Computational architecture: Focusing on the structural and layout complexity.
Abstract:
Architectural design is complex. It should be treated using appropriate methods. Intelligence methods, because those are able to deal with the complexity.

Introduction:
Design is complex. The complexity is due to the conflicting, soft nature of objectives and the excessive amount of solutions. Advanced methods are needed to deal with the complexity.

Dealing with the complexity requires advanced computational methods.

The outline to deal with it is as follows:
1- Generation of possible solutions
2- Performance analysis
   Methods for analysis:
   Perception: probabilistic perception simulation to evaluate visual perception aspects of spaces. It serves to quantify the degree an unbiased observer becomes aware of environmental objects.
   Fuzzy logic operations: a design requirement is generally not sharply defined, but it involves some tolerance for imprecision. This makes the requirement a fuzzy concept.
   Pareto front of solutions: group of the solutions that can not be improved further.
3- Optimization: Combination of values so that f(x) becomes maximum or minimum. For simple functions looking for where the derivative equals to 0 or a gradient based (slope) approach (direct methods). More complex problems need advanced methods (stochastic methods). These are more robust because they are not sensitive to the starting condition.
Genetic algorithm
Generation of first set of solutions.
Depending of their goodness, clone them
Matings / cross-overs. Bitwise swapping. Flip always one side. Mutation ensures we don’t get stuck in some solution.

Neural Fuzzy Model
Neural models perform non-linear computations at the neurons, that are logic operations. Thereby reasoning related information processing that occurs in brain is simulated. All computations are accomplished according to the fuzzy logic principles, i.e. fuzzy numbers, fuzzy arithmetic, etc.

![Complexity Diagram](image1)

**Fig 1.** Complexity.

Fuzzy neural tree for human-like assessment of soft objectives.

![Fuzzy Neural Tree](image2)

**Fig 2.** Fuzzy neural tree.
What is optimization?
Optimization is the process of finding solutions, so that they cannot be improved further with respect to some goals defined in advance. In other words minimizing or maximizing an objective can be considered as optimization. Design tasks involve multiple goals and many possible solutions, which optimization helps us to deal with them.

Single Objective Genetic Algorithm:
In the single objective (also called as cost function) approach several goals are combined artificially, forming a single objective (‘cost-function’), that should generally be minimized.

![Evolutionary algorithm](image)

A genetic algorithm is a stochastic search method. In this approach a population of random solutions is created. The superior solutions get a higher chance to reproduce themselves rather inferior ones which have less chance. Pairs of reproduced solutions combine to each other to create new ‘child’ solutions which are generally superior than the parent generation.

The limitation of the single objective approach is that it requires fixing the weights in the objective function, while before finding optimal solutions it is unknown what the inevitable trade-offs are that characterize the problem at hand.

Multi Objective Genetic Algorithm
In multi-objective optimization several objectives are to be satisfied simultaneously without artificially combining them beforehand. The goal of multi-objective optimization is to find the set of vectors $x$ for which a certain criterion holds, which is known as Pareto dominance.

![Pareto Dominance](image)

Given a set of objectives, a solution is called ‘better’ than another one when it has a better value in one goal rather the other solution; and a solution is called ‘Pareto dominate’ of another solution when its values is not inferior from the values of the other solution in all objectives, and at least in one objective has better value rather the other solution.
In multi-objective method, a set of Pareto optimal solutions will be found first, and then the decision maker will select the desirable solution among them, while in single-objective method the preference information is asked first, and then according to them the best solution will be found.

**Sensitivity:**
Expressed in the value of the slope and is sometimes called the "rate of change" because it measures the rate of change in $y$ as a result of a change in $x$. On our knowledge model, we can address which nodes we may improve to get the higher increase in the overall neighbourhood goodness.

This can be used to target which aspects of the design are more suitable to target in order to improve the goodness of the design.

![Sensitivity graph](image)

**Problem Statement**

How to involve computation to do better architecture?

During the first semester of the dual degree program, I started a research about plank timber curved surfaces. The idea of a plank line is that it bends in one direction, twists in the second direction, and is stiff in the third, like a thin board of wood. One of the interests was to research on how birds build their nests. They get stability by stacking a number of sticks. They use their instinct and use a higher number of sticks than needed. It can be said that it is a statistics instead of statics.

For the Graduation project, that approach would not fit the scale of the project. Instead, I studied ribbed timber shell structures. The typical construction of ribbed timber shell structures consists of wooden planks to form the ribs. These planks are approximately 3 x 16 cm, and several interlocked layers are used to form each rib. These planks are screwed together; usually no glue is used. Each layer of planks is continuous in one direction. The critical feature is that the wooden planks can only be bent, within reason, in their weak axis of inertia, the long direction. If they are bent in the other direction, they break easily.

![Building of the Download Gridshell](image)

**Fig 5.** Sensitivity for the arts in Lange Voorhout, Den Haag.

**Art Related**
- Established artists
- Upcoming artists

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Quality</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7</td>
<td>0.5</td>
</tr>
<tr>
<td>0.75</td>
<td>0.6</td>
</tr>
<tr>
<td>0.8</td>
<td>0.7</td>
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</tbody>
</table>

**Fig 6.** Building of the Download Gridshell. The built examples in this particular construction type helped to understand the construction properties and singularities of these structures.
Case studies:
Mannheim Multihalle by Frei Otto and Arup.
Jacques Herzog’s Expodach for Expo 2000 in Hanover.
Shigeru Ban’s Japanese Pavilion, with Frei Otto,
Buro Happold and SONOCCO. Flimwell Woodland Enterprise
Center Modular Gridshell by Feilden Clegg and Atelier One.
Edward Cullinan’s Download Gridshell.
Pishwanton Hand-Built Gridshell by David Tasker and Christopler Day.
Helsinki University of Technology Wood Studio’s timber bubble at the Helsinki Zoo (known as Villa Hara).
Gren Howells Architects’ Savill Building in Windsor Great Park, with Buro Happold.
Herbert Art Gallery & Museum.
Masserioa Ospitale’s terrace roofing and Pavillion in the courtyard of Naples Faculty of Architecture.
The paper can be downloaded from the blog with the complete list of references at: http://javierzaratiegui.blogspot.nl/2012/12/msc3-literature.html.

Basically, a grid is formed on the ground, and by scaffolding it is pushed to the designed shape. Latter, it is triangulated to add stiffness where needed.

How this relates to a museum?
The given scenario was the American Embassy building at Lange Voorhout 102, in Den Haag, and the topic to address was an Art Centre.
After an urban analysis of the area, I came with the conclusion that there is no need for a major urban intervention, as there are not key problems to target. On the neural tree that the group of experts did, most of the values were high for the current situation. Certainly, other parts of the city would get more benefit of such effort.
So I began to think about what type of centre would satisfy the demands of the citizens of Den Haag. First I rejected the common museum space that people visits once. Those mainly attract users from outside the city and to improve the neighbourhood I decided to design a social space that brings people together around art, debates, culture, politics, etc.
One of the first steps to climb, was the financial implications of such decision. To gather citizens often, the price should be low or free.

Economic viability
For the economic viability of the proposal I propose several strategies:
A sample of the Mauritzhaus collection will be exhibited, bringing a number of visitors (that is a studio imposed strategy).
Via museum card or museum membership: holders of the card would access the centre for free.
Donations, investors, and Crowd-funding: the political and social thematic of the centre would encourage companies to invest in it and politic parties as a mean to know what the habitants think and for their own purpose to gain affiliates.
Gift shop and restaurant: the income of both facilities would first be earmarked to cover the expenses of the centre and, when it generates profit, would be spent on social projects.
Magazine: edited and printed at the museum to advertise the activities from the museum and other interesting events at the city.
Along with it also I have considered establishing relations with the following:


De Affiche Galerij: De Affiche Galerij consists of a glass display case measuring 100 metres long. There is space for 60 different posters in illuminated frames. De Affiche Galerij is part of the Spui tram station. It can be visited all day long and costs nothing. The Hague Municipal Archives is in charge of organising expositions.

Gemak: The Gemak arts centre is designed as a place where contemporary non-Western art can intersect with politics and society and where the hot topics of the day can be explored by means of visual images and public debate. The Gemeentemuseum Den Haag and the Vrije Academie in The Hague joined forces in 2007 to set up the arts centre called Gemak. Central to the idea of Gemak are current trends in the arts, politics and social discourse, and the connections between these three. Gemak’s exhibitions are never isolated events; they are generally accompanied by lectures, interviews and debates, where art provides the inspiration rather than the subject. The activities often concern social issues and politics, though they can just as easily be about football or photojournalism.

- Historical Museum of The Hague: In the Historical Museum of The Hague you will become acquainted with the colorful history of The Hague.

- Humanity House: The Humanity House takes you on a journey, where you will see, feel, hear and experience what it’s like to survive a disaster or conflict. In the museum the unimaginable becomes imaginable.

- Loos Duinen Museum: What was used in olden days as a granary is now the Loosuinen Museum. The old ‘Korenschuur’ has been restored and now stands in the historic market garden village of Loosduinen.

- Museum for communication: There are exhibitions about the senses, communication in art and the human being.

- Prison Gate Museum: The Prison Gate is the former prison of the Court of Holland. The medieval building and its unique collection of punishment and torture devices introduce the visitor to the history of criminal law in Holland.

- Sarnamihuis: The Sarnamihuis is a museum and documentation centre focused on the history, language and culture of the Indian population in the Netherlands and Suriname.

- The Hague Museum of Photography: The Hague Museum of Photography organises around six exhibitions a year covering a wide range of periods, disciplines and genres in the history of photography, often focusing on the human figure.

- Yi Jun Peace Museum: The museum pays homage to the late Yi Jun (1859-1907), a resistance fighter who opposed the Japanese colonisation of Korea (1910-1945). In the summer of 1907 Yi travelled by railway to The Hague as part of Korea’s delegation to the Second Hague Peace Conference. He was commissioned to announce to the international community that Korea was an independent state and that the Japanese invasion was unlawful.

- Atelier Van Lieshout: Recurring themes in the work of AVL are autarky, power, politics and the more classical themes of life and death.

Because the social implication of their programs. I wish some of the exhibitions can take part in both centers, and specially the building at “Lange Voorhout” can organize tours around several of these museums, host and/or continue activities, relating their programs.

To outline some of the topics covered in the first year agenda in the form of exhibitions, conferences, projections...
- Nuclear discussion/Nuclear security summit 2014: debates and conferences.
- Turkish museum opening: The first Turkish museum in the Netherlands officially opened on 8 September in The Hague. The Turks Museum Nederland can be found in a former community center in Moerwijk, a neighbourhood where many Turks have traditionally lived.
- European capital of culture: Apart from The Hague other candidate cities and regions in the Netherlands are Maastricht, the city of Brabant, Utrecht, Almere and Friesland.
- Death cell museum: raising funds for the Stichting Oranjehotel to convert the death cell in the Scheveningen prison into a museum.
- Homeless: Winter measures stop for homeless. The municipality believes that everybody should have a roof over his head when temperatures drop below freezing: Is this the best we can do?
- Rio + 20: Earth Summit 2012 will be the fourth Summit of its kind and represents another milestone in ongoing international efforts to accelerate progress towards achieving sustainable development globally
- Energy saving tutorials: aimed to transmit children and adults about easy habits that reduce energy consumption as well as techniques to grow food.

Of course this is a brief example and the content should be thought out with the suggestions of the citizens. So, with this in the scope, I want that the place is easy to visit, and a place to gather. The multipurpose room and the conference room would be the main spaces of the building.

**Goals**

So the first decision was what to do with the actual building. We decided to involve computation from the beginning, since it is the specific theme of this studio.

The three different values to input were:
- not to change the existing building;
- renovate it;
- demolish and do a new one.

I established a neural tree for the success of the double degree program. I included both parts, TUDelft diploma, and METU thesis that contribute with different weights to the overall value. To give the weights I compared the duration of both parts of the program, and increased the value of TUDelft since it is an “IF CONDITION” for the METU part to occur, and since it is now, and the other it is a future event (0,70 and 0,30).

At TUDelft my two main goals are learning, and succeed with the Graduation (0,60 and 0,40).

The first difficult choice is what to do with a building of a re-known architect, Marcel Breuer. The first instinct was not to demolish it, because of the historic value. Then renovation could be an interesting point but, since this is not a renovation studio, we can’t get the real plans of the building. In both
cases I would hardly include it as a case study in the research I started, so both of them scored low in the neural tree.

Then, the studio also used a neural tree to decide the type of intervention by giving scores to the nodes analysed in the situations of not intervening, renovating and demolishing and building an art centre.

As part of the thesis, I aimed to include the diploma project as a new case study for free form timber shell constructions, under the scope of optimization, and to be more specific: multi-objective optimization.

I started to study the program, and focus in how computation could help me in solving the multiple relations between the different functions.

The first thing was to establish my goals from the beginning, so it can always be used to compare the results with the objectives. There are several levels at the neural tree. The first one are the variables, physical properties that we can modify. The second level are the first abstractions that we include in our tree. For this particular design, I am focusing on the program satisfaction through the layout research. The structure research will also be a key node at my project. At the third level, we can sum them into functional aspects, digital manufacturing and perception. The sum of all of them would give the overall goodness of the design, once the weights are given and the generations are created.
The variables were set by relating some of them to the others to reduce the amount of variables. For example: given a rectangle, instead of using both sides length, one is a variable and the other is dependent of the area, so less computation is needed, although we sacrifice solutions that could occur if the areas are changed. For that, we could fuzzify the areas and use them as a variable. But I am trying to reduce the number of variables.

The next step was to restrain the domain of some of the functions beforehand. In my case, I want the administration and the service areas not to be close to the façade, and much better if they are together at the north part. Also some spaces should be bound to the ground floor, like the shop or the lobby. The restaurant could be also, but perhaps it is interesting to see the outcome, and then decide if it will be at the top for the views, or at the bottom, for the accessibility.

### Determinants of the layout performance

<table>
<thead>
<tr>
<th>Vol A + Vol B + Vol C - Vol AUBUC = Vol A∩B∩C</th>
<th>Vol A∩B∩C</th>
</tr>
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<tbody>
<tr>
<td>Vol B - Vol (B \ A) = Vol A∩B</td>
<td></td>
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### Fig 10. Variable definition

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### Fig 11. Variable definition and restricted domains for each space

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The determinants of the layout performance was the most delicated step. The main goals addressed were to avoid that the building exceeded the site boundary, to minimize overlaps, the nearness among certain functions, and a circulation sequence to the building. There were troubles when computing the intersections and with the circulation sequence, which was not conclusive since not only one entrance was designed. But for three of the goals, the computer brought the possible best solutions on a clear pareto front.

Later on, voids where included, and the intersection with them was computed. At this point, with 5 goals the pareto was not so clear, and perhaps due to a low number of population size at the algorithm. But the project needed to be done and the decision was to leave the layout research, and start the building definition with a cognitive design approach.
Structure research and form finding
I started with a taxonomy study of hanged surfaces both the digital and the physical world. I got a better understanding of the possibilities of catenary shapes that could be applied in my design.

Fig 15. Structure study: taxonomy of hanged square grids.

But the control of the space was out of my hands because by wrapping it was only possible to modify the exterior skin.

Fig 16. Physical and digital model studies.

I questioned which should be the level of implication of the skin and the structure. I tried to shape the building with parametric tools, while being able to perform structure analysis. All this with the
Grasshopper plugins “Karamba” and “Kangaroo”. I did it for the auditorium, while controlling the view angles and slopes.

**Fig 17.** Shape generation of the auditorium with parametric tools.

**Fig 18.** Skin integration

**Fig 19.** Finite element analysis and contour optimization for manufacturability.
The main problem for not achieving all that I wanted was the continuous delay that the program layout research made. For example, at P3 presentation, Dr. M. Bittermann asked me to re-run it with a new space constraint. So at that moment, still the next steps were not fully implemented. Unfortunately, I didn’t manage to solve the algorithms to link the form finding and the finite element analysis, in which redoing the layout wouldn’t have been a problem.
During the structural research, the specialist guidance led me to the understanding that manufacturing usually is a bigger constrain than material use. So I oriented my study into the new topic, and in the same way, the graduation project.

Keeping the same free-form intentions, now the goal was to materialize them in a smarter way. The different parts of the building were isolated, and by this I could aim different construction methods in each of them. In this way, the private areas of the building remain straight or single curved, and the most visited kept the double curve shape. At the same time, the roof structure remained isolated from the other functions and from the load bearing function. Now it had to only sustain itself, and the wind and snow loads.

The smaller load came from the auditorium, so I decided to use foam based shape, covered with fiberglass. Different finishing was designed for the interior, to meet the acoustic demands. On the gallery and multipurpose, the overall shape was done with the same technique, using the foam
cutting robots. But in between the foam blocks was put a set of glulam curved beams, due to the higher load. The curvature of each of them was the most crucial factor. While there are methods like CNC to create any shape, I decided to use blending machine to reduce waste material. Therefore, the beams resulted with circular curvatures. Combining them into one beam, the curved beams are formed.


This rose my interest in automated machines, and decided to build a 3d printer. A friend (Lucas Ter Hall), from other studio, and I proposed to the faculty the construction of a 3d printer. They decided to sponsor this task and in return, the faculty would keep the machine. If this had happened earlier, I would have oriented the graduation project to plastic composites and the design possibilities of this materials and techniques. But I am very thankful to Dr. Martijn C. Stellingwerff and Peter Koorstra professors from Form Studies Department for this opportunity.

At the end, for P5 I changed the building because I was not having control of the blobs as I would have desired. The biggest problem was not being able to get the form finding parametrically out of the layout research. And, lately, trying to embed too many different topics into the same project.
Literature and general practical preference


Bittermann, M.S., Ciftcioglu, Ö.: “Solution Diversity in Multi-Objective Optimization: A Study in Virtual Reality”. IEEE World Congress on Computational Intelligence, Hong Kong June 1-6, (2008).


