceros with the Grasshopper plugin.

The printing was done using a robot arm of the type ABB IRB6400R. These robots have six degrees of freedom, which enables printing in almost every orientation and tool alignment. The robot has a printing speed of 80 millimeters per second. With this speed, the total girder could be printed in 24 hours. However, the printing process took three working days. The printed segments had one night of settling, after which they were transported to the test location. Once all the elements were finished, they were assembled and the reinforcement was set in the hollow elements. The post-tensioning cables

Figure 4: People standing on the girder

with plastic sheathing were also put in the elements. Then, the girder was filled with grout and set to rest for 14 days before the post-tensioning was applied to the strands.

In the end, it is possible to walk over the girder as shown in *Figure 4*, which proves that topology optimization and 3DCP can come together to build more material efficient designs due to the adaptive manufacturing properties of 3DCP.

Printing the bridge presented several challenges. For example, it is hard to print an overhang, which reduces the design options available. Therefore, Vertico came with a solution to use an accelerator that is introduced into the mix at the very last moment. When an accelerator is applied to the concrete mix it will cure faster, which means it becomes stiffer in less time. If this accelerator would be induced in the mix before pumping through the printer, the concrete would harden in the system and block it. Introducing the accelerator in the mix when it leaves the nozzle, the concrete will harden right after leaving the system. This makes it possible to create an overhang of maximum 60 degrees, as shown in *Figure 5*. A second challenge is the height of the girder parts, but higher structures can be printed by using a mixture that becomes stiffer is less time. In addition, placing the robots on a pedestal made it possible to go even higher, up to three meters in the current days. This still does not mean that everything with a height of three meters can be printed since this also depends on the shape of the element.

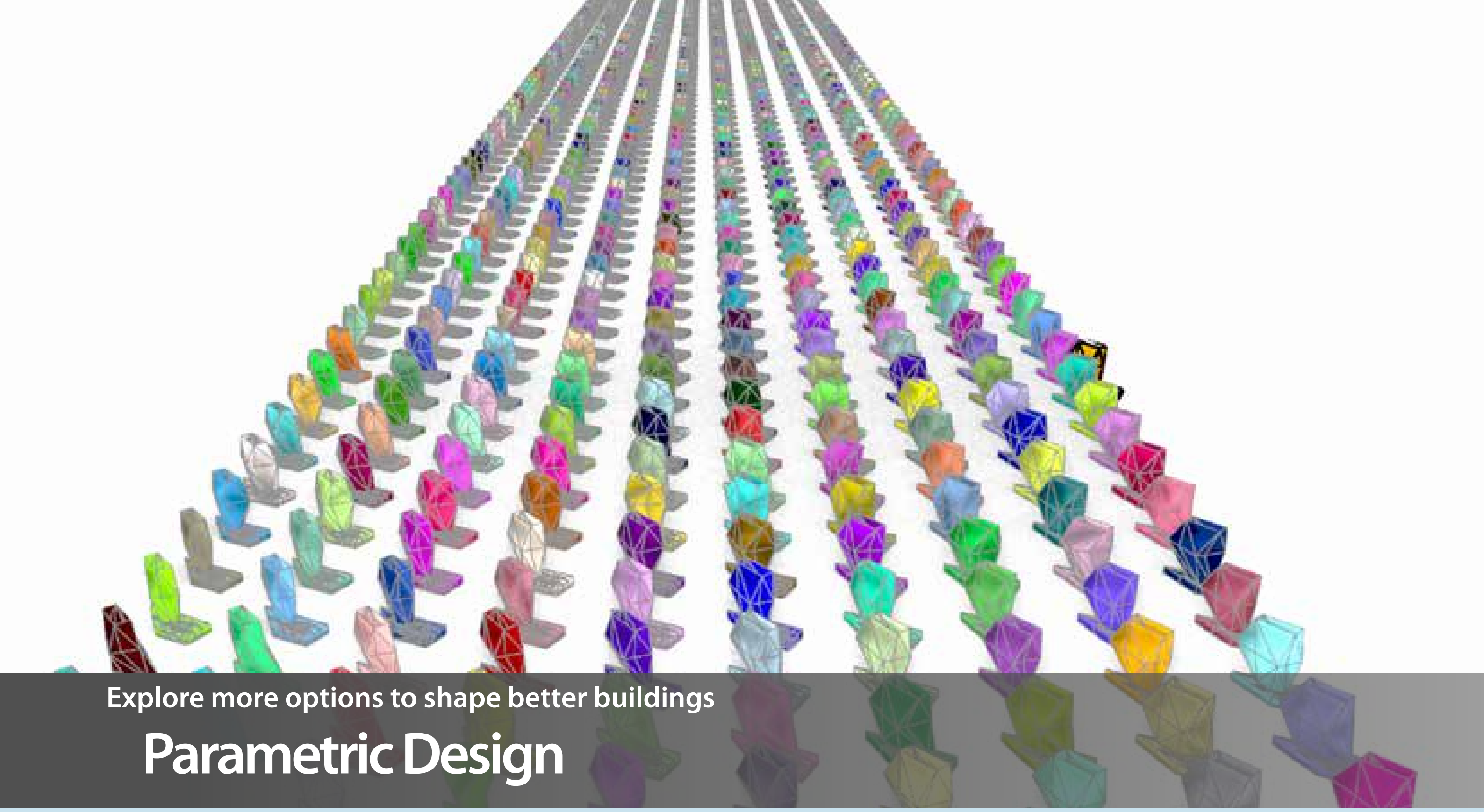
Figure 5: Concrete structure with overhang

Three-dimensional concrete printing is a relatively young field of engineering with many possibilities. Not only for structural engineers but also for architects and other creative minds who would like to create things without the boundaries of formworks. Vertico is on the way to do both and focuses on creating the best robot equipment to print with. ◀

References:

[1] *https://www.vertico.xyz*

[2] *3D printing of a post-tensioned concrete girder designed by topology optimization; Gieljan Vantyghem, Wouter De Corte, Emad Shakour, Oded Amir; Gent; 2020*



Explore more options to shape better buildings

Parametric Design

By: ir. Rick Titulaer and ir. Emilie van Wijnbergen
Structural Designers at Arup

Parametric design offers exciting new possibilities for engineers. Imagine being able to test thousands of design alternatives, instead of a handful. But how does parametric design work? In this article, Rick and Emilie will showcase how they have used parametric design for several projects at Arup.

The need for parametric design
At the moment, more than half of the global population lives in cities. This number is expected to grow to 70% in 2050. While people and buildings are coming closer together in high-density cities, we still want to live in buildings that have nice views and sunny balconies. We want to spend our free time in peaceful parks that shelter us from noise and wind.

It is clear that design assignments are becoming more complicated. Computational design methods can help us to navigate this complexity. And considering it's the early stages where we have most impact, imagine the gain if we can explore more options and compare them with quantifiable data? This is where parametric design comes in.

So how does it work?
Using conventional design methods, it is time consuming to evaluate many design options. So therefore, it is custom to only assess a limited number of options, that are designed from out personal knowledge and experience. With parametric

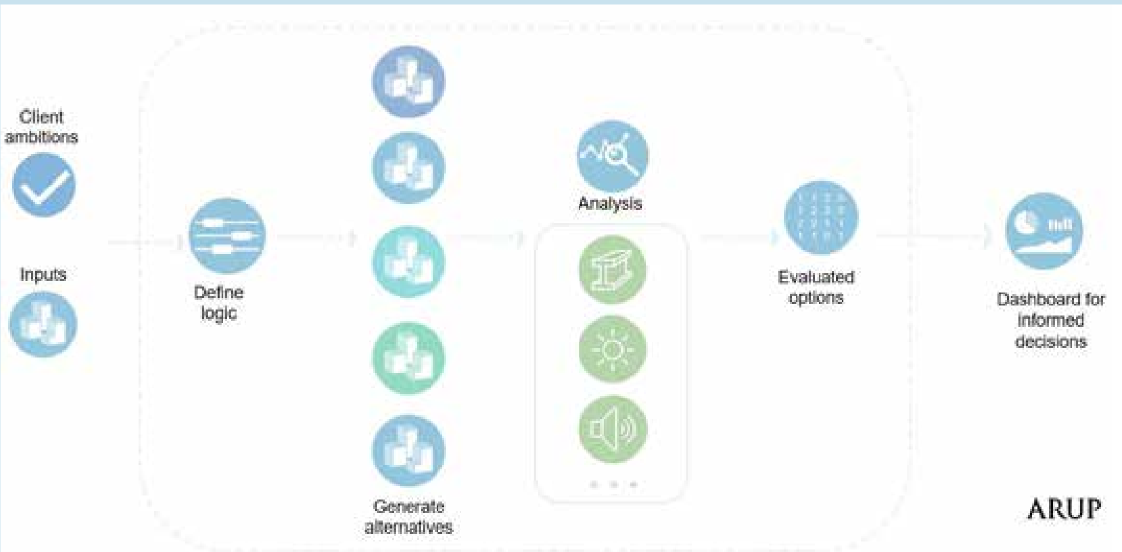


Figure 1: Parametric workflow for informed decision making

design, the relationship between the parameters of a building is described with an algorithm. By varying the different parameters, thousands of design alternatives can be generated.

In order to choose preferred alternatives, the client and design team need to formulate and quantify essential aspects that define the quality of the building. These aspects could be daylight, views, sun hours, structural systems, or whatever is important for your design. We call these KPIs (key performance indicators). To evaluate and compare many generated options, a script is written that automatically subjects all alternatives to specific analyses, which test their performance on the defined KPIs. To perform these analyses, Arup has built an extensive library of analysis blocks, including structural analysis, solar studies, view analysis, sound studies, and more. The evaluated options are shown in an informative dashboard to enable informed decision-making during design. Arup has embraced parametric design as a design service called Arup Inform (*Figure 1*). In the next section, parametric design's added value is presented with two recent design projects from Arup.

Smakkelaarspark: Designing a competition-winning proposal
The municipality of Utrecht set out a big design competition for a new residential building and public space on Smakkelaarsveld, and urban site right next to Utrecht Central Station.

Surprisingly, the municipality announced that they wouldn't choose the design of the best building, but the party that designed the best public space. This proved to be a challenging task. Although the plot has a lot of potential due to its central location, it is surround by traffic noise from the roads and railways. There is even a tramline running right through the plot. The design team chose to use parametric design to tackle the complexity of the assignment. This strategy allowed the team to explore a wide range of ideas, while getting direct design feedback on the quality created for both the building and its public space.

Figure 2: Rendering of Smakkelaarspark winning design [1]

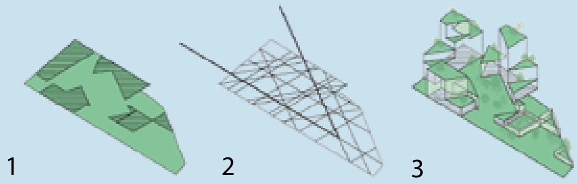


Figure 3: Design steps for Smakkelaarspark [2]

The design followed three steps (*Figure 3*). Firstly, the design team formulated a definition of a good public area: it had to be as green as possible. It was decided to cover the whole plot in greenery; to cover the tramline with a park, and to continue the park up onto the roofs. A pleasant park should also have enough sun, little hindrance of traffic noise, and apartments with good views and sufficient daylight. These aspects were defined as our key KPIs (*Figure 4*).

As a second step, the architects Studioninedots and Zus studied the urban fabric and existing road networks to define a mosaic pattern on the plot. Based on this pattern, the area was divided into multiple smaller surfaces. The third design step was to extrude these subsurfaces upwards to create building volumes. Arup wrote an algorithm that varied the height of the different volumes. In this way, a wide range of options was generated. The goal was to find a building configuration that would provide quality and comfort for both the apartments and park. Our engineers used multi-objective optimization algorithms to navigate the large field of possible solutions (*Figure 5*).

The outcome of the parametric studies inspired the design team to choose a U-shaped building configuration, resulting in an inviting gesture opening up the park to the city. This configuration mostly blocked the sound from the train tracks

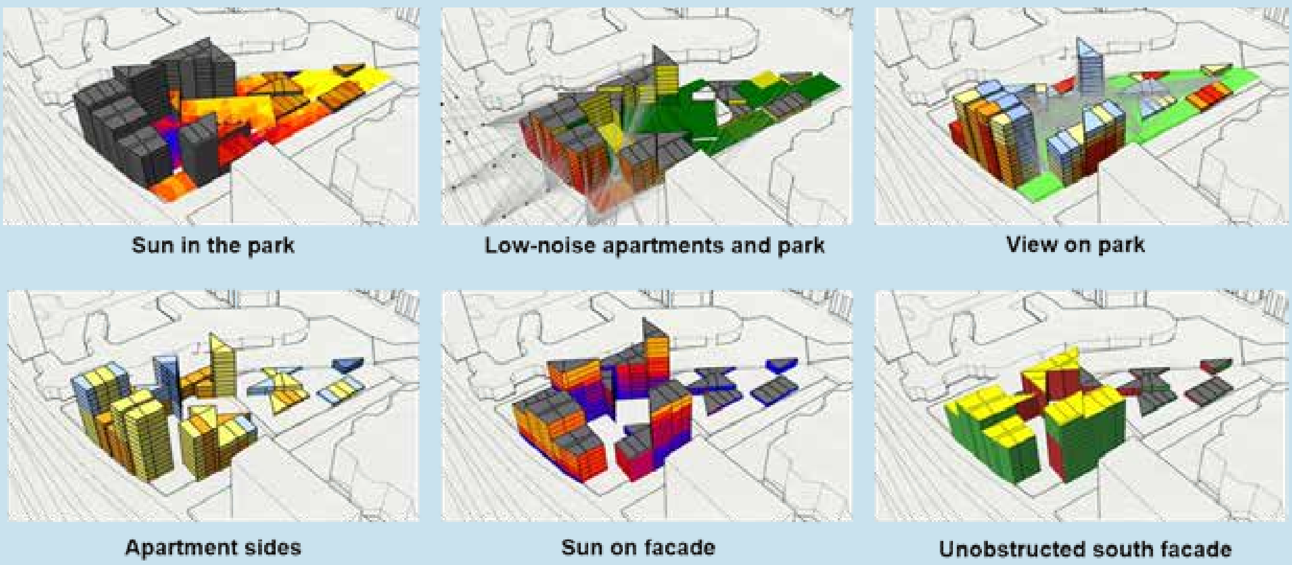


Figure 4: KPIs analysed for Smakkelaarspark

Figure 5: Exploration of the design space and solutions using Octopus [3]

while allowing the sun to flood into the park. A substantially different proposition compared to conventional urban blocks, that form a closed loop.

In the end, the jury was so charmed by the park-focused design that our design team won the job. At the moment, the project has reached the detailed design phase, while the construction of the foundations has already started. If you pass by Utrecht Central Station, you can see its progress

Towertools: Instant design feedback with parametric tools

The height and shape of tall towers are usually defined in the early stages of a project. These parameters have a big impact on the feasibility of the tower. A developer might want to increase the tower height from 180 to 200 meters, to increase the rentable area. As the governing design aspect, tower deflection, increases exponentially in response to increasing height, the extra 20m might make the project unfeasible. We felt there was a need to understand these effects in a quicker and more interactive way. Therefore, Arup developed so-called 'tower tools'. The toolset exists of scripts, that enable us to explore many different tower configurations and get instant feedback on structural feasibility, but also on aspects like embodied carbon and floor area.

The script is set-up with a user-friendly entry field for different input parameters. The input parameters can be varied, and include geometrical aspects like tower height, width, shape and structural dimensions (*Figure 6*). Based on the provided geometry, the script will automatically generate a structural configuration. It's possible to choose between different structural typologies: a stability core, a shear wall system, a core with an outrigger or a core with a façade tube. The generated structure is instantly analyzed by linking the structural geometry to the structural evaluation plug-in (Karamba3D).

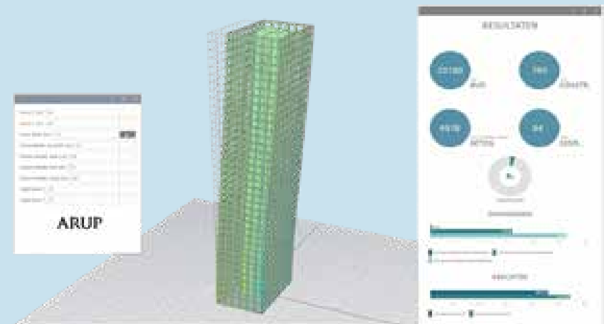


Figure 6: Interactive dashboard for structural tower design

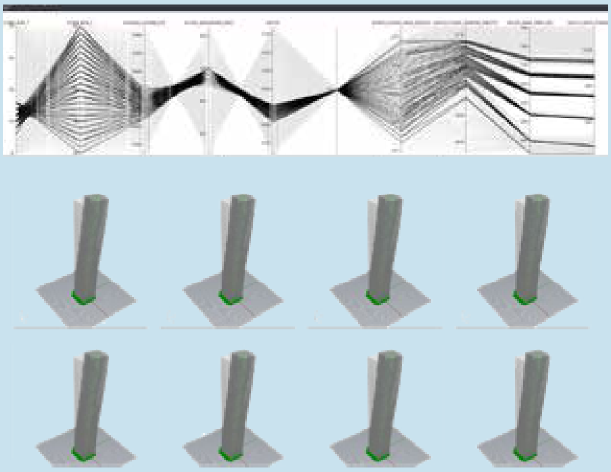


Figure 7: Exploration of different tower configurations

The structural design can be further explored by resizing the elements and evaluating the impact on the design.

With the help of a visual and interactive user interface, including a dashboard showing results, the effects of a decision like increasing the tower height can be explored live in meetings with the architects and clients. Just by shifting the input parameters of the script.

Another way of exploring the options is the parallel coordinate plot (*Figure 7*). For this method, a large set of different tower configurations are calculated beforehand. All the calculated alternatives and the corresponding analysis data are then stored and shown in a browser. Every design option is represented by a line, that connects different analysis scores which are plotted over the vertical axes. The field below shows all the generated design options in tiled view. By changing the sliders on these axes, you can filter out options based on their individual scores. This has proven to be a very intuitive method to explore the solution space.

Shaping better buildings

Parametric design can help us to shape better buildings in a shorter time. It enables designers to explore a wide variety of computer-generated options and quantitatively compare the quality of different options on the aspects (KPIs) important for the design. If parametric design is combined with a user-friendly interface to communicate the results, it is a powerful way to give design parties more insight to make quantifiably better decisions. From towers to public parks, parametric design empowers designers to make our living spaces more liveable, sustainable and affordable. ◄

References:

[1] *Lingotto, Arup, Studioninedots, ZUS, VKZ. Smakkelaarspark. Spark. [Online] . https://smakkelaarspark.nl/*

[2] *Multi-objective Parametric Massing Optimisation for a Sustainable and Healthy Urban Living Environment. Titulaer, R, Christodoulou, A and Vola, M. 2019. Impact: Design With All Senses; Proceedings of the Design Modelling Symposium. pp. 737-751.*

[3] *Vierlinger, R. (2013). Multi Objective Design Interface. 10.13140/RG.2.1.3401.0324.*

Figures:

Header — *Elements – Parametric design of hybrid timber tower. Volkor Wessels vastgoed/ Koschuch architecten / Arup. Showing the numerous options we can explore with parametric design*

1 ,3 ,6 ,7 — *Arup*

Using linear programming to optimize a structure

Dome of Plants

By: Diederik Veenendaal, Babje Rothe, and Laura Dings
Structural Engineer, trainee at Summum and editor KOersief

Summum Engineering is an engineering consultancy based in Rotterdam, founded in 2017. Arguably, it is the Netherlands' tiniest engineering office (1.4 fte). It specializes in parametric modeling, lightweight structures, natural building materials, complex geometries, and sustainable buildings, and always tries to apply that expertise to cool projects that have a positive impact. Yes, they stopped working on a building because the structural system changed from timber to concrete. They passed on work for the 2020 Expo in Dubai because safety for construction workers could not be guaranteed. And yes, that is why they are so tiny yet pretty happy about it. One particular tool in their belt is linear programming, the subject of this article.

Linear programming

Linear programming is a mathematical technique used for finding optimal solutions. In other words, it is a type of optimization method. The simplex method is a common algorithm to solve linear programming problems, that you might have come across in math class. Linear programs are problems where some maximum or minimum is sought, subject to so-called inequality constraints. A common example is trying to maximize a profit from products with different prices, that have to be made from the same set of limited resources. At Summum Engineering, two types of problems require linear programming. Firstly, constructing a lightweight structure from a certain supply of elements where you want to avoid cutting waste. Secondly, dividing a city block or apartment building, while maximizing profit or user satisfaction, using fixed types and sizes of houses or apartments. An example of the former is their work on the Dome of Plants.

Dome of Plants

The Dome of Plants, designed by LOLA Landscape Architects and Nomadic Resorts, is a lattice shell to be located in Luthuli Plaza in Cape Town. It has a span of 20 meters and a height of 15 meters. The dome is completely covered with vegetation. It houses a community space for events, workshops, exhibitions, meetings, and much more. The structure of the Dome of Plants is shown in *Figure 1*.

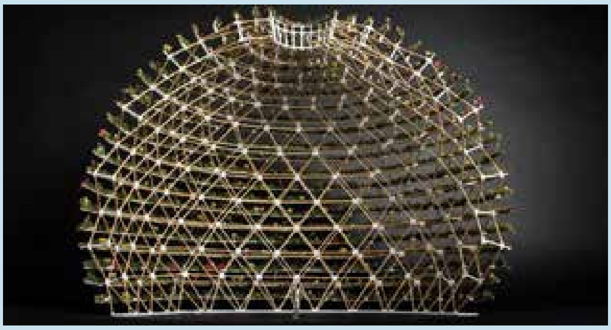


Figure 1: Dome of Plants

Figure 2: Glued laminated bamboo

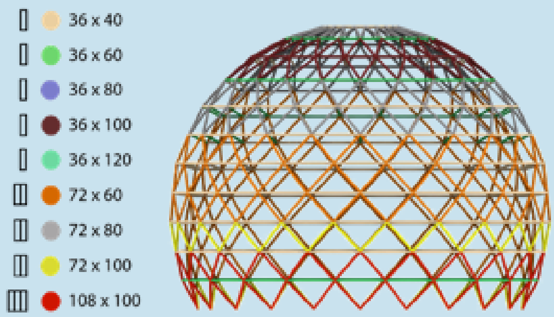


Figure 3: Cross-sectional optimization in the Dome of Plants

The sustainability of the design is incorporated in multiple ways. The vegetation has several functions. Most importantly, it captures moisture and is irrigated with purified wastewater. This way, it responds to the recent Cape Town water crisis. Furthermore, the plants lower the surrounding air temperature and create a habitat for birds and insects. Moreover, the primary structural material of the dome is glued laminated bamboo made by Moso, see *Figure 2*.

The lamination of bamboo serves two functions: it provides strength and allows for larger bamboo products. It is shipped from China, where it is regrown after harvesting. As a result, it has a net negative carbon footprint. The mechanical properties, a characteristic compression, and tensile strength parallel to grain are 34 and 40 N/mm^2 respectively, comparable or above the highest timber strength classes.

The dome structure follows a pattern, similar to a Fibonacci spiral, also known as a lamella dome. The main loads that the structure has to withstand are its own weight, that of the vegetation, and cyclone wind speeds. The cross-sections of the dome were optimized to achieve a minimal weight. The bamboo beams are slender at the top and increase in size towards the base, as shown in *Figure 3*. The optimized design contains no more than ten metric tons of bamboo, about 10 kg/m^2.

The lamella pattern is constructed using the compass technique developed by Jürgen Hennicke and Eda Schaur in 1974, see *Figure 4*. The idea is that all beams have the same length. A compass is used to draw circles with the same radius using two guide curves on a doubly curved surface. The intersections of the circles are the grid points. For this dome, the guide curves were omitted: all circles radiate from a single point at top of the dome, as shown in *Figure 5*.

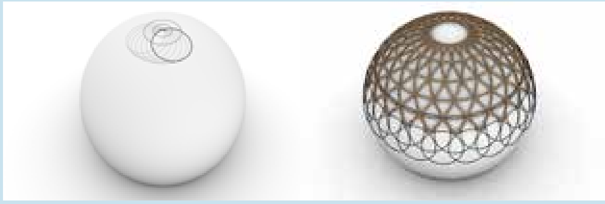


Figure 5: Using the compass technique for the Dome of Plants

The structure has to be cut from standard stock lengths of glulam bamboo. To reduce cutting waste, a cutting stock optimization was implemented in the parametric model. This is where linear programming comes in. First, a list of orders is made. This is a list of all the desired bamboo items. Next, a list of all possible combinations of cuts is generated. For every possible combination, the waste is calculated. An integer linear programming solver was used, relying on simplex methods and the so-called branch-and-cut method. Using this approach, it is possible to optimize the dome and its pattern to reduce waste during production. As a result, all the preliminary design variations already had less than 1.5 percent of cutting waste. The final result is shown in *Figure 6*.

Figure 6: Structure of the Dome of Plants

While the application to the Dome of plants is based on using virgin materials, the use of linear programming is possibly even more relevant in a circular economy, where resources are limited to the existing stock of circular, reclaimed building elements. Summum Engineering is currently exploring this topic through research and hopes to apply it soon to an ongoing circular building project. ◀

References:

[1] *https://www.summum.engineering/portfolio/dome-of-plants/*

Figures:

Header, 1 — *Nomadic Resorts, LOLA Landscape Architects*
2 — *MOSO*

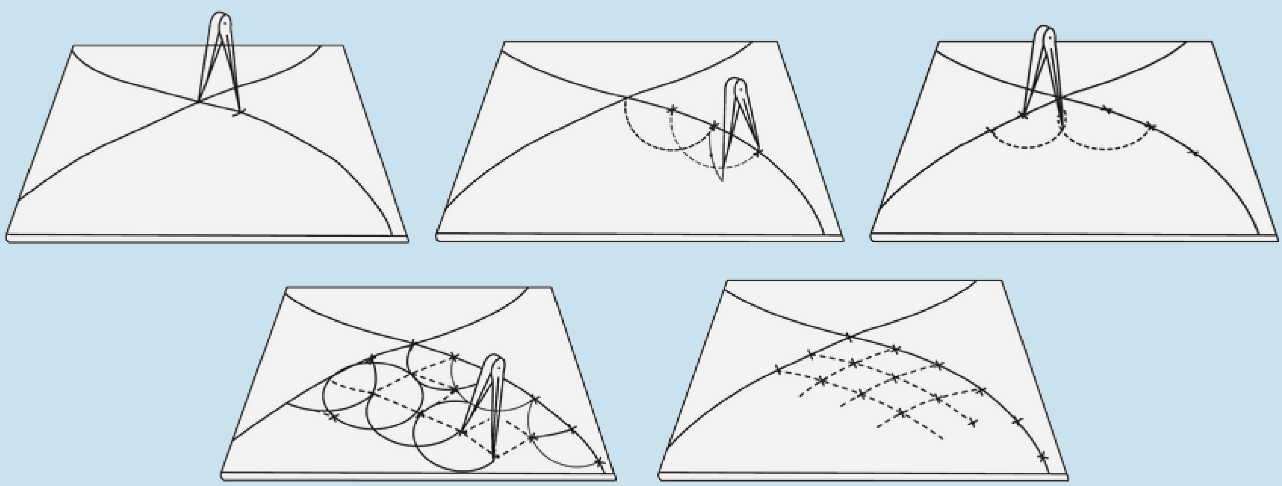


Figure 4: Compass technique

Make your own neural network in Python

Code Along AI

By: Tom Diks
Editor KOersief

Have you ever wanted to write your own neural network code? This code along article will enable you to create your own neural network. Step-by-step, it will be explained which python code is needed. This prediction method is illustrated by means of a simple example. The goal of this article is to create and train a neural network that predicts if a 2D input vector has a 'steep' or 'flat' angle. Indeed, you do not need a neural network to solve this problem, but it is easy to follow and therefore a proper example to start with. You can make your own script by overwriting the code in this article in any Python Integrated Development Environment (IDE) you like (e.g. Jupyter Notebook). Note: if you are not familiar with neural network jargon like weights and biases, please start first with the 'AI for Structural Engineers' article.

Step 1: Define variables

To learn the basics of a neural network we are coding one from scratch. First, start with creating an arbitrary vector:

```
input_vector = [1.12, 0.87]
```

This vector will be the input for the "neural network".

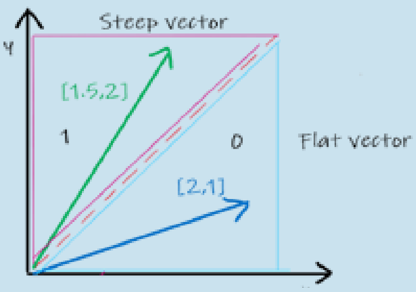


Figure 1: Example flat and steep vector

The result of the output should be 0 (flat vector) or 1 (steep vector). Now, define this variable:

```
output_number = 0
```

The neural network works on weights and biases. Take a look

```
weights_1 = [1.55, 1.76]
weights_2 = [1.78, 0.73]
```

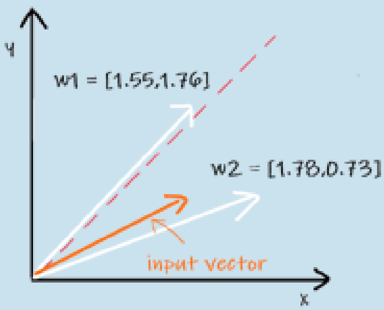


Figure 2: Input vector with weights

Which of the weight vectors is most similar to the input vector? Make a check, determine the dot product.

Step 2: Apply dot product

There are packages within Python which can do these simple mathematical calculations for us. These can be used:

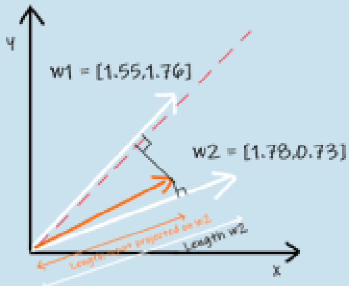


Figure 3: Dot product with input vector and weights

```
import numpy as np
dot_product_1 = np.dot(input_vector, weights_1)
dot_product_2 = np.dot(input_vector, weights_2)
print('The dot product of the input vector and
W1:'+str(dot_product_1))
print('The dot product of the input vector and
W2:'+str(dot_product_2))
```

What does the dot products mean? It shows us how similar the vectors are:

- dot product > 0 - same direction;
- dot product = 0 - orthogonal;
- dot product < 0 - opposite direction.

Step 3: Construct neural network

This dot product as well as the biases will both be used in a neural network. Now appliy it, also biases will be used. Let's apply it to a real neural network. To keep it simple we make a neural network that only consists of one hidden layer, besides the input and output layers.

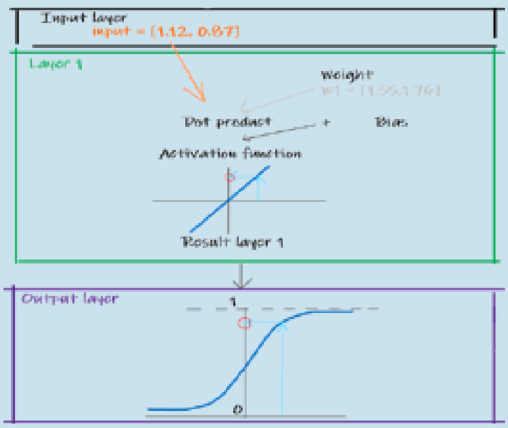


Figure 4: Overview Input later and Output layer

A linear activation function does not make any sense. Mainly in deeper networks a non-linear activation function should be used, such as ReLU. Also, all the weights should be summed up before applying it to the activation function.

```
input_vector = np.array(input_vector)
weights_1 = np.array(weights_1)
weights_2 = np.array(weights_2)
bias = np.array([0.0])
def sigmoid(x):
     y = 1/(1+np.exp(-x))
     return y
```

Constructing the forward pass:

```
def feed_forward(input_vector, weights, bias):
    hidden_layer_1 = np.dot(input_vector, weights)+
    bias
    output_layer = sigmoid(hidden_layer_1)
    return output_layer
```

Step 4: Test neural network

At this point the neural network can be tested:

```
prediction = feed_forward(input_vector, weights_1,
bias)
print('Prediction:'+str(prediction))
```

Translate it to the result we wanted:

```
result_cat = ['Flat vector','Steep vector']
result = result_cat[int(round(prediction[0]))]
print('Result of neural network:'+str(result))
```

Is this prediction correct?

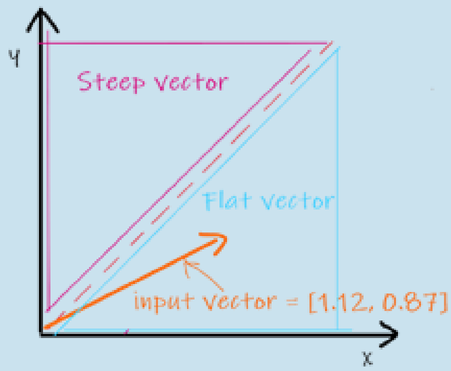


Figure 5: Check prediction

Not really. Now, check weight_2:

```
prediction_2 = feed_forward(input_vector, weights_2,
bias)
print('Prediction:'+str(prediction_2))
result_2 = result_cat[int(round(prediction[0]))]
print('Result of neural network:'+str(result_2))
```

Step 4: Train neural network

Wrong again. Our neural network is not that smart yet. It is time to train it. First we should calculate the error. For this, we will use the mean squared error (MSE):

```
ground_truth = 0
mean_squared_error = np.square(prediction - ground_
truth)
print('Error (MSE):'+str(mean_squared_error))
```

What does this error mean? Now, look at the relation between weights and prediction:

so:

- MSE > 0 Prediction to high --> decrease weights;
- MSE = 0 (No error);
- MSE < 0 prediction is to low --> increase weights.

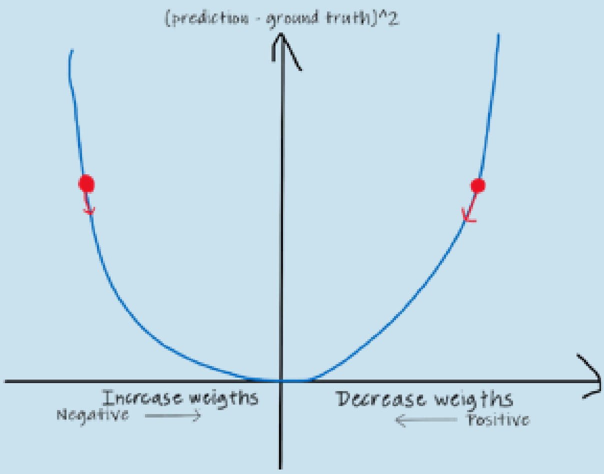


Figure 6: Relation between weights and prediction

In more complex error functions you can look at the derivative. Which in this case is:

```
derivativeMSE = 2*(prediction - ground_truth)
print('Derivative:'+str(derivativeMSE))
```

The derivative can be used to update the weights:

```
weights_1_updated = weights_1 - derivativeMSE
print('Original weight_1:'+str(weights_1))
print('Updated weight_1:'+str(weights_1_updated))
```

Step 5: Recalculate error

The next step is to recalculate the error:

```
prediction_updated_2 = feed_forward(input_vector,
weights_1_updated_2, bias)
mean_squared_error_updated_2 = np.square(prediction_
updated_2 - ground_truth)
result_updated_2 = result_cat[int(round(prediction_
updated_2[0]))]
print('Result of neural network:'+str(result_
updated_2))
print('Error (MSE):'+str(mean_squared_error_
updated_2))
```

The prediction is correct now. However, we still have a relatively large error. Let's update the weights_1 again:

```
derivativeMSE_updated = 2 * (prediction_updated -
ground_truth)
print('Derivative:'+str(derivativeMSE_updated))
weights_1_updated_2 = weights_1_updated -
derivativeMSE_updated
print('Original weight_1:'+str(weights_1))
print('Updated weight_1:'+str(weights_1_updated))
print('Updated 2 weight_1:'+str(weights_1_
updated_2))
```

Make a new prediction with updated weights:

```
prediction_updated_2 = feed_forward(input_vector,
weights_1_updated_2, bias)
mean_squared_error_updated_2 = np.square(prediction_
updated_2 - ground_truth)
result_updated_2 = result_cat[int(round(prediction_
updated_2[0]))]
print('Result of neural network:'+str(result_
updated_2))
print('Error (MSE):'+str(mean_squared_error_
updated_2))
```

Congratulations! You have created your own neural network. ◄

The opinion of professionals within the field of the built environment on our future

Artificial Intelligence as Structural Engineer

By: Marijke Veenstra
Editor KOersief

This KOersief edition gives insight into the digital era within the built environment, in which artificial intelligence becomes increasingly significant. Will this cause a change in the role of the structural engineer? We asked several professionals in our field to give their opinion on the following statement: *"The role of the current structural engineer will significantly change due to the future influence of Artificial Intelligence."*

Jeroen Coenders / White Lioness technologies

This is a really interesting and relevant question. Actually, in 2019 we started a special study group at Stufib [1] consisting of multiple industry experts to consider this question. We concluded that 'Artificial Intelligence' is a broad term that needs further definition.

We took the model of autonomous vehicles as a starting point to define our model. On one side of the model, we placed the state of no automation at all. On the other side of the spectrum, we put a utopian state: fully autonomous decision-making by artificial intelligence. We have defined several levels over this spectrum to consider what impact this would have on the role of the structural engineer. The positive aspect of this model is that you can position developments in this spectrum. For example, we can place parametric design in the model: it is a form of computational intelligence, as we are putting our logic in the computational model, but it is not very autonomous. Optimization and generative design are not autonomous either, require similar parametric logic, but are much more automated since the computer drives the algorithm to an answer. Machine learning is perhaps even closer to autonomous intelligence but is less defined in the sense of computational logic. Therefore, we could argue that it is intelligent.

I guess that the conclusion that we could draw from the model and the discussions we have in our study group is that the impact on the role of the structural engineer will be quite extensive. I fully support this: I have been advocating for over 20 years now that we can and should replace the engineer's 'sweat' with her intelligence. Using the visual programming languages to define and automate our logic in computational models for me is a no-brainer: the advantages are so big - I really do not understand why we would do otherwise. The impact will be massive, but also positive: the job of a structural engineer will be less about repetitive tasks and much more about defining logic, systems and controlling them to act in the right way. In my opinion, this leads to a need for engineers to be educated in a different manner, and I have been advocating for this. I sincerely hope that the universities are working in this direction too.

For artificial intelligence and machine learning in their purest form (close to the utopian side of the spectrum), we still need to find good uses. I believe that, for example, generating recommendations is a good case of AI usage and that engineers will need to learn to apply these new tools.

Will we lose our jobs? I do not think so. Every innovation in history so far has replaced old jobs with new jobs. Make sure that you follow the innovations, educate yourself, and you will be just fine.

Laetitia Koning / Arup

Currently, major steps are being taken in the field of new digital technologies like artificial intelligence (AI) and machine learning (ML). These technologies make it possible to optimize, automate, speed up, and upscale processes in all industries, among which the building sector.

In the first place, it will be role of the engineer to have a basic understanding of these new digital technologies to be able to recognize how they can be beneficial. Then, before applying a new technology, it is important to have a basic understanding of the background, capabilities and limitations, just as is the case for currently used technologies such as FEM software.

The application of AI will enormously increase the computational capabilities, which will allow us to upscale projects, make frequent use of data, and increase the complexity of models and designs. Although this has huge advantages, it can also result in unnecessary work being done 'just because it is possible' or in a lack of focus. Therefore, it will be the task of the engineer to put emphasis on what is important.

To conclude, I think that role of the engineer will be to use his/her engineering judgment to feed the AI algorithms in a targeted manner and validate, calibrate, and interpret their outcomes. This role is not very different from the current role of an engineer. Therefore, I do not think that the role of the engineer will change much, but rather the way of working.

Diederik Veenendaal / Summum Engineering

"I've got a mild inspiration; I'd like to see if it checks out. I'd like to run one last simulation before we pack it in for the night. This time, in the shape of a Möbius strip, inverted please", Tony says. "Processing.", F.R.I.D.A.Y. replies. Inspecting the strip, almost instantaneously rendered, along with the results from the analysis, Tony continues: "Right, give me the eigenvalue of that particle, factoring in spectral decomposition. That will take a second." His sarcasm is lost on her, as she responds: "Just a moment. … Model rendered".

This exchange, from the movie 'Avengers: Endgame', is between a sophisticated AI system called F.R.I.D.A.Y. and its inventor, Tony Stark – billionaire, CEO, superhero, but mostly an engineer with a double master's degree from MIT. He never touches a physical interface; her interface relies on motion sensing, voice recognition, and holographic projection. He doesn't model the complex geometry he requests himself, nor does he stipulate the algorithms she should use to compute the eigenvalue or perform the eigendecomposition. She even interprets which physical property and dimensions she is supposed to derive the eigenvalue of. He never told her. Named after the faithful servant Friday, from the book 'Robinson Crusoe', she never refuses any command, nor seems to feature any degree of autonomy that should concern us (see Asimov's Three Laws [2]).

My own immediate conception of near-future AI does not wander beyond this movie scene. Tony never stops being an engineer. Although his tools are cutting edge, and he has equipped himself with the knowledge to exploit them, fundamentally, his role is still the same. Imagine the following: "Give me a hybrid office tower, 30 levels with a concrete core, 20 by 20 meter CLT floors and glulam columns, please. Right, run a finite element analysis, factoring in non-linearity of the concrete and second-order effects." It is not a black box; you could ask your structural engineering AI which assumptions it made. Did you use some kind of regression to gauge the pile capacity based on local soil measurements? Monte Carlo methods to assess the probability of failure under seismic action? What were the shape functions of the finite elements? My hope is that AI, along with new types of interfaces, will reduce the time between a thought occurring to us, and us having fully explored or executed that thought. I believe the world could be better for it.

A common sentiment is that AI will change us into computer scientists or IT specialists. I don't agree. This is no truer than that past advances in science and technology have turned engineers into mathematicians, physicists, geologists, material scientists, or really-good-spreadsheet-makers. We are none of those, or maybe a bit of all of those, but mostly we are engineers (though maybe with just the one master's degree). ◀

Glossary:

[1] ***Stufib*** *is a society for structural concrete and is connected to the Betonvereniging (Dutch concrete society). The purpose of Stufib is to stimulate the theoretical and practical development of structural concrete and to spread knowledge about this topic.*

[2] ***First Law)*** *A robot may not injure a human being or, through inaction, allow a human being to come to harm;*
Second Law) *A robot must obey the orders given it by human beings except where such orders would conflict with the First Law;*
Third Law) *A robot must protect its own existence as long as such protection does not conflict with the First or Second Law.*

Figures:

Header *https://www.brainfacts.org/neuroscience-in-society/tech-and-the-brain/2020/the-next-generation-of-machine-learning-111920*

The future of architecture, engineering, and construction is digital and intelligent

Artificial Intelligence in the AEC Industry

By: Susanne Knorr
Lead data & analytics at Arcadis

As the world shifts towards a more digitized future, the data economy is thriving, and many companies are starting to see AI as an important means of creating a competitive advantage. Through applications of AI, companies of different backgrounds in various industries are finding evermore effective solutions, meeting their demands at a faster pace, and tackling larger and more impactful challenges every day. Together with increased connectivity and automation, AI is a fundamental component of the Fourth Industrial Revolution (Industry 4.0). Up until now, the Architecture, Engineering and Construction industry has had a slow response to these developments, but now, we are standing at the brink of disruption and we predict significant changes will happen to our industry in the near future.

Climate change, population growth, urbanization, and globalization are megatrends that are creating different societal needs related to housing, infrastructure, transportation, and construction. Furthermore, 2020 – with the pandemic, economic turmoil, and societal unrest - has increased the demand for more effective and faster solutions for societal challenges. A paradigm shift is required to successfully face the future.

Despite the significant potential to boost services within the AEC industry using existing technology within data analytics and artificial intelligence, the adaptation rate in the industry has been rather low. This could partly be due to fragmentation of our industry, which makes large collaborative research and development projects difficult, which further slows down innovation.

We successfully started to explore AI capabilities in the AEC industry and we have delivered numerous projects that focus on data analytics to our clients with cutting-edge analytics solutions. Arcadis would like to share its AI expertise with the industry, with the hope that this will be a step in the direction towards a more collaborative, digitized, and innovative industry. We believe that by adapting to the digital transformation, we all can deliver better, faster, and more effective solutions to our clients – and consequently, improve the quality of life for people all over the globe.

We came together and worked collaboratively on a joint document: "Artificial Intelligence in the AEC Industry – a Code of Practice", which is a comprehensive report about the current state of AI in our industry, the future opportunities, trends and examples of work we have conducted together with our clients. The main areas of AI in the AEC industry, as illustrated in the *header*, include; (1) Sensory, (2) Language Processing, (3) Perceive, (4) Knowledge Representation, (5) Learning, (6) Decision-making, (7) Augmented Creativity, and (8) Motion. These branches of AI can be applied to a variety of client challenges, and in our Code of Practice, we illustrate how AI can be used in all our solutions and market sectors.

The *Artificial Intelligence in the AEC Industry – A Code of Practice* is the result of global collaboration between regions and sectors. We are proud to utilize the knowledge of several of our industry experts and to share this with the rest of the industry. We hope that this report can inspire other companies in the industry to also take the step towards a more digitized future. We are excited to face the challenges of the future and further investigate how we, as an industry, can revolutionize the nature of architecture, engineering, and construction. ◀

By: Cement
Knowledge platform about concrete structures

Optimizing constructions with generative design
Computational design is a new and, at the same time, essential design technique in in the toolbox of the manufacturer. For example, parametric models can be linked to the structural design. Nowadays, it is even possible to optimize structures automatically. An example with which this can be done is the generative design tool of Autodesk, simply called Generative Design. Due to a coupling with structural calculation software, results, such as the results of deformation or strength calculations, can be minimized or maximized. Results can also be kept within a range of values. The tool optimizes a design by choosing different input parameters several times and in a smart way. After a number of analyses, an optimum is found on the so-called Pareto frontier.

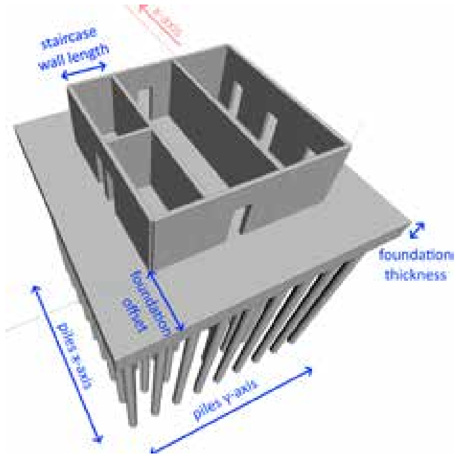


Figure 1: Model of the optimized core.

Arcadis has gained experience with the technique in the design of a stability core. A principal design is optimized to the slimmest possible design, where the construction is optimized for strength and stiffness aspects. With variations in the thickness and dimensions of the foundation plate, the number of piles, the thickness of the core walls and the length of these walls, a minimum of the total weight of concrete in the foundation and the core and the number of piles has been sought, see *Figure 1*. The displacement, the pile distances, the pile reactions, and the concrete pressure were limited. A total of 200 models were generated and assessed in this analysis. Of course, the intention is to discuss these results with the other design parties and the client to determine the consequences for the integral design. It is not the case that this technique can replace an experienced designer. However, it can complement an experienced designer.

More about optimizing a core with generative design can be found in the Cement article 'Optimizing core structures'. This article can be read on www.cementonline.nl/optimaliseren-kernconstructies

Seismic cut between substructure and superstructure
In the heart of Groningen, on the Grote Markt, Merckt, a 25 meters high building with restaurants and luxury apartments, is being finalized. Merckt is located in the region of gas extraction-induced earthquakes, which meant that measures had to be taken to realize an earthquake-proof building. For a compact and rigid apartment building like Merckt, applying 'base isolation' is an appropriate solution. The loads from the earthquakes are therefore significantly reduced by the use of so-called 'sliders', which consist of two stainless steel slides with a Teflon-clad 'puck' in between, see *Figure 2*. Often these sliders are placed as low as possible in the building. In this case, however, it was decided to construct the slider level between the restaurants and the living floors. This allowed the seismic decoupling to be combined with the acoustic decoupling, which is also necessary. The sliders, 31 pieces in total, are set up on a 'foundation layer' (an intermediate floor) and under a beam frame, consisting of concrete beams integrated into the floor. To make the cut possible, smart solutions had to be devised for various parts, for example, for the lift shafts that pass through the slider level. The lift structures are suspended from the floor above the sliders and kept free from the underlying structures all around.


Figure 2: Substructure and superstructure can move separately due to sliders

More about earthquake-resistant design of the Merckt in Groningen can be found in the Cement article 'Horecalandmark hangt boven de markt, this article can be read on www.cementonline.nl/horeca-landmark-hangt-boven-de-markt ◄

Parametrically designing a free-form gridshell

Topped by a Shining Diamond

By: Koos Fritzsche and Daniël van Kersbergen
Sales engineer and project engineer at Octatube

A striking spatial gridshell roof structure of glass and steel, free of form, shines like a diamond on top of the historical Diamond Exchange, Capital C in Amsterdam. Designed parametrically to find the optimal geometry towards planar quadrilateral glass units.

The Diamond Exchange – now called Capital C Amsterdam – at the Weesperplein in Amsterdam is a symbol for the glory days of the diamond trade in Amsterdam, see *Figure 1*. The building, built in 1911 after a design by Gerrit van Arkel, was reinstated in 2019 and functions as a new creative hub with offices for creative companies, meeting rooms, event venue, and co-workspace. It is topped with a brand new spatial gridshell roof structure of glass and steel over the full width of the building, designed by the architectural studio ZJA in collaboration with Heyligers design + projects. It functions as an event venue and offers a truly breathtaking view of Amsterdam.

Figure 1: Capital C Amsterdam (Photo: J.W. Kaldenbach)

The large two-story dome is about 45 meters long, 21 meters wide, and 10 meters high. The structure of the roof is based on the gridshell principle: the constructive force is absorbed by the double curvature in the roof's surface. That allows enormous freedom in form and a large span without columns. The dome's structure, covered with 423 glass panels, is transparent, light, and open, as can be seen in *Figure 2*.

More importantly, this gridshell has a free-form, meaning it cannot be defined by a certain geometrical shape such as a cylinder, sphere, or cone. ZJA determined this free-form shape by using a parametric computer model. With their in-house written program, the boundary conditions were defined, with the software searching for the most suitable shape. In the case of Capital C, this was a geometrical free-form shape, but with planar or minimal curved quadrilateral glass. This represents the faceted aesthetics of a diamond as a reference to the building's heritage. Additionally, optimizing the planar glass panes also increased the feasibility and cost-efficiency of the design. During this design and feasibility process, Octatube, as a specialist Design and Build contractor, was approached and challenged to realize this innovative and complex design.

In principle, the gridshell is built from just a handful of connection types. However, due to its free-form shape, every connection is geometrically unique and composed of various individual parts. Octatube turned the design into a parametric production model with their own software, which converts the complex wireframe geometry into a FEM-model and a detailed production model.

A parametric model is a schematic model consisting of lines (beams) and points (connections), which contain properties describing their location, geometry, and material. Octatube digitally generated and processed all of the more than 1000 unique steel elements and more than 200 unique glass panels into compositions within four hours. This made it possible to implement changes and optimizations until late in the design and engineering process. This flexible way of working enables Octatube to make projects like this successful. The roof structure was parametrically designed down to the last detail controlling both the production and prefabrication of the structure.

By designing the project parametrically, the construction proved to be not only technically feasible but cost-effective as well. The applied methods of parametric design and engineering allowed the team to not only optimize the glass-design until late in the engineering phase, incorporating a file-to-factory workflow, but it also allowed for fast and very precise prefabrication. Not unimportant when installing a free-form glass and steel gridshell on top of a listed building in the heart of Amsterdam.

Figure 2: Interior view of the gridshell (Photo: J.W. Kaldenbach)

Realizing a challenging structure like this is our driving force at Octatube. It requires a thorough foundation embedded in structural engineering. Through extensive iterative calculations, detailed drawing, testing, and creativity, we design and build the most challenging and complex architectural structures, with emphasis on advanced applications of glass and steel. See and read more on our website www.octatube.nl. ◀

Project information
Client: Zadelhoff B.V.en Sijthoff Media
Architect: ZJA, Amsterdam in collaboration with Heyligers design + projects, Amsterdam
Engineer and contractor roof structure: Octatube, Delft
Design Engineer: Pieters Bouwtechniek, Amsterdam

Hillebrand constructs main boom for Mammoet self-erecting pedestal crane

A Valuable Reference

By: Offshore-industry.eu
Structural engineers at ASK Romein

In our industry, good reference projects are a valuable way to promote a company's skills. Steel constructor Hillebrand is aware of this. With their recent contribution to heavy lift specialist Mammoet's new Focus 30 crane, the company showed what they are capable of in the field of fabricating high-strength steel structures.

Frank Buijk is Project Manager of Fabrication and Operations at Hillebrand and further elaborates on this prestigious project. "The Focus 30 crane that was recently constructed for Mammoet, is a high capacity pedestal crane. This specific crane, with a maximum capacity of 1,000 tonnes in this configuration, will be deployed during turnarounds at refineries. What makes the crane unique is that it is vertically self-erecting. It can be built vertically up to a height of 150 meters, with a footprint of just 26 by 25 meters, without compromising stability and strength. For the assembly, only a small hydraulic crane is needed to lift the sections into place. As a result, it can be assembled in an area of 26 by 40 meters."

The advantage of this configuration is evident for refineries. "Usually," Mr. Buijk continues, "pedestal cranes are assembled horizontally. This process requires a lot of space. Part of the booms, for example, often need to be laid down over pipelines and other objects on site. Consequently, these pipelines need to be shut down for security reasons, meaning an additional extension of the turnaround period. A lot of money and time can be saved with the Focus crane as small assembly footprint."

Four contractors

The construction of the crane was awarded by Mammoet to four construction companies, of which Hillebrand constructed the main boom. Worth mentioning is Mammoet's desire to have the main components constructed by Dutch contractors. Only the slewing ring was taken realized by the German company Liebherr. As part of ASK Romein, Hillebrand has ample in-house expertise in constructing large (high strength) steel structures, such as bridges and steel structures for plants and stadiums. The company also built an impressive track record in structures for the offshore industry. Although Hillebrand has constructed various crane components before, the main boom, which is 80 meters long and consists of eight segments, was a nice challenge.

Complicated welding details

As Mammoet developed the crane in-house and took care of the entire design and engineering of the crane and its parts,

Figure 1: Artist impression, courtesy of Mammoet

Figure 2: Welding the connections

Hillebrand was, in this case, only asked for the fabrication of the main boom components. "The input from Mammoet contained some complicated welding details, which forced us to look for an intelligent and practical implementation of those requirements. But things worked out fine. With the main boom, we have shown our skills in the delicate welding of S690 high-strength steel. On behalf of Mammoet, the work has been approved and certified by Lloyd's Register. A repair rate of less than 0.2% was achieved during fabrication, demonstrating the quality of our work", states Mr. Buijk proudly.

Knowledge and experience

Looking at other projects, Hillebrand reveals it is also capable of independently designing and engineering. "We have been involved in the entire process for many projects in various industries", Mr. Buijk voices. "Customers often come to us with a basic idea and a few requirements. Our specialist engineers and calculators, together with a dedicated project team, translate these into a completely executed project from scratch to a high quality piece of work, including the verification by independent parties such as DNV Gl and Lloyds' Register. Being part of ASK Romein gives us the opportunity to make use of all knowledge and experience available within the group. In our region, we can rely on many experienced partners as well. For example, the construction of the contact surfaces was crucial for the main boom segments, which is why we subcontracted the machining of these surfaces to one of our local partners."

Aiming for more

With the Focus 30 project, Hillebrand is aiming for more. Mr. Buijk concludes, "This crane is the first one in a series of a new concept for Mammoet. Mammoet is currently (at the time of the interview early in July) assembling and testing the crane at its Westdorpe terminal, after which it will be shipped to the US. When the Focus 30 has proven its abilities there, it is expected that more orders for this type of crane will follow. We are certainly eager to do the job again. On the other hand, taking part in this project is also a valuable reference for projects in many other industries." ◀

The human factor in a digital era

~~Structural~~ Computational Engineers

By: Eren Duru
Structural Engineer at BouwQ

Structural engineers are a critical link in the process of building. They facilitate the realization of safe, durable, and economically justifiable buildings, as well as other structures. Structural engineers are typically involved in every phase of the building process. They therefore require broad technical knowledge and the skills to apply this knowledge. This is not only important when designing new structures but also - and possibly more so - when coming up with additional measures for dealing with execution errors or when designing changes to an existing building. Furthermore, answering third-party questions before, during, and after a building process is customary to a structural engineer. Knowledge and skill are, after all, the engineers' trade.

Being an inspection firm, we are involved in design reviews as well as inspections on the execution of building projects. During our operations, we increasingly find errors linked to unskilled use of calculation software. While the digital revolution in our trade creates opportunities to design more attractive and complex structures, our reviews are also showing the perils and pitfalls of current and future automation and the hazards they may pose to the integrity of building structures.

Time is money!

"Time is money! Structural design needs to be faster and more efficient." This sums up the motivation of many engineering firms, which are focusing on automation to obtain this goal. While it is completely logical in today's economy, this motto would have been laughable forty years ago. Back then, labor was cheap, and building materials were costly. There was no calculation software, so without specialist knowledge, it was impossible to make structural calculations. Mechanics schemes were calculated by hand. The more complex the calculation, the more knowledge and experience was required. With the rise of calculation software, enveloping both mechanics and building codes, the trade has gradually evolved. The early software was great for quickly producing a presentable calculation, which would have taken considerable time without a computer. One could input an entire steel truss for instance, and get a clear overview of its response to loads. Because the level of automation was fairly low at that time, the experienced engineer running the computer model could easily see whether the output made sense or not.

The button-pushers…

Currently, many companies are investing large sums into the automation of their engineering processes. They are also developing their own tools to run alongside the more established and widespread calculation software available. This is fine, as long the people using these tools are aware of their inner workings, or there is an experienced structural engineer at the end of this design process, as a checksum. Unfortunately, as an inspection firm, we come across errors in calculations by engineers and suppliers on a daily basis. We find that users assume the output of their software tools as gospel, regardless of their own input. This is especially the case with complex calculations, often utilizing FEM software or extensive spreadsheets, where the individual steps of a calculation are no longer evident to the user. The calculations being performed inside such a software tool can be seen as a black- box, introducing a new group of engineers: The button pushers. They forget that software can only do what it is asked to do. Moreover, the software is not able to validate the correctness of the input. The human factor continues to play a vital role in this.

It should be obvious that experienced engineers will remain indispensable to the design process to yield structures with guaranteed safety. When dealing with complex structures, the involvement of an experienced structural engineer is of vital importance. She or he can use their experience to judge manufacturability and the plausibility of the results of a calculation. However, it is not just complex structures and homebrewed software in which user errors occur. We also see an increasing number of cases where basic structures are wrongly modeled into common framework software. This must be because engineers are unaware of their own inability to schematize correctly, which is called unconscious ineptitude. In the end, a clear understanding of the tools at hand and proper communication are key. Without this, projects can turn out disastrous, as illustrated in *Figure 1*.

Models with built-in structural calculation

A current trend is software that can link structural calculations directly to a BIM model, virtually without user interference. This is an especially potent application, offering many interesting possibilities. However, this type of far-reaching automation will lead to increasingly fewer opportunities for new graduates to be involved in schematizing structures and doing calculations by hand. This threatens to erode professional knowledge (including the relationship between mechanics and detailing), possibly eliminating the (traditional) structural engineer in the future.

BouwQ: an independent and expert quality assurance firm

Logically, incompetent use of calculation software will lead to errors. To prevent these errors, experienced engineers' continuing presence, involvement, and alertness are of vital importance. Unfortunately, this isn't always the case in practice. This will, in fact, in light of the revolution in calculation software, be the case more and more often. For this reason, or to safeguard the safety and quality of buildings and infrastructural works, BouwQ is enlisted as an independent technical quality assurance firm. By performing targeted checks in all phases and on all aspects of buildings and the building processes, BouwQ can guarantee quality and safety. It is our task to reduce errors in building practice and to lift build quality and safety to a higher level. Obviously, this requires expertise. We have the knowledge, experience, and processes to prevent errors from creeping into structures. Our primary focus is looking for risks, schematization, cooperation between structural elements, and the required detailing. We make approximating calculations by hand to reveal whether the computer analysis of the designer makes sense or not. Furthermore, we train young engineers to schematize thoughtfully, make quick approximations to compare their complex computer models with, and always, ALWAYS keep thinking about their actions.

The gap between study and practice

"Why do we study complicated sums while companies use calculation software to do this?" If you have done an internship, you may well have wondered about this. Don't worry; knowledge of the craft will undoubtedly remain necessary to fulfill the profession of structural engineer. However, reshaping the curriculum may prove necessary to bridge the gap between study and practice. Technical education will need to prepare students for a lifetime of collaboration with computers. For instance, by adding a course specifically targeted to automation, where you might learn to set up a (basic) spreadsheet. In the future, structural engineers need to be better at understanding the internal processes of the software and to appreciate the importance of the inputs.

Impossible? No, but only if there are enough capable structural engineers providing continued support to the automation process

Automation is a beautiful thing that provides the possibility to achieve even more beautiful structures (which may have been impossible to design in the past). One day it might even be possible to have computers and robots that design and build entire buildings without us ever lifting a finger. But we do need to realize that enough checkpoints have to be built in. However, this type of far-reaching automation will lead to increasingly fewer opportunities for new graduates to be involved in schematizing structures and doing calculations by hand... Imagine working at a company that does just that. ◀

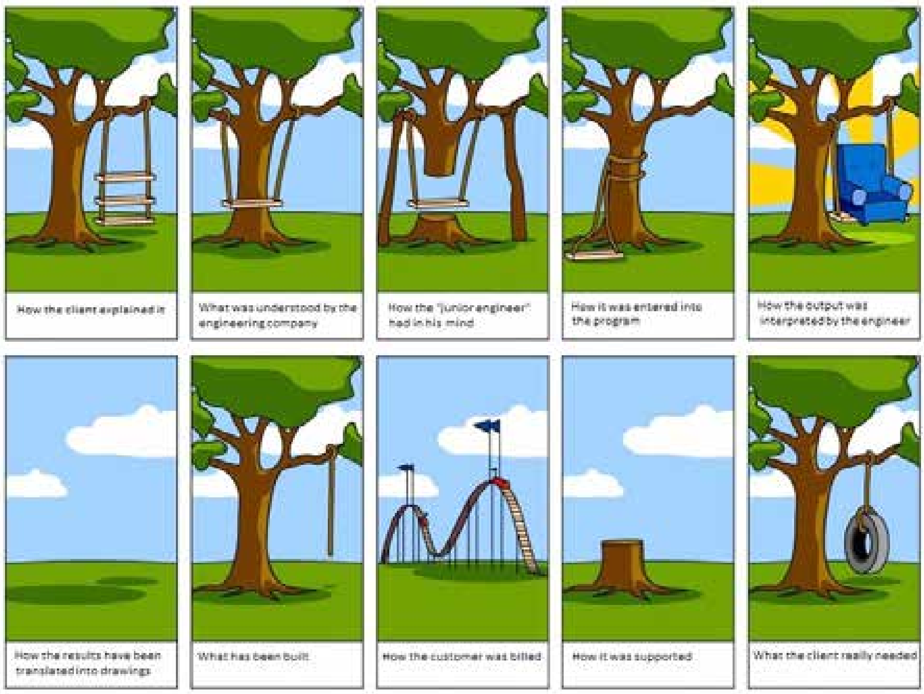


Figure 1: How things can go wrong because of the human factor

Towards dynamic interoperable modelling

The Third Digital Age in Design

By: ir Rayaan Ajouz
Bouwen met Staal

Just three decades after the century-long Paper Age seemed to come to an end, the Digital Age is already moving to its third phase. To create an overview of its current status, Bouwen met Staal is hosting the webinar series Digital innovation.

1. Continuously striving for more efficiency

The architecture, engineering, and construction (AEC) industry is constantly evolving. It is hard to imagine that just three decades ago, all design drawings were made by hand. These hand drawings were labor intensive and were prone to have errors.

CAD-software packages were developed to stimulate efficiency. The implementation of CAD-software completely changed how our workspaces looked like. Drawing boards were replaced by computers and these 2D drawing were created with mouse clicks and drawing pads. A new digital era emerged. Nowadays, 2D drawings are not created separately anymore, but are extracted from a full 3D model containing all project information. Often this is referred to as building information modeling (BIM). Unfortunately, these models are static and are therefore not able to adapt to design changes or new demands quickly.

The need for dynamic models defines the next era, where we are currently in the middle of. Instead of building a digital model, we are creating the logic to generate the digital model. The creation of a dynamic model always starts with defining what should be variable and what should stay static. Depending on these variables, or parameters, we define the logic that produces the desired outcome, which we call a parametric model.

1st Digital Age	2nd Digital Age	3rd Digital Age
Computer Aided Design (CAD) Drawings	Building Information Modeling (BIM) Information	Parametric Design and Interoperability Platforms Logic
Drawing 2D Single disciplinary Stand alone Design skills	Modeling 3D / 4D (incl. time) Multidisciplinary Network / Intranet / Internet Design skills	Programming Dynamic Multidisciplinary Interoperability Design and programming skills

But what is the current level of implementation of these innovative digital techniques? To answer this question, Bouwen met Staal started the webinar series Digital innovation. In this series, every month, a guest speaker working at one of the Dutch design companies or manufacturing industries, presents in a short 30 minute presentation how these new digital techniques contribute to a better project delivery [1].

2 . The creators of parametric models

The bigger part of the presenters are creators and users of parametric models. They work as structural engineers or architects. Different from a traditional design process, a parametric model is able to model complex geometry and can quickly adapt to changing demands. At the beginning of the projects, relatively little information is known. This makes dimensioning elements difficult, both element length and section size. In a later stage of the design, transport dimensions for example, will determine the maximum length of the beams segments. The parametric model then enables you to quickly implement these changes without risking to redo all the work and risking a loss of quality in the design.

During the webinar sessions, presenters give elaborate examples of their projects where a parametric workflow has been used. *Figure 1* and the *Header* show prime examples where a parametric approach was paramount to the design.

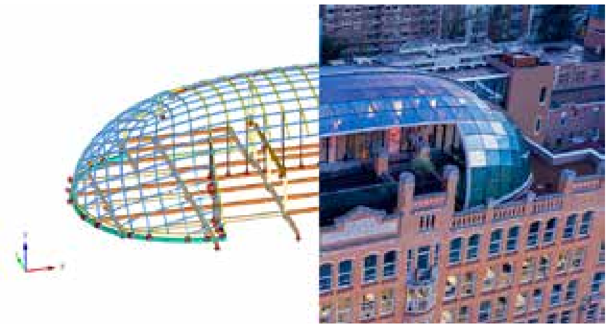


Figure 1: Diamantbeurs, Capital C Amsterdam

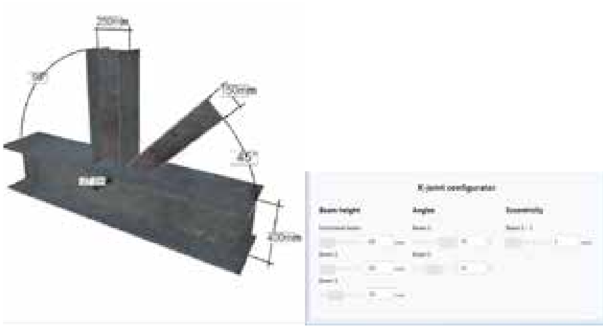


Figure 3: Example of an online configurator

3. The rise of interoperability platforms

Another striking trend, besides the increasing implementation of parametric scripts, is the rise of interoperability platforms. Some of these have been presented during the webinar series. In a parametric model, often multiple software packages are linked. However, every link should be created and maintained. Making a separate link for every software package results in having a high number of these links, which comes with tremendous work needed for maintenance. Therefore, interoperability platforms are becoming more present. The platform contains a centralized definition to store all information, which links to every software package separately, eliminating the need to maintain many links, as illustrated in *Figure 2*.

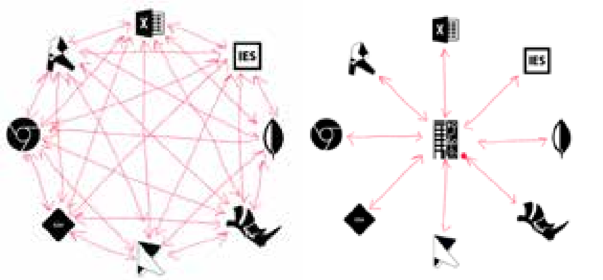


Figure 2: Eliminating the number of links in an interoperability platform

The 3rd Digital Age is data-driven and enhances the cooperation of different competencies in the design team. Interoperability encourages faster and more accurate collection and interpretation of data. This leads to increased efficiency, because it eliminates repetition and helps to control consecutive steps in the design process. This frees up resources, both human and material, and facilitates designers to communicate and organize the process better.

There is a wide variety of interoperability platforms available in the market. These are either open source or serviced. The serviced options can guide you in creating your parametric workflow and can help you to publish the model as an online configurator, like the one in *Figure 2*.

Interoperability platforms enable us to create enormous parametric ecosystems, where various companies and disciplines can add their logic into and where the system will generate the multidisciplinary final design. Designing will no longer be done by hand, but instead, designing will consist of creating the logic to generate the design.

Open-source	Service
Bhom.xyz	Packhunt.io
compass.dev	ParaPy.nl
speckle.systems	Shapdiver.com
	Viktor.ai

4. Bouwen met Staal's activities within the 3rd Digital Age

Parametric design is becoming a more and more important discipline for the construction industry. Therefore, besides this webinar series, Bouwen met Staal is making its contribution to stimulate the use of parametric design within the industry. For example, during the Staalbouwdag 2019, Bouwen met Staal organized a Hackathon where architects, structural engineers, and detail engineers from different companies worked together in multidisciplinary teams to design a hockey stadium within 6 hours. For the last two years, we did research on how steel connections can be included in parametric models and how cost optimization can be made [2]. Lastly, since last year Bouwen met Staal is giving five-day courses, where participants learn the fundamentals of parametric design.

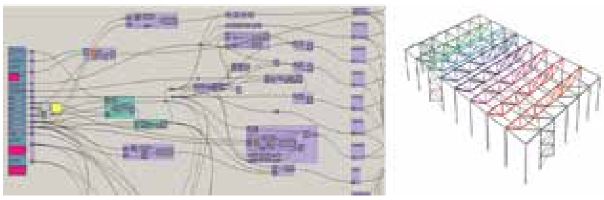


Figure 4: Parametric design

Bouwen met Staal is excited about the benefits that this 3rd Digital Age will bring to the design and construction industry. We are looking forward to the 4th Digital Age, where machine learning and artificial intelligence will potentially take over parts of our work

5. Bouwen met Staal YouTube channel

Interested in watching the webinars? Past webinars can be viewed free of charge on the YouTube channel of Bouwen met Staal: https://www.youtube.com/BouwenmetStaal1 ◀

References:

[1] *https://www.bouwenmetstaal.nl/evenementen/webinar-reeks-digitale-innovatie/*
[2] *https://www.bouwenmetstaal.nl/evenementen/hackathonstaalbouwdag/*
[3] *SMARTconnection: https://www.bouwenmetstaal.nl/THEMAS/PARAMETRISCH-ONTWERPEN/SMARTCONNECTION/*
[4] *https://www.bouwenmetstaal.nl/CURSUSSEN/PARAMETRISCH-ONTWERPEN-VAN-STAALCONSTRUCTIES-2E-EDITIE/*

Figures:

Header — *Studio RAP*
1 — *Octatube*
2 — *bhom.xyz*
3 — *Bouwen met Staal, Packhunt.io*
4 — *Bouwen met Staal*

The sense and nonsense of 3D

Floating Donuts

By: ir. Steven van Eck
Structural Engineer at Pieters Bouwtechniek Delft

These days any building larger than a backyard shed is designed in a 3D environment. Architects, structural engineers, and contractors all work together in BIM to ensure that the models from the individual disciplines fit together like pieces of a puzzle and are considered 'clash-free'. It might come as a surprise that the models for structural calculations are often still simplified 2D interpretations of their 3D Revit counterparts. Especially now that tools exist to easily transfer the geometry from these Revit models to structural software such as SCIA or Robot. So why still use 2D calculations at all?

Well, there are many advantages to boiling down engineering problems to their basic elements. That way, you can get rid of many potentially unwanted side effects, making the calculation process a lot more transparent. It doesn't mean that all that innovation in the 3D space was for nothing; there are many structures that heavily depend on 3D force flow, which can't be solved on the back of a coaster. An example of this is the new headquarters of Krinkels, a large landscape contractor who's active in the Benelux, Germany, and the UK. The headquarters was designed by Paul de Ruiter Architects, based in Amsterdam, and consists of three levels: a hexagonal basement, three wings under a 120 degree angle which meet in a central atrium on the ground floor, and to top it all off: a donut-shaped first story which appears to be floating. Pieters Bouwtechniek was responsible for the structural design of this project, all the way from the initial design sketches to the reinforcement detailing. Since it's the headquarters for a landscape contractor, the building is integrated into the landscape by having lush vegetation around and on top of the building.

Back to the floating floor: the idea was to have the first story slightly elevated above the roof of the ground floor and to have the 12 load-bearing columns positioned inwards, to give the illusion of a floating floor, resulting in a five meter cantilever. The circular shape was actually really beneficial: if the floor wants to deform, the so-called ring effect will counteract this, kind of in the same way how the roofs of large football stadiums work. This ring-effect cannot be taken into account if you make a simple 2D calculation of a cantilevering floor. Determining the contribution of this effect was crucial, because the floors had to be propped up a couple of centimeters to account for the deflection due to self-weight. The goal was to have a flat floor after this deflection had taken place, so we did not want to underestimate nor overestimate this deflection. It goes without saying no client would be happy with a crooked floor. It turned out that the ring-effect led to a 50 percent decrease in deflection of the floor slab: from roughly 10 cm in a 2D calculation to 5 cm in a 3D calculation, as shown in *Figure 1*.

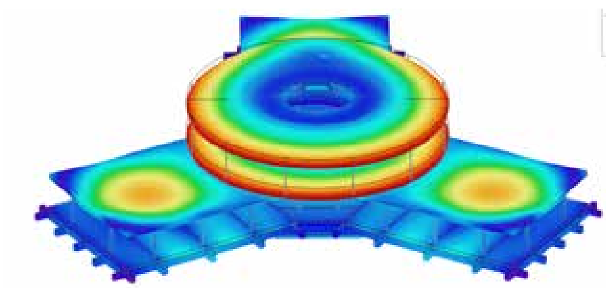


Figure 1: deflections under self-weight

So choose your battles wisely: don't just put everything in a 3D model just because you can. Think of the advantages and disadvantages a 3D calculation might have. But, regardless of how many dimensions your model has, always set it up in a flexible way, because for some reason, there are always changes at the very last minute. And you don't want to be stuck with a hard-coded Excel sheet at that time. ◀

Digitization in the job market

The Digital Age & The Future of Job Applications

By: Continu Professionals

In this KOersief, you can read everything about digital innovations such as BIM, AI, robotization, parametric, and more. You will have to deal with this in your work, but did you know that when you apply for a job, you will also have to deal with digital innovations? We would like to tell you more about it in this article.

There is nothing more dynamic than the job market, since trends are added every year. This is also the case when you are applying for a job. Especially now with the corona crisis, a lot has changed when it comes to finding a job and the way of applying. The application process will change partly due to the impact of Artificial Intelligence (AI) and digitization will accelerate everything.

1. Apply digitally

The entire application process has moved from offline to online since the Corona crisis. From sending your application, to the first job interview, to your first working week. This is not always the case, but it has resulted in faster developments;

- Apply via WhatsApp. Did you know that all our advisors can also be reached via WhatsApp? In this way, it is more accessible and easier to ask questions about a vacancy or to submit a direct application.
- Video applications. A video application gives the employer a good impression of the applicant and what his or her social skills are like. However, applying with a video does require the necessary adaptability and preparation. After all, it is still a different way of applying than a face-to-face interview.
- Drawing up your letter or Curriculum Vitae (CV). For example, we offer you a free tool that will give you a nicely formatted CV in no time. But did you know that there are also tools that can help you draft an letter by means of AI?

2. The impact of Artificial Intelligence

Artificial Intelligence ensures that the recruitment process is further digitized. Now, consider the chatbot. A chatbot is a great support for applying quickly and easily. For example, you can already ask a number of questions in an easily accessible way about matters such as salary, culture within the company, and more.

In addition, a chatbot can help you to apply in a more targeted manner. For example, you are considering applying for a vacancy that concerns a position in Amsterdam and you currently live in Maastricht. Then the chatbot is able to recommend another similar vacancy in the Maastricht region in a fun and friendly way. A win-win situation!

Did you know there even is a job application robot in the making that can conduct interviews? Application robot Sigmund is from the assessment provider LTP Business Psychologists. The robot uses algorithms to make a judgment. Sigmund assesses applicants on the basis of ten questions without the need for a resume.

For now, we would like to stick to our real advisors and they will be happy to help you find your first job! As an intermediary, we have been working for 25 years in realizing the growth ambitions of young professionals in construction, infrastructure, technology, supply chain, and the public sector. We look at your ambitions and goals. With our personal approach, we will help you further in your career. We do this thoughtfully and with conviction. So, say hello to Continu Professionals and your ambitions! ◄

CONTINU PROFESSIONALS

Building Information Modelling integrated with fire design

The Fire Separation Tool

By: Croes Bouwtechnisch Ingenieursbureau

BIM stands for Building Information Modelling. By starting with virtual building, the failure costs during the actual construction process will decrease considerably. Furthermore, the construction period will be shortened, and with clash detection, the quality will be better.

As an innovative company, Croes Bouwtechnisch Ingenieursbureau aims to develop every project with Building Information Modelling. In addition, KlokGroep, their partner on the Havenkade project, also uses BIM whenever possible. Croes and Klok speak the same BIM language, share the same vision, and have the ambition to maximize the use and results of BIM in projects. Fabian Verwoert, BIM coordinator at Croes, and Wijnand Hoogerbeets, BIM coordinator at KlokGroep, collaborated intensively on developing a tool to automate three-dimensional visualization of fire resistance requirements.

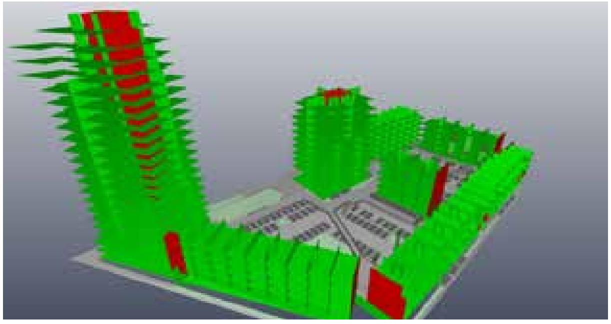


Figure 1: BIM model

Achieving the best result together

The working relationship has been great from the beginning. During the kick-off meeting for the collaboration format concerning the Havenkade project (apartment buildings in Nijmegen), the subject of fire resistance requirements came up. Fabian indicated that the experience of the Croes architecture and structural departments shows that fire resistance requirements can be a very complex issue, especially in case of a large and complex project. He therefore suggested automating this, which perfectly suited the philosophy of KlokGroep.

The extra effort it takes to create a well-defined BIM project is well worth it in the long run. The strength lies in not only focusing on your own discipline but also going the extra mile to make it easier for the other project partners. It ensures that all project partners think constructively and work with the other disciplines of the team towards solutions. The design team strives towards a collective result, which works very efficiently and positively.

Figure 2: Fabian Verwoert and Wijnand Hoogerbeets

Multidisciplinary clash control

Traditionally, an external advisor makes a fire safety report, which includes the theoretical requirements and a two-dimensional visual representation. Fabian: "This means that not all the information is clear to the installer. Drilling a hole in the wall for ducts has direct consequences on the fire resistance." Fabian (Croes) and Wijnand (KlokGroep) developed a BIM tool to effectively illustrate which measures every discipline should take to meet the requirements. It is great to see that both Croes and Klok contributed from their own field of knowledge and expertise. The tool was developed for Revit (a BIM program) with the use of Dynamo. With the tool, fire zones can be drawn in a simplified way, and the tool checks the requirements applicable to the zones. Then the separations between the different areas will be generated in 3D. The generated model can now be overlayed on top of the models of other disciplines for checking so-called clashes; pre-emptive conflicts in the model that indicate the adjustments that must be made to meet the fire separation requirements.

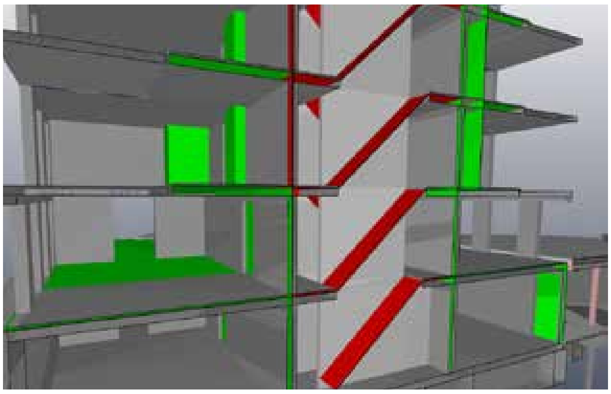


Figure 3: 3D representation of the fire zones as generated by the tool

3D sections in no time

The fire separation tool, as Fabian and Wijnand call it, does not necessarily ensure additional speed yet, but it definitely creates consistency. Furthermore, it is possible to quickly generate a good and complete 3D section of the drawing at any position in the model. Fabian is enthusiastic about the tool: "Croes also used the tool for another project. The bugs that we encountered at that time have meanwhile been resolved. In the case of new projects, we probably meet new challenges to further fine-tune the tool." Wijnand shares this ambition: "During the production phase of Havenkade, we would like to check the 3D models of the suppliers against the fire separation tool." Fabian and Wijnand have great expectations for the tool they have developed and its results. Both parties are looking forward to strengthening their cooperation in the future.◀

Figures:
2 Hans Barten Fotografie (Druten)

The Fenix

By: ir. Lennart Wiltjer
Structural Engineer at IMd Raadgevende Ingenieurs

Large cantilevers, a structure that seems to float, a structure that was not a building nor a bridge, but a sculpture, a piece of art, that should be useable and safe. IMd found a solution for the challenging structural design of the Fenix landmark (the "tornado"), by using parametric tools such as Grasshopper.

The vision of the architect for the design was clear: it should be a floating structure with as little visible supports as possible. Very few supports were used, with large spans and enormous cantilevers. The first hand calculations gave a clear conclusion: the design as the architects imagined it, would not be possible, no matter the amount of steel (or other materials) that would be used. We had to prepare for a design process that was not straightforward as we are used to in more conventional projects. We needed a strategy in which we could test numerous design changes in a limited amount of time.

Since the architectural model was a Rhino-file, the first logical step was to use Grasshopper to see if the structure could be calculated quickly, for instance with the FEM-plugin Karamba. Due to the complexity of the structure and the demand to verify the desired design changes, Karamba proved not to be sufficient for this phase. So, we had to use a more advanced package, in this case SCIA.

The shape of the tornado is not straightforward, which makes it hard to model in SCIA. Especially, if you have to check multiple designs in a short cycle. We created a Grasshopper script that transforms the architectural model into a FEM-model. For the first calculations, we used a centerline-model. This centerline represents the entire structure of the tornado, but the structure is modeled as centerlines rather than 3D structure. By giving this centerline the structural properties from the 3D structure, a fairly simple model is created that is capable of checking the structural behavior of the tornado as a whole, including dynamics. The structural properties are determined by making small 3D FEM-models, which describe small parts of the tornado. The interaction between the several models and the centerline model is visually represented in *Figure 1*.

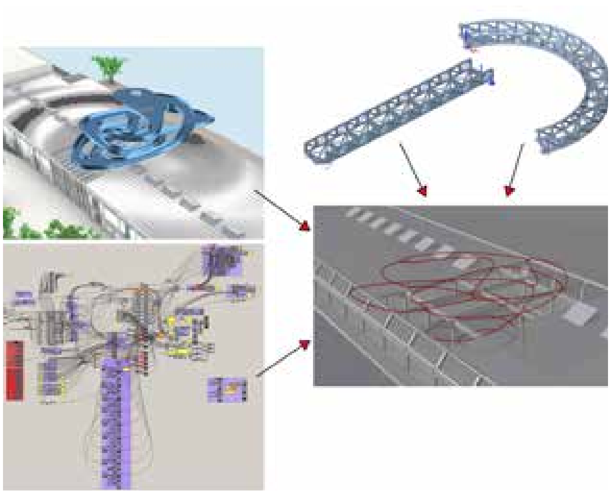


Figure 1: Interaction between the grasshopper script, architectural model, 3D FEM models, and the centerline model

Figure 2: Fenix landmark

With this centerline-model we were able to check the structural behavior of the tornado and show the locations where additional measures were needed. These measures could be an extra support, extra structural height in the cross-section, heavier profiles, or a (slightly) different shape of the tornado. The challenge was to modify the structure without losing the original concept of the design. For a few months, we were in a two-weekly cycle, in which we tested the structure, gave directions to the architect, and received a new design.

The usage of a Grasshopper script made it possible to check the design multiple times a week and, in close cooperation with the architect, in the end it led to a structurally feasible design.

IMd stands for the idea that the structural engineer is not only the one who calculates the structural elements in the design of the architect, but is also a design partner. Early cooperation with the architect leads to designs that are structurally much more optimized, which leads to lower material usage, lower costs, and a lower impact on the environment. Also, (structural) issues can be revealed earlier in the process, so the design adjustments can be smoother. The preliminary design phase of the Fenix was a clear example of the vision of IMd. ◄

Figures:
1, 2 *MAD Architects*

Changes in the curriculum

Previously on the KOersief

By: Arjan Habraken, Hèrm Hofmeyer, and Faas Moonen
Teachers at TU/e

In 'Previously on the KOersief', companies that have published articles in previous editions are asked to write about changes that happened in their company over the years. For this edition, three professors at the TU/e are asked how their courses and the master track SED has changed over the years.

Arjan Habraken

Universities are the founders of new innovative developments to improve the construction sector. However, current developments are so large-scale and broad that new ideas are introduced and developed from different angles. The construction sector is changing rapidly, which is nice, but how does education deal with that?

The construction sector is catching up considerably in its development. Changes are enforced by, for example, nitrogen policy, depletion of raw materials, CO_2 accountability, and housing shortages. There are many great initiatives to improve the construction sector. Education is an essential basis for the broad integration of these improvements. Innovations in materials, engineering tools, production techniques, construction methods, etc., need to be incorporated into education. A difficult task that is never finished. The reality is that developments are moving so fast that it is challenging to keep up. Teachers cannot build up knowledge in all areas at a high level. Therefore, education should not be a framed piece of knowledge, but a dynamic content that receives an update every year and, where needed, guest lectures to present the latest development.

Circular building is an important spearhead for the SED unit. Until the year 2019, the course "Lightweight structures" has been given. However, it became clear that minimal material use within new structures was only part of an overarching goal: global optimization of materials usage. The use of bio-based materials (*Figure 1*), optimization in production, reuse of materials, and extending the life of existing buildings are also part of this goal. The course 'Resource-efficient structural Design' (RESD) was set up to cover all these topics. It has become a mandatory course and has been enlarged to 5 ECTS. This indicates how important the development towards circular building is within the unit.

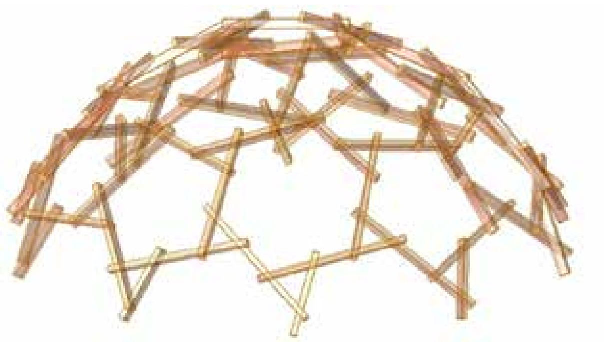


Figure 1: Lightweight structures with bio-based material

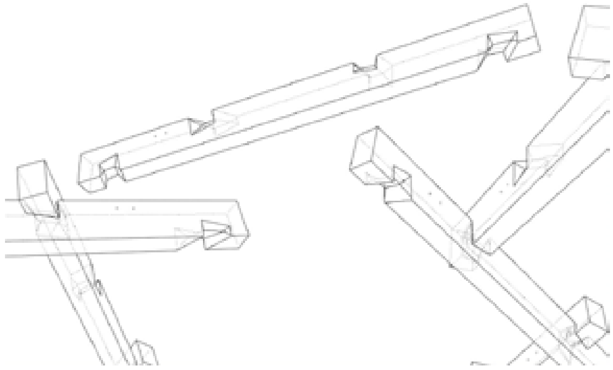


Figure 2: digital fabrication

During the year, new knowledge is collected and integrated into the course. There are several PhD guest lectures to cover specific topics. The exercise within RESD is related to robotics (*Figure 2*) to introduce innovative production methods.

By having students working on parametric design in the Bachelor End Project (BEP) and then in RESD with robotics and circular building, a broader insight is given into subjects they can further develop themselves. It is very nice to see that many students have found their topics of interest and are asking for more in-depth teaching materials.

Hèrm Hofmeyer

In 1990 at SED, only one course, "7P610", existed on the Finite Element Method (FEM), using the well-known books of Blaauwendraad and Kok. Around 1993 already two courses were scheduled. The first (elective) course someone could follow was "7P790 Mechanica 8", given by Piet Hiemstra, see *Figure 3*.

Although the study guide promised an overview of the field, I can guarantee that we were only seeing an endless and clueless string of element derivations, for eight weeks long, without any framing. In the next trimester, "7P793 Oefening Mechanica 8" could be joined. The study guide promised the simulation of a simple problem for which the solution was known using an existing program. It may not sound exciting, but to be frank, educationally, it was a sound practice, and it was not that different from our current approach. Last in the sequence, "7P810 Mechanica 11" was meant to introduce non-linear finite element methods. However, the lecture notes were still in preparation, and for the lecturer, there was a vacancy. When Monique Bakker finished her PhD and started to work as an assistant professor, she was asked by Jan Kerstens (at that

7P790 **Mechanica 8** B-3.2 (T8)

Vakgroep:	BKO	1 SP
Docent:	ir. P. Hiemstra	
Voorkennis:	Mechanica 1 t/m 4, 5 en/of 7	
Studiemateriaal:	dictaat 7242: Eindige Elementen Methode	
Onderwijsvorm:	2 uur college p/w	
Tentamenvorm:	schriftelijk	

Eindige elementen methode

Constructie opdelen in een eindig aantal elementen en het kiezen van relevante vrijheidsgraden (Veplaatsingenmethode). Met behulp van een arbeidsprincipe (meestal virtuele arbeid) een stelsel lineaire vergelijkingen opstellen, per element, dat het verband weergeeft tussen de krachten (belastingen) en verplaatsingen (vervormingen). Constructie-eisen: Elementstelsels samenvoegen tot één stelsel lineaire vergelijkingen, geldig voor de hele constructie. Lokatiematrix. Oplossingsmethoden voor dit stelsel. We onderscheiden: één dimensionaal element, zoals staaf- en balkelementen en driedimensionale elementen, zoals volume- en massa-elementen. Elementen kunnen gemaakt worden op cartesische coördinaten, cylinder-coördinaten of kromlijnige coördinaten. Hybride elemeten worden eveneens behandeld.

Figure 3: Technische Universiteit Eindhoven, Studiegids 1993-1994, page 554 (TU/e library)

time chair of Applied Mechanics) to take care of 7P790 and 7P810. Under the supervision of Jan, she overhauled the courses completely (also, 7P790 was recoded as 7P840).

Consequently, the courses from then on included backgrounds, pre- and postprocessing, an extensive discussion on possible errors and interpretation of results, and most importantly, many practical exercises with Ansys. Monique wrote excellent lecture notes (but for now, unfortunately in Dutch). The setup of these courses was so tempting that in 1997 I followed them as a PhD student again. When Jan and Monique told me, I would receive a 9 for the assessments two times, I firmly rejected it, for I did not feel I understood all the details fundamentally well. They got angry and told me they were the persons to decide, not me. Finally, around 2009, Jan asked me to redesign the Applied Mechanics courses in the Master, and besides 7P840, which I ran already from 2002, I then also took over 7P790. In 2015, 7P840 was merged with 7P865 (Energy principles) into 7KP6M0, and 7P790 was renamed as 7P870 first and then as 7KT7M0 (why all this renumbering?). Although the merging into 7KP6M0 was seen first as somewhat incidental and caused by bureaucratic considerations, it now comes out that the principle of stationary potential energy is an excellent introduction to the derivation of a finite element. It is good to know that 7KP6M0 and 7KT7M0 are still primarily based on the quite timeless and outstanding work of Monique. Besides this history on 7KP6M0, see https://koerstue.nl/articles for a very small history on 7KP6M0, computers, and daily life at SED.

Faas Moonen

My memories of SED go a long way back to my college years at the campus. Over the years, I witnessed many names: I started studying at THE (Technische Hogeschool Eindhoven) at the "Afdeling Bouwkunde," where at that time every graduate was registered in the Architects Register, including all techies such as me. Later, THE became TU/e (first without the unstable column between the U and the e). And I remember being involved in determining the English name (for which we choose "Built Environment," with as a decisive argument that we liked the abbreviation "BE"). Then "opleiding Bouwkunde" became AUBS, ABP (and CME); and the title ir. became Master. Our department (named KO, "Konstructief Ontwerpen") became a unit, and the KO changed to CO, then SD, and now SED.

When I was a student myself, KOers was already an essential element in keeping my studies enjoyable (small anecdote: the name KOers is not about a direction or anything like that but stands for "Konstructief Ontwerpers" thus KO'ers.). Back then, KOers already organized unforgettable excursions, great lectures, challenging workshops, and excellent evaluations of courses. KOers still does all of this up to today. Also, while I was a student myself, I was already a member of a team that made canoes out of concrete. Building and canoeing was a serious, professional activity for us at that time. And look at today, new concrete canoes are still "poured" every year.

Moreover, the current lecture notes of Statics of Structures are not at all that different from then. The primary ambition to teach architectural designers, technicians, and managers to understand each other was already the core of the strategy and is still our primary goal. The casual interaction between teachers and students has fortunately remained virtually unchanged over the years.

Though one thing that did change significantly is the digital support. It is hard to imagine that during my studies, the standard way to calculate a structure was by punching holes in a large number of cardboard cards, then putting all cards in precisely the correct order in a tray, so that a rattling machine was able to read this.

What has not changed is that my professors back then were already convinced that students of the old days were a lot better than we were. That perception is not different nowadays either and will persist stubbornly across generations because -I quote one of my colleagues- they have burned all teachers' exams themselves. And that certainly is true for the exams I once made, including my resits.

Yet, it is great to realize that our department somehow must have an invisible solid foundation. Its essence still functions somewhat similarly, even after so many years with modifications. ◀

Vincent van der Wal

My first SD

Interview with: Vincent van der Wal
Team manager at BAM Advies & Engineering

By: Tom Diks
Editor KOersief

In a world that is in a digital transition, with a demand for young new structural engineers who are skilled at working with software, it is important to remember the earlier generation. In 'My first structural design', an old hand in the built environment is questioned about his experience. There is plenty to learn from this older generation. In this third edition of my first SD: Vincent van der Wal.

Where and what have you studied?

After completing my VWO in Den Helder, it was not immediately clear which study I wanted to do. At the time, I considered economics, medicine, and civil engineering, among other things. In 1988 I started studying Civil Engineering at TU Delft. The lab for the Delta Works was one of the things that impressed me. The possibilities for studying internationally also got my interest. The choice between Delft and Eindhoven did not really matter to me. I also found many different topics interesting within civil engineering. Ultimately I opted for non-residential construction (Dutch: utiliteitsbouw) because of the combination of technical calculations on the one hand and practical construction on the other. After six years, I graduated in 1994 from the civil engineering faculty's non-residential construction department.

What jobs have you had so far?

After my studies, I started as the penultimate generation for military service. That was a special but also fun and insightful period. In 1994 there was also a crisis in the construction industry and in 1995 I could not find a job immediately. Eventually, I started at Pieters Bouwtechniek through an employment agency. After 3.5 years, I felt the need to be more involved in the execution phase. I became a work planner (Dutch: werkvoorbereider) at BAM. My first project was the new head office of private bank Insinger de Beaufort in Amsterdam, which was partly covered in gold. For this project, I had to take care of the hinges and locks. I soon found out that this was not my type of function. Subsequently, I was offered a position as a structural engineer in Insinger de Beaufort; *see Figure 1*. I am now team manager engineering at BAM Advies & Engineering; *see Figure 2* My team consists

of structural engineers, architects, quality consultants, and construction method consultants. The first employer is the employer you think back to the most. I certainly have good memories of it.

Which projects are you most proud of?

There are many. It is also something that grows over time. You will always never forget the first project. After that, it is something else that sticks with you the most. One of those projects was a project with a Spanish architect. There, we made several blocks in housing construction. Another project is Kloosterveste in Assen; *see Figure 2*. The exciting thing about this project was the phased method that allowed you to build very efficiently. To this day, I have never reached that level of efficiency again. Finally, the Hoog Catharijne parking garage (*see Figure 3)* was also a very special project where I worked as a consulting engineer. That project was built simultaneously downwards and upwards.

Figure 1: Hoofkantoor Insinger de Beaufort

Figure 2: BAM Advies & Engineering office

Figure 2: Kloosterveste

Do you think the knowledge you acquired during your studies was in line with practice?
Not very much. During your studies, you learn how to make a sum. But on my first day of work, I had to do a weight calculation, and I did not know how to do it exactly. You learn these more practical matters during an internship. I really can recommend an internship where a student gets to know something from practice. It is important that you develop yourself very broadly in the beginning. It is also just as vital that you find a position where you feel good. If this is the case, you can easily build up long-term employment. I notice that in myself and many of my colleagues. Most colleagues within BAM have had a very long career within the same company.

What are the most significant changes you have experienced?
The biggest change was, without a doubt, digitization. At Pieters Bouwtechniek, an ordinary calculator was the norm. At the time, we had one computer, and we had to put a floppy in there so that you could calculate a structural framework. That was cutting-edge technology. You wrote almost everything by hand. When I started at BAM, we had a small office of about ten structural engineers and project managers and six people from the secretariat. Their task was to write out our hand-out calculations on the computer. Digitization has had a significant impact on the role of the structural engineer due to the introduction of calculation software. At the same time, I would like to mention that calculation software is not a holy grail. If you do not understand it yourself, you have to simplify it first. You must always be able to interpret and justify the results of the computer as a structural engineer. It is our responsibility and not of the computer.

The entire contract formation from large clients has also changed. Sometimes it is a construction team, then building alone, and another time a PPS contract. We, the

Figure 3: Hoog Catharijne parking garage

construction sector, react badly to this from the construction sector, because it is always different. I am also not a fan of the earliest possible price determination. Large and long projects should be allowed to use the best of both worlds. By that I mean a client who specifies in detail what he/she wants and a contractor who can respond to that accurately.

Has your vision on construction changed?
Absolutely. Both sustainable and energy-neutral construction will have a significant impact for the coming years. I think it is a bit disappointing to conclude that circular construction is still at a low pace. We also see that circular construction still has administrative problems because sustainability is rather complex and can be explained in different ways.

What advice would you give to students who want to become a constructor?
First of all, I advise everyone to do an internship and look around and see what options there are. Secondly, I always say to people is that they should use the first years to bring their technical knowledge to a higher level, soil mechanics, steel, concrete, timber, prefab, etc. You can always organize and manage later. If you become a manager early in your career and cannot give the right answers, you might lose your authority. ◀

Figures:

1 *Insinger de Beaufort headquarter, monvisovastgoed.nl/project-3/*
2 *Kloosterveste, am.nl/31x325-12-assen-kloosterveste-13-okt-2011/*
3 *Parkeergarage hoog catharijne, link: https://cu2030.nl/*

Denise Kerindongo

The Experience of ...

By: ir. Denise Kerindongo
Structural engineer at Heijmans

In August 2020 I graduated from the master Structural Engineering & Design at Eindhoven University of Technology on the topic of the structural reuse of concrete. After all those years of hard work and focusing on that graduation day, suddenly my life as a student was over. Change is always exciting, especially during the COVID-19 period. The plans that I had made for myself were not certain anymore. And how about finding a job during this pandemic? Luckily everything turned out just fine!

Graduating

Towards the end of my graduation project, the first 'intelligent' lockdown was announced in the Netherlands. My plans to perform experimental research in the Structures Laboratory were canceled and I had to find another way to obtain experimental data. I worked my way around this obstacle and was able to finalize my research in a good manner. When it was time for me to present my work, fortunately I could do this in front of a small audience at the TU/e. I am very glad this was possible; it gives your presentation a more personal touch.

Applying for a job

After graduating, I planned to travel abroad, however that was also not possible. Instead, I spent my summer as a tourist in the Netherlands, exploring places that I had never seen before. Then it was time to start looking for a job. One thing I knew for sure, is that I wanted to work in a multidisciplinary company with many fields of expertise. So I spread my wings and tried to find a company that would fit me. Due to the lockdown, the interviews took place online. This concerned me a bit, because when you do not meet in person and you have to introduce yourself through a screen, the impressions people get of you can be different. However, this concern was totally unjustified because the conversations I had were very pleasant. Finally, I made the choice for the company I was attracted to the most, based on those conversations and the outlook for the future, which was Heijmans. One of the major infra & construction companies in the Netherlands. They take great pride in working on projects that contribute to a smarter, safer, greener, and healthier living and working environment.

New experiences

I have been working at Heijmans for a little bit longer than a month now, so the experience is still fresh. On the first day of work, I went to the office in Rosmalen. I had a warm welcome and was able to meet my new colleagues in person. The first weeks, I went to the office quite often. While it was quite empty, everyone made sure to make me feel at ease. Normally, all kinds of introduction days take place in person. However, these now took place online. Heijmans has made a great effort to make everyone feel welcome! Online interactive introductions took place where you get to know the other new employees and learn a lot about the company.

The days I work from home, we make sure we stay in contact with each other through video calls. Besides, I can get enough help through screen sharing. So the rate at which I get to know my new colleagues may be lower than normal and learning while working from home is more challenging, however, we make the best of it. In the beginning I had to get used to the working life, but it did not take long and I can say that I found the right place for me.

CHECK!

CONSTRUCTIEVE VEILIGHEID

Figure 1: Structural safety logo used for internal communication

Projects

In my first weeks, I contributed to the structural safety of several projects. Safety is a topic that is very important throughout the whole company, see *Figure 1*. To make sure that everyone who is involved in the building process is aware of this, good communication between the different parties is required. Together with a colleague, I determined who is responsible for different tasks throughout the entire building process. We made detailed descriptions to avoid possible confusion.

Nowadays, we see that the collaboration between structural designers is lacking with regard to taking responsibility about structural safety. So we need to make sure that the involved parties know their responsibilities, with a smooth collaboration and a minimization of damage as the result.

The second project I worked on was a tender. In a tender, several companies compete against each other, with the goal to build, design, and or maintain a project. My role as a structural engineer was to search for ways to optimize the structure. I made some calculations to see whether it was possible to optimize while ensuring structural safety. During this project, I needed to apply the knowledge I obtained during the masters. At first, this was challenging since it was a while back since I made structural calculations. But after a while, with the help from my colleagues, I determined a routine and now I know how to tackle structural calculations again.

Figure 2: Roof structure of the Droogbak

Currently, I am working on a project for the Droogbak in Amsterdam, see *Figure 2*. We got the question to perform a number of structural calculations to check the capacity of the roof. Since the Droogbak is being renovated, there was a question to see whether the roof is capable of carrying additional elements for the regulation of sound and for fire safety. To start, I visited the project to get a feeling of the structure and see what I was going to work on. Now I am modeling the roof structure with the help of a structural analysis software, see *Figure 3*. After I obtain the needed information from the model, I will be able to advise on the addition of the roof elements.

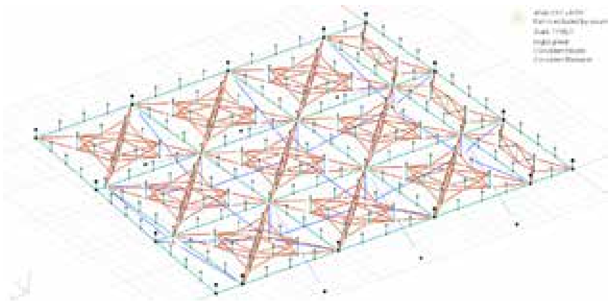


Figure 3: Structural model of the roof

Outlook

What excites me about Heijmans is the broadness of the company. The company has a lot of in-house knowledge and they make sure it is used optimally. Besides, since they are responsible for the construction of a wide range of structures, one needs to make sure that what is engineered, can also be made. In my opinion, you can learn a lot from this, because how you execute a design is very important. Often the makeability of a structural design is not taken into account, and this is rarely discussed during the study. So a lot can be learned from this.

Another aspect that attracts me is the strive for continuous improvement at Heijmans, summarized in: 'Better, Smarter, Sustainable'. Especially the last one, sustainability , is an interest of mine. Besides working as a structural engineer, I am able to give a small contribution to this ambition. Together with a number of other colleagues from different departments of the company, we work towards achieving the goal to be 100% circular in the future.

So far, I can say the projects that I have worked on and the projects that my colleagues have discussed with me are diverse and challenging. These projects have inspired me and I cannot wait to be as experienced as my colleagues. So I look forward to the coming period of working here and learning a lot in different fields.◀

Arup

Internship

By: Laura Dings
Structural design student

From November 2020 until April 2021, I did an internship at Arup which is an international multidisciplinary engineering firm. I joined the infrastructure department, where I helped with multiple projects. The main reason I chose Arup is because of their attitude towards innovative techniques, such as parametric design, which they try to incorporate in as many projects as possible.

The biggest project I worked on was the Circular Viaducts project. The main goal was to prove the feasibility of a viaduct composed solely out of timber elements. This project is part of a challenge by Rijkswaterstaat. For the three winning designs, money will be available for prototype testing. My main contribution to this project consisted out of helping setting up a parametric model for the bridge. This model was used to compare different design options and for optimizing both the dimensions and center-to-center distances of the main girders. All calculations were carried out using Karamba3D, a plugin for Grasshopper. Therefore, all structural data, such as moment lines, stresses, and displacements, could be directly retrieved from Grasshopper. A visualization of the final design is shown in the *Header*.

Furthermore, I helped on a project called Bridges to Prosperity. This is a charity organization that focusses on building bridges to combat isolation of developing nations. Since construction drawings can be complex to read for the local construction workers, a digital tool is designed that can easily visualize the construction sequence of several bridges. Different required dimensions can be used as an input in this tool. The digital tool is built with Python scripts. However, visualization can be difficult in Python, and therefore the model is built in Grasshopper first after which it is transformed into a Python script. Using dictionaries in Python, the elements can have properties connected to them, such as a material type or dimensional information. For this project, I helped making two detail models of the anchorage block in Grasshopper. For one of these details, I also wrote the Python script.

After these two parametric design related projects, I became interested in what other projects Arup did. Therefore, I joined the Van Brienenoordbrug project. This is one of the largest projects within the infrastructure unit. For this project, I did several calculations, such as determining the mass moment of inertia of the bridge around the rotation axis and analyzing different fatigue details. Finally, I analyzed the influence of different support conditions in GSA (see *Figure 1*). The model will be more accurate when the horizontal support is modeled as a non linear spring that only starts moving when a certain friction threshold is exceeded. However, when a roller will yield similar results, the more simple boundary conditions are preferred.

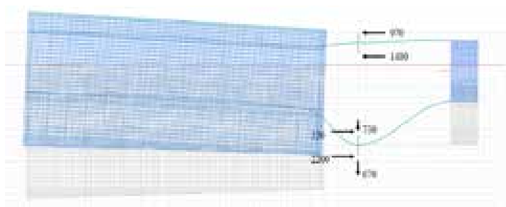
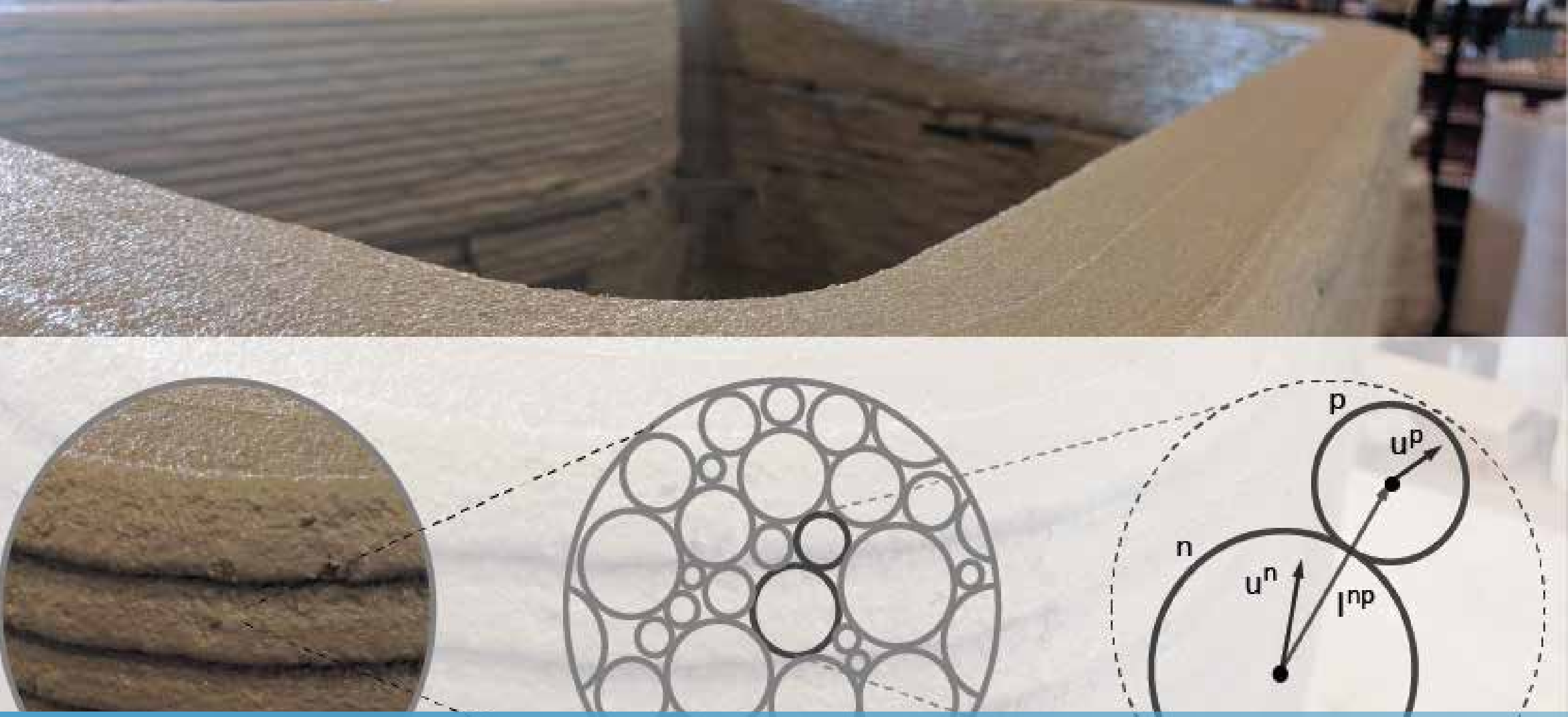


Figure 1: Top view of the Van Brienenoordbrug in GSA

Due to the COVID measures, the entire internship was online unfortunately. Nevertheless, I really enjoyed my time at Arup. Besides the projects described above, I also joined several general meetings, online coffee breaks, quizzes, and even an online escape room! This gave me a good impression of the company. I can recommend everyone to do an internship during their studies, since it is an incredible experience where you learn a lot.◀



Master's Thesis

Load Path Dependent Failure of 3D Printed Concrete

By: Jorn Neelen
Supervisor: dr. P. (Payam) Poorsolhjouy, dr.ir. R.J.M. (Rob) Wolfs, prof.dr.ir. A.S.J. (Akke) Suiker

A material system at failure is often characterized by its inability to sustain higher stresses (i.e. σ_{ij} =0). Consequently, the failure criterion can be defined as a singularity of the stiffness tensor. In practice, however, the failure criteria are most often described as functions of the stress tensor acting on the material, which can be described as $F(\sigma_{ij})=0$,where F is a general function. However, in many cases, the material's behavior depends on the load-path and not only on the state of stress. In other words, the history of loading in different directions will affect the behavior of the material.

For example, in 1D, concrete fails at f_c, which has a value of a few tens of MPa. However, under hydrostatic loading, concrete fails much later. Even in biaxial loading, it fails at approximately $\sigma_x=\sigma_y=1.2\,f_c$, which can be observed in *Figure 1*.

In granular materials, the effect of load-path is present due to the evolution of microstructure during loading. Granular materials consist of particles that can transfer force to other particles through contacts between the particles. The response of these inter-particle contacts to external loading depends on the orientation of the contact. The response will change the mechanical properties of the contacts (increasing or decreasing

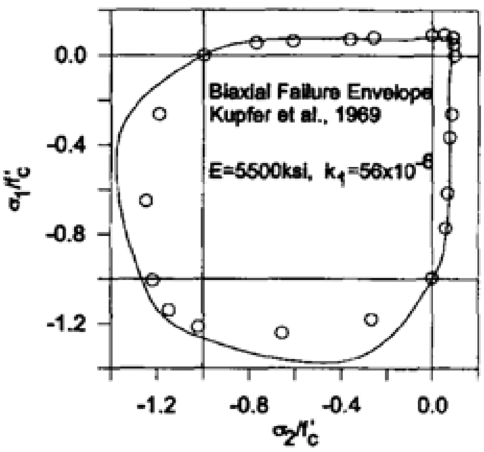


Figure 1: Biaxial failure envelope for concrete (Bazant et al, 1996)

the stiffness). As a result, the material's properties during loading will evolve in a generally anisotropic manner. Therefore, failure of a granular material cannot be defined by the state of stress but by studying the stress path.

This project will focus on the load path-dependent failure of 3D-printed concrete. The project is divided into two parts: a numerical part and an experimental part. In this article, only the numerical model and the theory behind it will be highlighted due to a lack of experimental results at this moment.

The numerical model is based on Granular Micromechanics Approach (GMA). In GMA, the material is modeled as a collection of grains that interact with their neighbors. Within GMA, inter-particle contacts in different directions are studied separately, and the effect of the loading on the properties is incorporated in the model. Finally, the energy stored in all contacts (through the deformation of contacts and the force that is caused by the deformation) is set equal to the macroscopic energy of the material.

Two neighboring particles have been illustrated in *Figure 2*. The normal and tangential directions and force vectors are displayed in *Figure 2A* and *2B*, respectively. By defining constitutive equations for the normal and tangential direction, see *Figure 3*, it is possible to derive the stiffness of the contacts in the normal and tangential direction. The graphs in *Figure 3A* and *3C* are for tension and shear and the graph in *Figure 3B* is for compression.

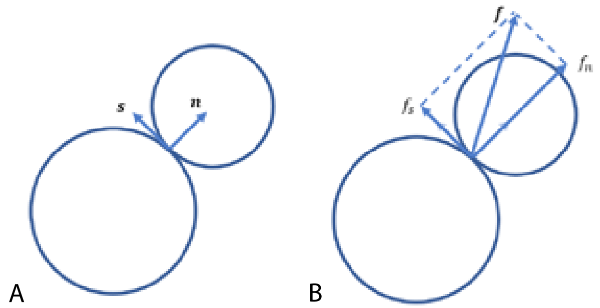


Figure 2: Two neighboring particles. (A) Normal and tangential directions of the contact. (B) Normal and tangential force vectors of the contact

The properties of grain-pair interaction depend on the loading history that they experience. These properties are also affected by whether the material is experiencing loading, unloading, or reloading. In this model, we assume that upon unloading, the force-displacement relationship will go through a linear load path back to the origin (as seen in *Figure 4*). Unloading and reloading are fully elastic in the current model (in the future, this might be changed). Therefore, unloading can be described according to *Figure 4*. Where $\delta^T_{n,max}$, $\delta^C_{n,max}$, and $\delta_{w,max}$ are the maximum tensile, compressive and shear displacement that have occurred during loading, respectively. In *Figure 4*, the unloading-reloading curve is drawn for a random value of $\delta^T_{n,max}$ and $\delta^C_{n,max}$. As long as the displacement does not become bigger than $\delta^T_{n,max}$ or $\delta^C_{n,max}$, the red curves in *Figure 4* describe the relation between f_n and δ_n. When the displacement becomes bigger than $\delta^T_{n,max}$ or $\delta^C_{n,max}$, the blue curves in *Figure 4* describe the relation between f_n and δ_n.

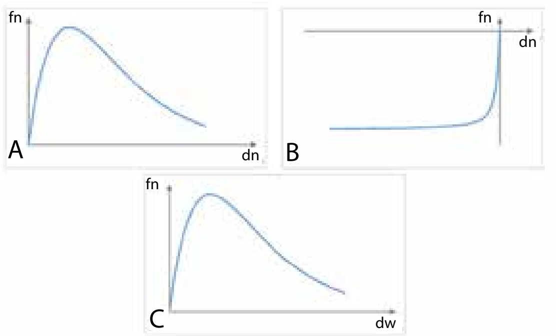


Figure 3: Constitutive equations for (A) tensile stresses and strains, (B) compressive stresses and strains and (C) shear stresses and strains

The normal and tangential stiffness found for every contact can be used to derive the stiffness tensor for the representative volume element, RVE. *Equation 1* shows a summation of all the microscopic stiffness components, divided by the volume of the RVE. This, however, assumes that the location and all stiffness components of the inter-particle contacts are known. The summation can be replaced by an integration, *Equation 2,* over the RVE when the assembly is sufficiently large and contains enough grains. The integration does not require the exact location and stiffness components of all the inter-particle contacts.

$$C_{ijkl} = \frac{1}{V}\sum_{\alpha}((l^{\alpha})^2 n_i^{\alpha} n_j^{\alpha} K_{ik}^{\alpha}) \qquad (1)$$

$$C_{ijkl} = l^2 N_p \int_{\theta=0}^{\pi}\int_{\phi=0}^{2\pi}(K_{ik} n_j n_l)\xi \sin\theta \, d\phi \, d\theta \qquad (2)$$

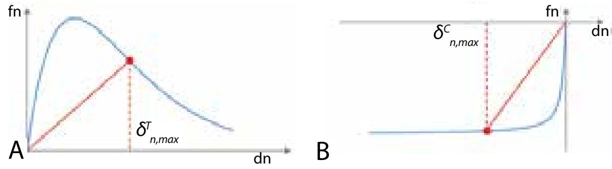


Figure 4: Unloading-reloading trajectories for a random value of (A) $\delta^T_{n,max}$ (tension) and (B) $\delta^C_{n,max}$ (compression)

Where C_{ijkl} is the fourth order stiffness tensor, n_i, n_j and n_l are normal vectors (for the contact between two grains), l is the distance between the centroids of two neighboring grains, K_{ik} is the stiffness tensor in RVE coordinates of a certain contact, N_p is the number density of grain-pair interactions (total number of contacts divided by the volume V of the RVE), ξ is the intergranular contact directional density distribution function, and θ and φ are the two angles from the polar coordinate system.

In this research, we utilize GMA to model a stress-controlled experiment to study the failure behavior of 3D printed concrete structures. The stress is applied in two steps: confinement and deviatoric loading. The stress will be uniaxial or biaxial to match the possibilities of the experimental research. Both the confinement stress and deviatoric loading stress are applied in small increments. By using the Euler method, the stiffness tensor can be calculated by using the strain of the previous increment. When the stiffness tensor is found, the strain can be updated, and a new load increment can be applied to the system.

The effect of load-path will be studied in the biaxial plane by varying the level of confinement. *Figure 5* shows three different confinement levels: no confinement, 0.4 times, and 0.8 times the uniaxial compressive strength. From these points, the deviatoric load will be applied in all directions with different ratios between s_{22} and s_{33}. The results show a clear difference between the obtained failure envelopes and illustrate the effect of load-path.

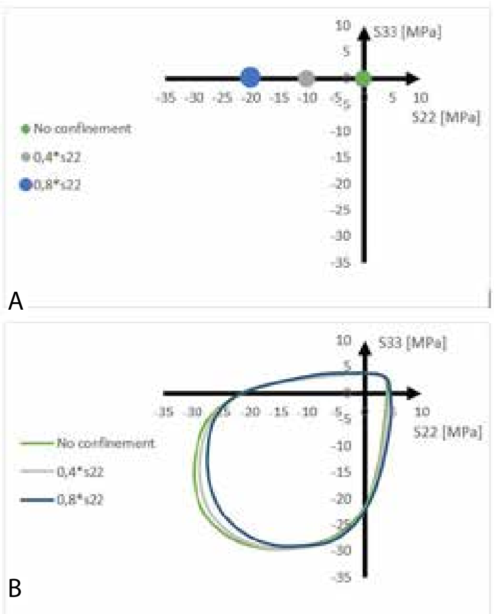


Figure 5: Three different levels of confinement (A) and Failure envelopes for different levels of confinement (B)

The experimental research is not yet executed and is still in the starting phase. It is expected that within 3 months the first results are obtained.◀

Master's Thesis

An Optimization Tool for the Product Development of Concrete Sandwich Panels used within an Industrialized Construction Method

By: Stan van de Schoor

Supervisor: Prof. dr. ir. T.A.M. (Theo) Salet (TU/e), Dr. ir. R.J.M. (Rob) Wolfs (TU/e), Ir. Maarten Janssen (Mooduul)

Ask a kid to sketch a house and you will obtain a simple image with a wall, a door, some windows, and a roof. Ask the same kid to make a drawing of a car and you will obtain a box that indicates the silhouette of the car with some wheels, see *Header*. In essence, both products are as simple as that. However, in reality, both these products are a bit more complicated and contain many more elements that are not directly visible through the eyes of a kid.

An aspect that differs significantly between the two products is the manufacturing process. The car is industrially manufactured in a factory, while the house is constructed on-site. The industrial manufacturing process of a car, in which the same procedures are carried out repeatedly, results in accumulated knowledge and experience on the product development. As a result, the product will improve in quality, it can be manufactured faster, and it will become cheaper. Therefore, nowadays cars are significantly different from those that are manufactured decades ago. In comparison, houses are still constructed in about the same manner. Compared to cars, the manufacturing process of houses is far less efficient and outdated.

There are many problems within the Architecture, Engineering, and Construction (AEC) industry. First of all, the AEC industry is suffering from low productivity. Furthermore, the Netherlands currently has a big housing shortage. On top of that, the AEC industry is known for its lack of innovation, high failure costs, and large ecologic footprint. Lastly, the AEC industry in the Netherlands is suffering from a decrease in the number of employees. Reason enough to change the way we currently construct buildings and move towards an industrialized AEC industry.

Such a transformation starts with understanding how the AEC industry currently operates. A typical aspect of this industry is the on-site construction of buildings. Furthermore, any design needs to fulfill an enormous amount of boundary conditions.

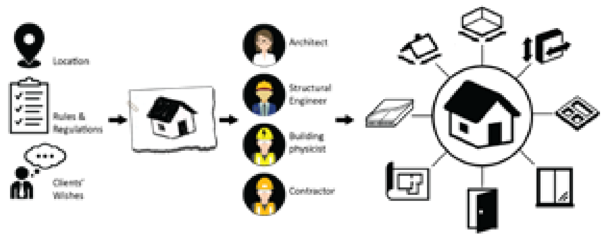


Figure 1: Engineer-to-order manufacturing strategy in the AEC industry

Many of these boundary conditions come from the wishes of the client, the rules and regulations, and the unique location for the building. Each design is fully customized to create a building within this framework. For this, the AEC industry typically uses an engineer-to-order (ETO) manufacturing strategy. In such a manufacturing strategy, the design of the product demands a certain amount of engineering. When the design is finished, a 'factory' is made at the construction site to manufacture the product. When the product is finished, this 'factory' is transported to a different location to construct a fully customized building again. This results in temporary organizations that manufacture one fully specified product. A visualization of this manufacturing strategy is given in *Figure 1*.

An industrialized AEC industry focuses on manufacturing standardized building components off-site. Such a component is seen as the product. By assembling these products in a certain way, a building is obtained. However, the use of such a product transforms the entire operation of the AEC industry.

The design phase will become fully digital. Based upon a set of boundary conditions (properties of the product, the wishes of the client, the location, and the rules and regulations), several possible design options can automatically be configured. In real-time, this configuration software calculates the total costs and the performance of the building, and it generates all drawings and files for manufacturing. This design phase is very fast and completely transparent. A visualization of this design phase is given in *Figure 2*.

The organization that is responsible for the manufacturing of the product is responsible for the design and assembling as well. Thus, a single, permanent party works on multiple projects, resulting in accumulated knowledge and innovation.

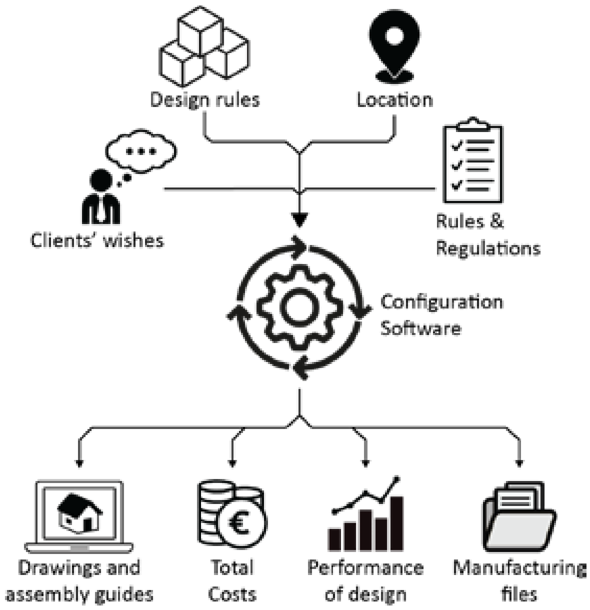


Figure 2: A visualization of an industrial, digital and transparent design phase

A company that sees the potential of industrialized construction and already operates accordingly is Mooduul [1]. Mooduul uses a concrete sandwich panel as their product. These sandwich panels consist out of two thin concrete layers on top of an EPS core. During the development of such a product, many decisions need to be made. As an example, Mooduul is facing challenges regarding the connection of the elements. Any decision made considering the connections has many consequences for the success of the product in the future. Therefore, a parametric model has been made to help with the decision-making in the product development of industrial manufactured concrete sandwich panels. This model gives a performance score based upon comparing a set of geometrical input-values of two different designs; a reference design and an alternative design. Due to the parametric structure of the model, the design of both the products (input) and the generated graph (output) is fully customizable by the user.

The model was used to indicate the consequences of the connection-type between the elements that Mooduul uses. In their current design, Mooduul uses a fixed connection between the elements. This design is used as a reference. The alternative design is the same on all input values, except for the connections; these are hinged. A result of the output of the model is given in *Figure 3*.

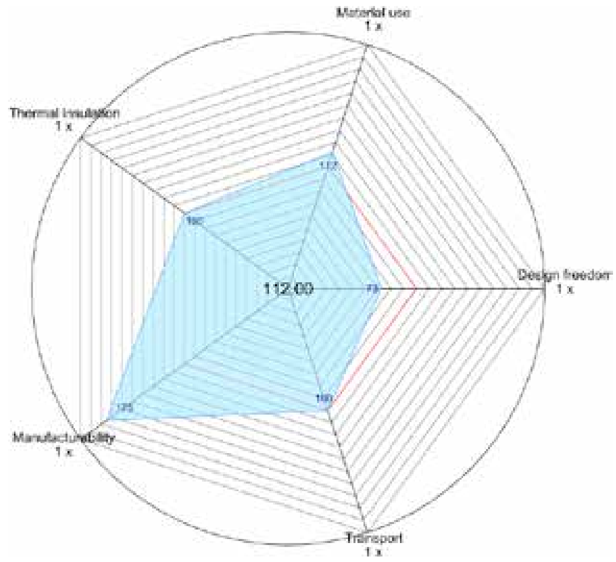


Figure 3: Output of the case study

The main conclusion of this case study is that using hinged connections results in higher manufacturability but in a lower freedom of design. Higher manufacturability results in faster production in the factory and assembling on-site. Therefore, a hinged connection will be cheaper as well.

In general, the main benefits of industrialized construction are a reduction of construction time and costs. However, industrial construction will almost always automatically lead to limited freedom of design. With this in mind, Mooduul should use hinged connections in their designs. This way, the benefits of industrial construction are exploited. The lack of design freedom is something that should always be taken into account.

The high speed, low costs, and lack of design freedom are related to industrialized construction. Therefore, this construction method would not be very beneficial for private housing, but the main potential would be within serial housing. Due to the digital design phase and the fast generation of different designs, each house within a serial housing project could be customized individually to satisfy the wishes of the client.

Figure 4: Visualization of a serial housing project, where every single house is customized to satisfy the resident's wishes

With the upcoming technologies, the AEC industry can manufacture buildings in an industrialized manner . In this way, houses can be constructed fast, cheap, and have interesting designs as well, see *Figure 4*. Would that not be an interesting way to construct 1.000.000 houses in the upcoming ten years? ◀

References:
[1] *https://www.mooduul.nl/*

Numerical Modelling of Rail Squat Defects

By: Milos Visnjic

Supervisors: Prof. Dr. ir. J. Maljaars, Asst. Prof. Dr. D. Leonetti, ir. Bart Schotsman, Prof. ir. H.H. Snijder (Advisor)

The rail squats defects are the consequence of the rolling contact fatigue which occurs due to the alternating stresses generated by the wheel-rail interaction [1]. These rolling contact fatigue cracks can have detrimental effect on the rails, since potentially complete section fracture is possible due to extensive crack growth.

The initiation of the squats takes place on the running surface of the railhead. There, their presence is evident due to the dark spot, as visible in *Figure 1*. Another feature of the squat defects is that their growth and critical size are dependent on many factors, such as wheel-rail interaction, track foundation stiffness, moisture, and temperature. Furthermore, these defects are increasingly present, primarily due to greater axle loads and larger traffic volumes of the modern rail transport [3]. Therefore, determining the crack growth and critical crack size, the remaining fatigue life, is an important aspect for the rail industry. Subsequently, many numerical approaches are proposed in literature for the assessment of squats defects. The output of these models are the values of the stress intensity factor (SIF) for various wheel positions relative to the crack mouth. This factor is fundamental for the assessment of the crack growth and critical crack size as it describes the intensity of the stress field at the crack tip. Various numerical approaches mainly differ in terms how the different influencing factors are modelled. While some analyses are extensive, others introduce some aspects with significant simplifications or completely omit them. This results that various modelling complexities and the accuracy of the results are encountered. Consequently, the objective of this research will be to identify the modelling strategy which represents the optimal trade-off between the modelling complexity and the accuracy. Due to that, in this master thesis, through a numerical, finite element (FE) investigation, the modelling strategies will be compared on these two terms. More specifically, among the influencing aspects, one of the most significant is the modelling strategy for the different loadings acting on the rail. These include the contact loads (normal, tangential, transverse), residual and thermal, as visible in *Figure 2*.

Secondly, the influence of the type of analysis (2D and 3D FE) will be evaluated. Additionally, the investigation will include the aspects concerning the interaction between crack faces for various conditions. In case liquid is present on the rail, it can flow in the crack where it reduces the friction between the crack faces. Even more severe is the effect of fluid entrapment where

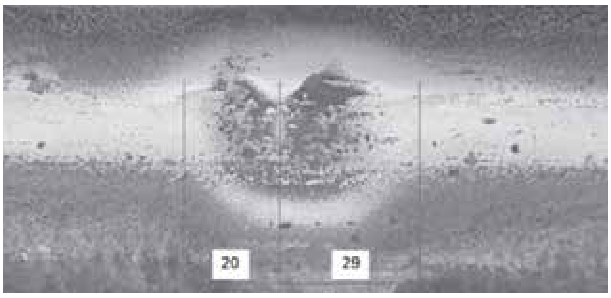


Figure 1: The typical surface appearance of a squat, the numbers represent dimensions in mm [2]

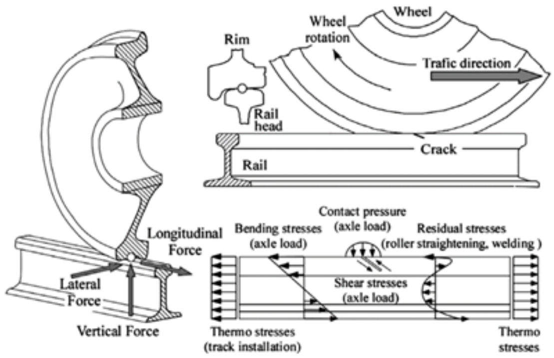


Figure 2: schematic representation of the various loads which act on a rail [3].

the fluid exerts hydrostatic pressure on the crack faces near the crack tip. This consequently results in higher tensile stress normal to the plane of the crack. The phenomena occurs when the liquid is drawn into the crack as the wheel is approaching the crack and then gets entrapped due to the wheel pressure locking the crack as it passes over it [4]. This effect is visible in *Figure 3*.

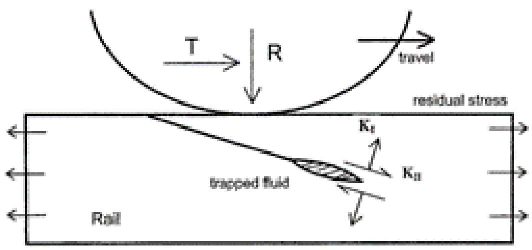


Figure 3: The schematisation of the fluid entrapment due to crack locking caused by the wheel [4]

Finally, the various modelling approaches for the track foundation will be considered. The modelling complexities will range from the rails which are fixed at the edges to the modelling of the sleepers with exact geometry using finite elements. The comparison will be based on values of the stress intensity factor (SIF) for various wheel positions relative to the crack mouth. ◀

References:

[1] *Pal, S., Valente, C., Daniel, W., & Farjoo, M. (2012). Metallurgical and physical understanding of rail squat initiation and propagation. Wear, 284, 30-42.*

[2] *Li, Z. (2009). Squats on railway rails. In Wheel–rail interface handbook (pp. 409-436). Woodhead Publishing.*

[3] *Zerbst, U., Lundén, R., Edel, K. O., & Smith, R. A. (2009). Introduction to the damage tolerance behaviour of railway rails–a review. Engineering fracture mechanics, 76(17), 2563-2601.*

[4] *Bogdański, S., Stupnicki, J., Brown, M. W., & Cannon, D. F. (1999). A two dimensional analysis of mixed-mode rolling contact fatigue crack growth in rails. European Structural Integrity Society, 25, 235-248. Elsevier.*

Preliminary Model for Glulam Accoya® Wood

By: Ellen van den Tillaart
Supervisors: dr. ir. S.G.P. (Faas) Moonen (TU/e), ir. W.H. (Wim) de Groot (TU/e), ir. H.P.M. (Ferry) Bongers (Accsys Technologies)

With the increasing popularity of timber and other sustainable building materials, there is a growing demand to expand their applications. This is also the case for acetylated wood, known by the trade name Accoya®, a relatively new material on the market, which shows potential for a new range of possibilities in the building industry. Among these possibilities is glued laminated Accoya® wood, which has already been studied over the last 15 years. For this research, a new approach has been considered.

Glued Laminated Timber (GLT) is a structurally engineered wood product that is manufactured by gluing together multiple layers of lumber, thus optimizing the structural abilities of the wood and maximizing the dimensions of the beams. Along the length of the beam, single boards of timber are connected to each other by finger joints, see *Figure 1* and stacked on top of each other by gluing the faces together. Experimental tests on GLT beams require a lot of material and labor and are, therefore, a costly way to determine the characteristic properties of glued laminated timber. Because of this inconvenience, the NEN-EN 14080 [1] suggests an alternative. Glued laminated timber beams in bending will most likely fail due to exceeding tension stresses. For that reason, the tension properties of the boards will determine the bending properties of the composite beam. With the tensile strength, stiffness, and density of the timber, a so-called 'T-class' is assigned to the boards. The NEN-EN 14080 connects the T-classes to the corresponding GL-classes. However, this method is not verified for chemically modified wood that alters the properties of the wood. This research will focus on establishing T-classes for Accoya® wood by conducting experimental tension tests, see *Figure 2*. By simulating GLT beams, the corresponding GL-classes are estimated. Besides the tension properties of the Accoya® wood, the properties of the finger joints in tension need to be determined as well. In total, 81 specimens of Accoya® wood and 30 specimens of Accoya® wood with a finger joint are tested in tension.

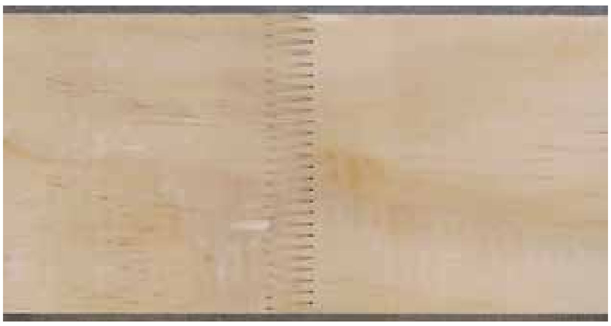


Figure 1: Finger joint in Accoya® wood

The acetylation process that modifies the original wood, radiata pine, is carried out at Accsys Technologies in Arnhem. The finger joints in the wood are made by HEKO Spanten B.V. in Ede. The boards from Accsys Technologies are pre-selected based on a visual classification system, placing the tested boards in visual grading class A1 (practically defect-free) or A2 (practically defect-free on three sides of the board). From the 81 tested specimens, 35 originate from A1 and 46 from A2 classified boards. The 30 finger joint specimens originate from A1 boards.

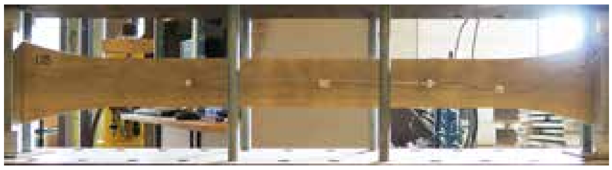


Figure 2: Tension test set-up

The dynamic Modulus of Elasticity, MOEdyn, is measured with a Brookhuis MTG for all specimens. The MTG measures the natural frequency of a timber piece by sending a sound-wave through the board. The MOEdyn is then calculated based on the density of the board, the length of the board and the measured frequency. The relation between MOEdyn and the tensile strength and stiffness allows a batch of Accoya® boards to be selected based on a threshold value for MOEdyn. Increasing the threshold value of MOEdyn will result in higher quality boards and possibly higher quality glued laminated timber beams. Based on this principle of shifting the threshold value, an optimal relationship between T-classes and GL-classes may be established.

The GLT calculation model is based on the transformed section method, which transforms a combined beam built up from layers with different mechanical properties into a fictitious beam with homogeneous material properties. Additional compression tests are carried out on Accoya® wood to monitor and describe the elasto-plastic behavior of the wood in compression. This elasto-plastic behavior in compression is incorporated in the calculation model as well.

The final results from this research will lead to several possible T-classes for Accoya® wood based on different threshold values for MOEdyn. These T-classes are used as input for the GLT calculation model, which will predict the corresponding GL-classes. ◀

References:

[1] *NEN-EN 14080:2013 en (2013). Timber structures - glued laminated timber and glued solid timber - requirements. NEN: Nederlandse Norm*

Deep Convolutional Neural Network for Fibre Segmentation of 3D Printed Strain Hardening Cementitious composites

By: ir. Karsten Nefs
PhD Candidate

3D Printable Strain Hardening Cementitious Composites (3DP-SHCC)

Currently, 3D printed concrete has several serious shortcomings in terms of post-fracture tensile strength and ductility. For structural applications, warning systems, such as large deformations before the structure collapses, are of utmost importance. Ductile materials can play a big role in warning mechanism, however, unreinforced concrete is known for its contradictory brittle behaviour. The solution might be strain hardening cementitious composites (SHCC), which already exist for conventional applications of concrete, that show ductile properties. These mixes consist of different short polymeric fibers that bridge cracks in the matrix in such a way that a new microcrack will appear before the previous crack becomes a major discrete crack. The location and shape of these fibers are therefore of large influence on the structural properties.

Micro-computed tomography (µCT) scanning

Micro-computed tomography scans, or in short µCT-scans, are used to get a 3D representation of the volume in a non-destructive manner. The scanner consist of an X-ray transmitter, specimen holder and receiver plate, see *Figure 1*. In order to get this 3D volume, three steps are needed. The first step is to make five 2D µCT-scans of the specimen quarter of a degree and repeat this until the entire specimen is rotated. These five images are then averaged into one 2D image. The second step is to combine these images with a mathematical algorithm to reconstruct a representative 3D volume. The final and last step is to apply filters over the volume to reduce noise in the images. The resulting 3D volume consists of voxels (3D pixels) which contain a grayscale value related to the density of the material at that specific location.

Figure 1: µCT-scanner; X-ray transmitter (1), Specimen (2), X-ray detector (3).

Image segmentation: the problem.

The obtained 3D volume with voxels, containing grayscale values based on local densities, might seem like a very straight forward segmentation task. However, the density of the fibers overlaps with air voids and the matrix of the material, as shown in *Figure 2*. Therefore, local threshold filtering is therefore not possible. There are many other methods to segment images or volumes such as: feature-extraction, level-sets-based methods, graph-cut, and trainable approaches. The last method seemed most promising for the segmentation problem at hand, see *Figure 3*. After preliminary research, a sparse feedforward neural network type called 'convolutional neural network' is used.

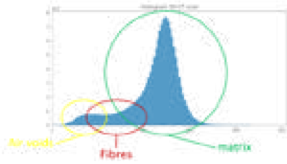


Figure 2: Histogram of 3D printed strain hardening cementitious composites.

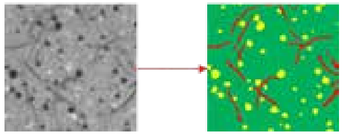


Figure 3: Segmentation task; classify and label fibre, air void, and matrix.

Convolutional neural network

A convolutional neural network uses the dimensionality of the object inputted, without applying any flattening approach to transfer the data into 1D arrays and efficiently predict the class for each voxel of the object inputted. Convolutional filters strives of small filters over the entire volume are used to create an efficient sparse method to segment images.

Training versus use-phase

The neural network can only become as good as the training data that it learns from. Therefore, it is of utmost importance that the training data is accurate. Manually selecting a small part of the to be segmented images is often used and a successful approach. However, this is very time consuming and might not always be as straight forward to see if the fibers are 3D bent and are going out of the plane continuously. A soon to be published paper focuses on the methodology to efficiently train the neural network for different mixes containing fibers, in which this manual segmentation of randomly orientated fibers is not needed. The use-phase of the neural network becomes then relatively straightforward. The 3D volume is divided into arrays of 32x32x32 voxels; the size on which the neural network is trained, after which a feed-forward through the network takes place. The output is also a 32x32x32 array with predictions for each class in each voxel.

Applications

The obtained information of the fiber (location, orientation, and shape) and the air voids can be used as input for a homogenization procedure, to obtain macro-scale properties from micro-scale features. The results of the neural network can also be useful to see the influence of nozzle design on fibre distribution and orientation. An ongoing research project, performed by Kim de Kroon and Joes Sloots, focuses on this topic.

3DCP-SHCC group

This research is part of a bigger project to systematic develop 3D printable strain hardening cementitious composites for structural applications. The project consists of three work packages: WP1 Anne Linde van Overmeir (Delft University of Technology), WP2 Karsten Nefs (Eindhoven University of Technology) and WP3 Stefan Chaves Figueredo (Eindhoven University of Technology). ◀

Green Energy Mill

By: ir. Floor van Schie
PdEng

Every year more than a thousand festivals take place within the Netherlands. The most popular ones are summer outdoor festivals, which generally occur in remote areas far from urban spaces. The majority of the festivals are not able to obtain power through the national grid. Festivals need to create their own off-grid energy system. Energy for this system is usually provided by rented diesel generators, typically under-utilized and oversized, resulting in a large amount of CO_2 emission.

Increased awareness for climate change combined with new regulations requires emission reduction from every sector, including the festival industry. Most festivals focus on the reduction of CO_2 emissions of audience transport and on-site waste disposal. Power provision is a topic that has been focused on by festivals very briefly, despite the large amount of CO_2 emissions.

The Green Energy Mill uses a combination of different renewable energy sources: solar power and wind power. These sources are combined with a battery system to provide sustainable energy during all weather conditions. The GEM-tower combines a Vertical Axis Wind Turbine that can generate wind power, with semi-rigid solar panels and Luminescent Solar Concentrator (LSC) panels, powered by direct and diffuse sunlight, that can generate solar power. The hybrid unit stores the surplus energy in a Battery Energy Storage System. The function of the tower is to produce sustainable energy and, as we believe, raise awareness among festival visitors. And especially festival organizers.

Figure 1: GEM Tower, Bart van Overbeeke

The GEM-tower has been developed in collaboration with the PowerVIBES consortium of partners from the energy and festival industry. The lead in the process was taken by the Eindhoven University of Technology team composed of several PdEng-trainees, each with their own expertise. This ensured that an integrated design is made, in which architecture, structural design, construction, transportation, building technology, and building methodology are united. The 22-meter-high steel-frame eye-catching GEM-tower is transportable in two 20ft high cube containers and can be installed within one day without any earthwork.

Figure 2: Green Energy Mill

The stability of the GEM-tower is provided by the wide base and 6500-kilogram dead load in the bottom part of the tower. This wide base consists of six main radial trusses with a concrete footing connected to the end and covered with a wooden platform. Each pair of opposite trusses work as a truss beam due to the connection with the core of the GEM-tower. When the wind exerts a load, one footing of the truss works in compression while the opposite footing works in tension.

The upper part of the GEM-tower consists of 8 foldable elements which are connected to the radial trusses with six stay-cables. The cross-sections of the foldable elements are optimized with the 3D modeler Rhino combined with graphical algorithm editor Grasshopper and the parametric structural engineering tool Karamba3D, which led to a significant reduction of material used.

The development of the GEM-tower is still an ongoing process. Recently, the GEM-tower has expanded with a stage, and the capacity is increased with a new energy source: hydrogen. The GEM-stage will be tested at several events in 2021. Do you want to know more about the Green Energy Mill? Floor van Schie and Patrick Lenaers have been guests of the podcast 'Kunnen we het maken?', where they elaborate more on the GEM tower. Listen to the podcast on Spotify, Apple podcasts or Soundcloud. ◀

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Moniek Sanders, project assistant
Ester Pujadas-Gispert, PostDoc

Technical designers
Marius Lazauskas, PDEng
Patrick Lenaers, PDEng
Floor van Schie, PDEng

KOers Committees

Beer Crate Bridge Committee

Hello! My name is Anna, and I'm the secretary of the 2021/2022 Beer Crate Bridge Committee. With this committee, we will attempt to build a bridge made from only beer crates with a span of 44 meters.

At this moment, the world record of 26.69 meters is in the hands of KOers. However, in November this year, the University of Twente will try to break that record with a bridge of 36 meters. We are already in preparation to take that record back in 2022. Now you could ask: "Why make a bridge of 44 meters if you only have to make a bridge of 37 meters to break the record?". Well, in the year 2022, KOers will reach the age of 44. Next to that, we also want to show all our skills and knowledge related to building with beer crates.

To reach maximum efficiency, the committee is divided into three sub-committees: a general, a structural design, and an execution committee. Each committee has its own chairman, planning, and meetings. The general committee keeps an oversight to make sure everything runs smoothly, and is also responsible for permits, PR, and budgets.

According to Joes, being part of the structural design committee is the most fun. "During the second semester, the team has worked hard to define and design the beer crate bridge. During design, we make use of digital design strategies and lab experiments." Especially the latter he finds exciting: "The lab experience and the physical meetings are super cool.".

An interesting part of the lab experiments is the challenge of the new cut-outs in the beer crates of Bavaria. These cut-outs, together with other adjustments, reduce the self weight of the crates. The downside of this could be that the crates are also less strong. Lab tests are performed to determine which influence these cut-outs have on the structural properties of the crates.

The design of a span of more than 30 meters made with only plastic remains a big challenge for the structural design committee. Teun says: "Perhaps, the wind will bring the greatest challenge to the stability of the bridge. At this moment, we are working hard to solve this issue. We will have to investigate innovations in design to reduce the effect of the wind on our bridge.". They are determined to overcome this challenge with a sturdy design for a world record-worthy beer crate bridge!

After the design is finished, the role of the execution committee will become more prominent. Linda, the main responsible person of the execution committee, finds her committee very interesting. She says: "We work together to bring the execution of the beer crate bridge to a success. We started quietly and are now mainly focused on the location and safety around the event. Later, we will focus on more specific applications in the execution. The execution is a part of the built environment that not many structural design students come in contact with during their studies, for instance, the practical execution of the foundation. By participating in this committee, the engineering work can be experienced from the other side."

As you can see, the committee is working hard, and we are still in the beginning phase of our project. If you have any questions, or if you would like another update somewhere in the future, feel free to send me an email and/or follow us on social media!

Kind regards,

Anna Ongenae
Secretary of the Beer Crate Bridge committee ◀

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KOers Committees

The way to the ConcreteCanoeRace in 2022

As everyone might have expected, KOers cannot shine on the concrete canoe race of 2021 since the race will not take place this year for obvious reasons. However, that does not mean that this academic year cannot be used to the association's advantage. Within the concrete canoe committee of this academic year, now consisting of 6 members, it was a simple consideration: making everything ready to get to the most successful concrete canoe race upcoming year.

Even though some committee members will graduate before the next edition of the concrete canoe race in 2022 and leave the committee at the end of this academic year, it was not an option to let this year pass by and not use the available time. Therefore, several tests are set up to be conducted within the last months of this academic year. During these tests, several concrete mixtures will be tested to their structural capacity and behavior. These concrete mixtures are built up differently than the conventional concrete mixture. The first innovative concrete mixture will be strengthened with elephant grass. This grass will replace the fibers that were used in the past for one of the Canadian canoes. The previously used fibers were already made from plastic instead of steel, but elephant grass could be a new durable alternative.

The second concrete mixture will be made by replacing a part of the cement for wood waste ash provided by a biomass power plant near Strijp-S in Eindhoven. Cement is the most environmentally hazardous component of concrete, so by replacing cement with a waste product, CO_2 emissions can be lowered.

Lastly, some tests with a high-performance concrete mixture will be executed to gain more information on the innovative ideas for a canoe of last year when the concrete canoe race was also canceled. Both the strength of the concrete itself and possible connection techniques will be tested in the coming months.

By working more on the fundamental side of the canoes, namely the concrete mixture, instead of the manufacturing method or the shape, the basis of the canoes becomes more sustainable. This sustainable mixture even leaves room for other creative ideas on top of this basis, such as an innovative manufacturing method. For this year, it seemed logical to focus on the part of the canoes that can still be improved, made more sustainable, and can hopefully be used for many years to come.

Figure 1: Flexural bending test of the high performance concrete sample

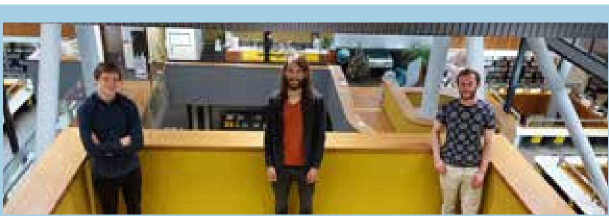
Many more ideas were considered for testing, trying, and documenting. However, within the current situation with the COVID-19 virus, the tests should be limited and executable with 1 or 2 members of the committee to test in a safe environment. In the upcoming months, the test specimens of these different concrete mixtures will be tested and compared to the conventional concrete mix. From these test results, recommendations for the next edition of the concrete canoe race will be made for the concrete mixture for the Canadian canoes and the innovative canoe based on the executed tests. The new concrete canoe committee can choose their own approach for the mixtures and innovative canoe, of course, but by conducting research this year and documenting this for the following members to use, hopefully, KOers will be one step ahead of the other participants of the concrete canoe race in 2022 and able to take some shining trophies home to Eindhoven. ◀

Kunnen we het maken? - The KOers Podcast

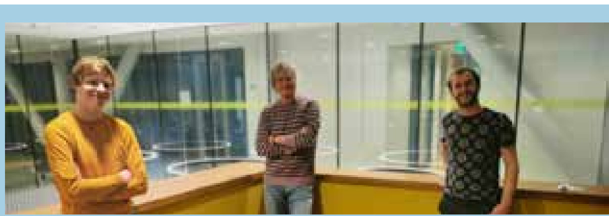
"Kunnen we het maken" is a primarily Dutch podcast created and run by KOers members. The goal is to bring interesting conversations to everyone interested in the Built Environment and Structural Design. The final episode of the first season will be released in the summer. But you do not have to wait long for the second season, which will start in September! Scan the Spotify code or search for "kunnen we het maken?"on Spotify, Apple podcast, or Soundcloud.

Episode 1: Theo Salet – Industry 4.0
In this conversation with Theo Salet, he tells us interesting stories about some of his past projects. For the main subject of this podcast, Theo explains what industry 4.0 is and how it relates to the current innovations in the building industry.

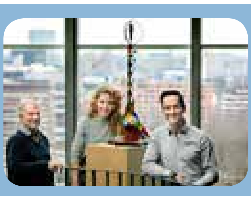
Episode 2: Wim de Groot – Building with timber
In this episode, we talk with Wim de Groot about Timber. What is the future of timber and what is the current state of the timber sector and the education of future professionals.



Episode 3: Derk Bos – Future of the building industry
The construction industry is notoriously struggling to succeed with efficiency. In this episode, we discuss with PhD-candidate Derk Bos what the future of construction could be. We also talk about his research and many more subjects.



Episode 4: Arjan Habraken – Modular building
Modular building is an important theme within sustainable construction. We discuss this subject together with Arjan Habraken, who has a company specialized in modular buildings.

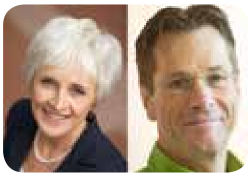


Online recorded

Episode 5: Floor van Schie and Patrick Lenaers – GEM tower
Behind the beautiful world of festivals, there are still plenty of opportunities in the field of renewable energy. Floor and Patrick have designed a mobile tower that generates sustainable power from wind and solar energy. In this episode, we learn everything about the GEM tower.

Online recorded

Episode 6: Arjan Deetman – Robots in the building industry
The question "Kunnen we het maken?" is central in this episode. The manufacturing process in construction is changing. We talk with Arjen Deetman about the role of robots in the construction industry.



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Episode 7: Jacqueline Cramer and Henk Wapperom – Betonakkoord
Like all sectors, the concrete sector must also become more sustainable. The concrete agreement (betonakkoord) was created to aid with transitioning the entire sector. In this episode, we talk with former minister Jacqueline Cramer and Henk Wapperom of the concrete association.

Online recorded

Episode 8: Mantijn van Leeuwen – Sustainable building
Sustainability is all around us. The transition is also in full swing in the building sector. But what exactly is sustainable building? And what do all the abbreviations stand for, such as LCA, EPD, MPG, NMD, etc. In this episode we talk with Mantijn van Leeuwen, director of Nibe.

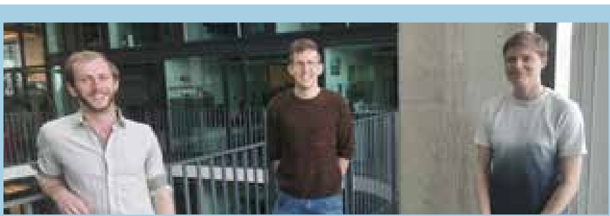
KUNNEN WE HET MAKEN?

De KOers podcast

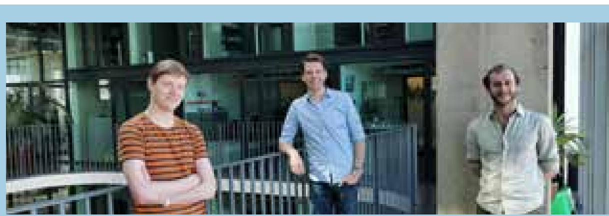
Online recorded

Episode 9: Faas Moonen – Innovative design
The Structural Engineering and Design master has four chairs: Concrete, Steel, Mechanics, and Innovative design. We discuss the latter with associate professor Faas Moonen. Faas shares some great stories of his past at Philips and talks about more recent projects where sustainability is a recurring topic

Episode 10: Dorien Staal – Innovation and collaboration
Innovation in the field of sustainability and automation, Voorbij Prefab does both. General director Dorien Staal explains how corporate culture can integrate these concepts into the construction sector.



Episode 11: Pierre Hendrikx – Design and execution
The name of the podcast certainly applies well to this episode. Pierre Henrikx tells us about all kinds of things that structural engineers can expect that you hardly come across in your studies. This time practice comes to visit theory.



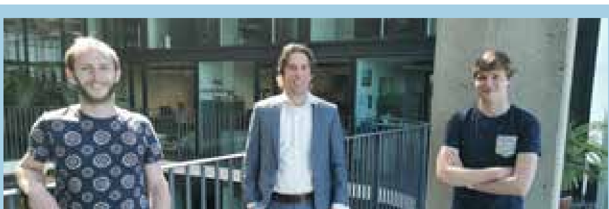
Episode 12: Gijs Schalwijk – Innovative foundation beams
Entrepreneurship may not be the first thing that comes to mind when it comes to structural engineers. Gijs Schalkwijk founded, together with a fellow student, the fast-growing company B-invented. But how do you set up such a company?

Online recorded

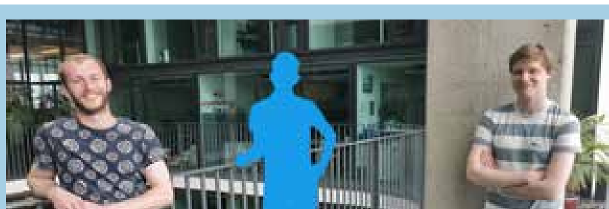
Episode 13: Chris Noteboom – Structural Design with glass
We see glass everywhere around us, we use glass every day, and every building uses glass. However, structural glass is a lot more rare. Chris Noteboom is specialized in this unique transparent material and tells us about the opportunities and challenges of building with glass.

Online recorded

Episode 14: Gosse Slager – Seismic Design
As structural engineers, we work almost every day with static loads such as wind, rain, snow, and temperature. Seismic loading caused by earthquakes are a whole different story. Gosse Slager, who lives in Groningen, tells us more about this. What should you consider if you want to build in a seismic area?



Episode 15: Luuk Janssen - Development of Eindhoven
When you think of designing, you might think of architects. However, designing can be done in many ways, such as structural design or integral design. In this episode, we talk with Luuk Janssen about integral design. As Director of a consultancy firm, he explains how he applies integral design in the built environment.



Episode 16: End-of-Season-Special
This episode will be released after the release of this KOersief. Therefore we will keep the theme of this End-of-Season Special a secret. You can check it out on the 15th of July.

KOers Puzzle

By: Derk Bos & Jelle Versteege
Creative KOers members

Puzzle from Derk

Timo has designed a beautiful steel hall, as shown in *Figure 1*. He used steel cables to stabilize the building since all connections are hinged. After he ordered the cables, the client decided to put a huge window on top of the middle nave. Of course, the client would prefer if there was not a cable running in front of the window. Therefore, Timo is asked to find a stable solution for the building with the same number of cables as before without crossing the red areas, as indicated in *Figure 2*. Can you help Timo?

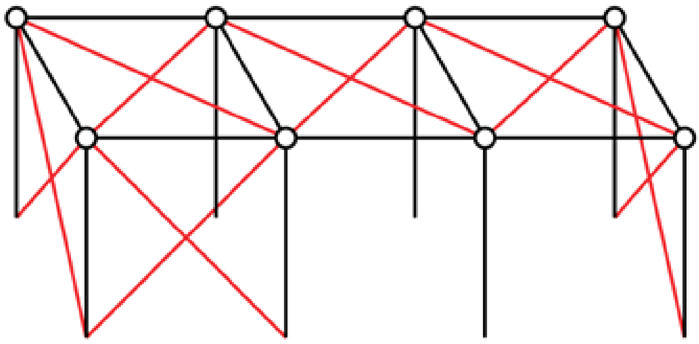


Figure 1

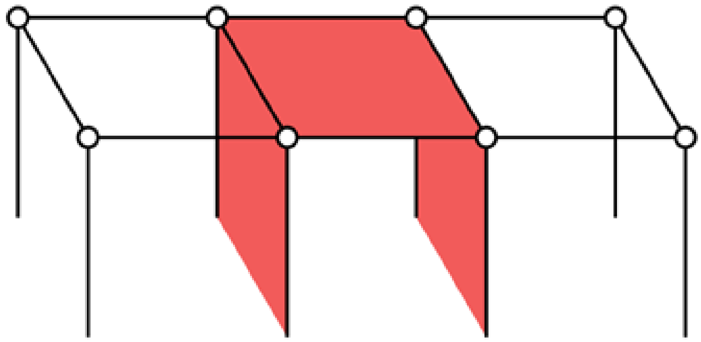
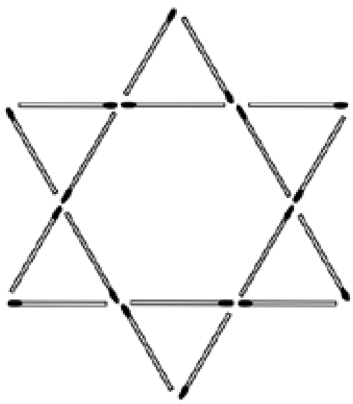


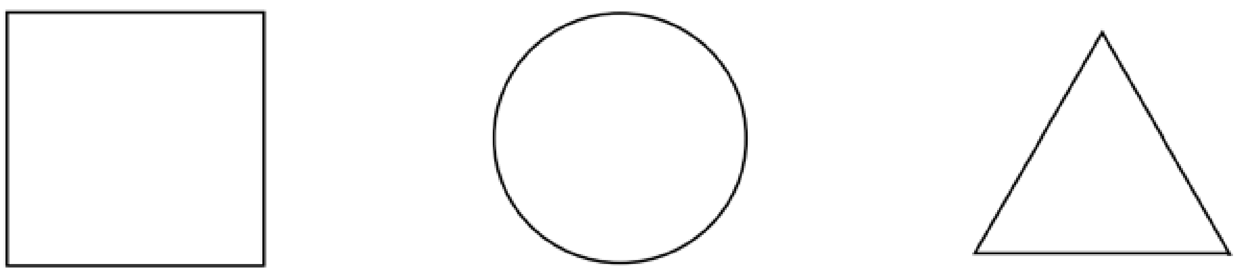
Figure 2

Puzzle from KOersief 23

1) By moving two matches you can change the star below so that it consists of six triangles.



2) What is the shape of the solid element that passes appropriately through a round, square and triangular hole respectively? (The hole must be completely filled!)

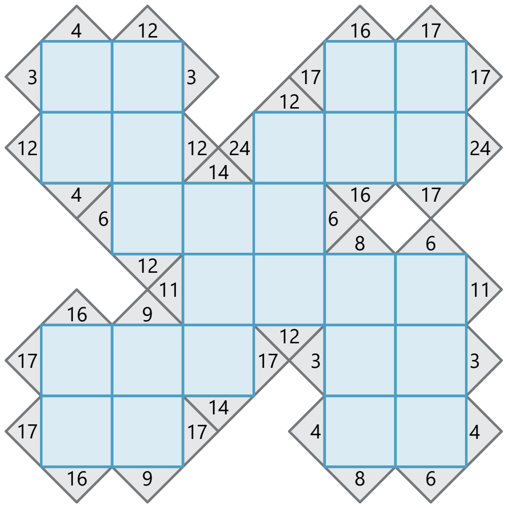


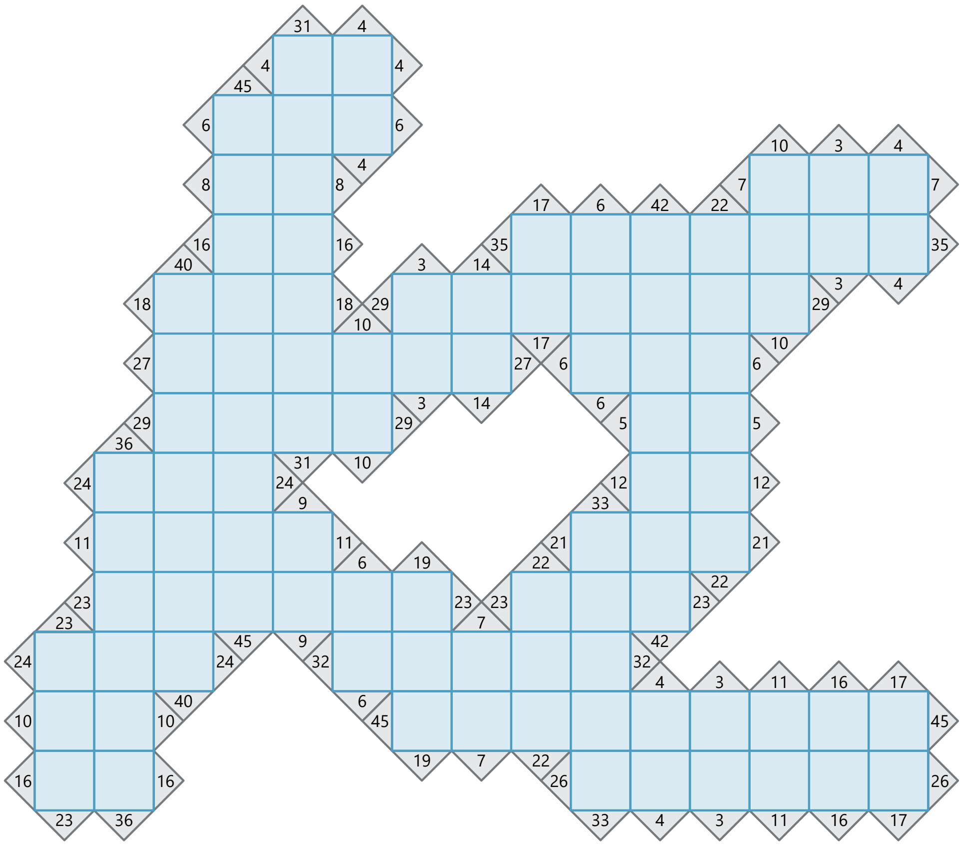
Puzzle from Jelle and Michelle

The objective of a Kakuro is to fill all empty squares using the numbers 1 to 9, such that the sum of the horizontal entries is equal to the number given on the left and the right, and the sum of the vertical entries is equal to the number on the top and bottom. On top of that, no duplicate numbers may be used in a sum. A small practice Kakuro is also provided for anyone unfamiliar with the concept!

Because the KOers-Kakuro turns out to be quite difficult, there are some 'magic combinations' given in the table below. These combinations can only be made in a single way, and are therefore an easy way to start the puzzle.

3 in 2 digits:	1 + 2
4 in 2 digits:	1 + 3
16 in 2 digits:	7 + 9
17 in 2 digits:	8 + 9
6 in 3 digits:	1 + 2 + 3
7 in 3 digits:	1 + 2 + 4
23 in 3 digits:	6 + 8 + 9
24 in 3 digits:	7 + 8 + 9
10 in 4 digits:	1 + 2 + 3 + 4
11 in 4 digits:	1 + 2 + 3 + 5
29 in 4 digits:	5 + 7 + 8 + 9
30 in 4 digits:	6 + 7 + 8 + 9
15 in 5 digits:	1 + 2 + 3 + 4 + 5
16 in 5 digits:	1 + 2 + 3 + 4 + 6
34 in 5 digits:	4 + 6 + 7 + 8 + 9
35 in 5 digits:	5 + 6 + 7 + 8 + 9





Every edition a new puzzle, can you find the correct answers? Try, and send them to secretaris@koerstue.nl, this is possible until 4th of February 2022. Good luck!

Column

More Recycling? Or new Bio-based?

Hans Lamers

Photo: Vincent van den Hoogen

The transformation from a linear economy to a circular economy! A strategy for the reduction of carbon dioxide, our favorable greenhouse gas. Last decade many developments were initiated. The growing demand for materials and the subsequent waste problems are crystal clear to everyone, I hope.

One of the hot topics is Bio-based materials from all kinds of plants and animals. Of course, we all know natural materials - like wood, leather, flax, hemp, bamboo, sisal, jute, coconut, peanut shells. These materials are often described as 'renewable' materials. They form a fast-growing area of interest. Why so? They are carbon neutral! According to the 'Paris Agreement' from 2016, the world must be carbon neutral in the year 2050, a serious tough break! You may wonder if we are going back in time towards a prehistoric way of living by using Bio-based materials? No, not quite. These conventional Bio-based products may become the materials of the future. Bio-refining processes can already turn corn or sugar beets into a polymer like PLA (polylactic acid). With algae, large amounts of biofuel can be produced. Very promising, but unfortunately, there are still shortfalls to overcome. Producing algae-based biofuel requires fertilizers plenty of clean water, and also energy. From the mycelium of fungi, packaging products and fiberboard are already produced. Natural materials are by no means inferior. The strength of cellulose fibrils or the toughness of spider silk demonstrates the quality of Mother Nature's materials.

At this very moment, it is obvious that for the building sector, timber structures will support the expectation of climate goals and also fulfill the urgent demand for new houses. With the harvest of eight cubic meters of wood per hectare, architect Bjarne Mastenbroek stated: "In Finland, every 14 seconds a new wooden house is born", wow! Traditional building materials will not disappear but will become more climate neutral. In general, the improvement of materials, smarter design, the reduction of materials, enlarging the life span of products, and putting more effort into recycling are undeniably valuable. So there are many ways to the more resourceful use of materials. Developing bio-based materials is just one of them. If you thought you could hear 'klick, klick, klick' of wooden shoes again all over Holland in the future, you really have the wrong idea about bio-based materials and products. Be amazed about bio-based!

Colophon

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