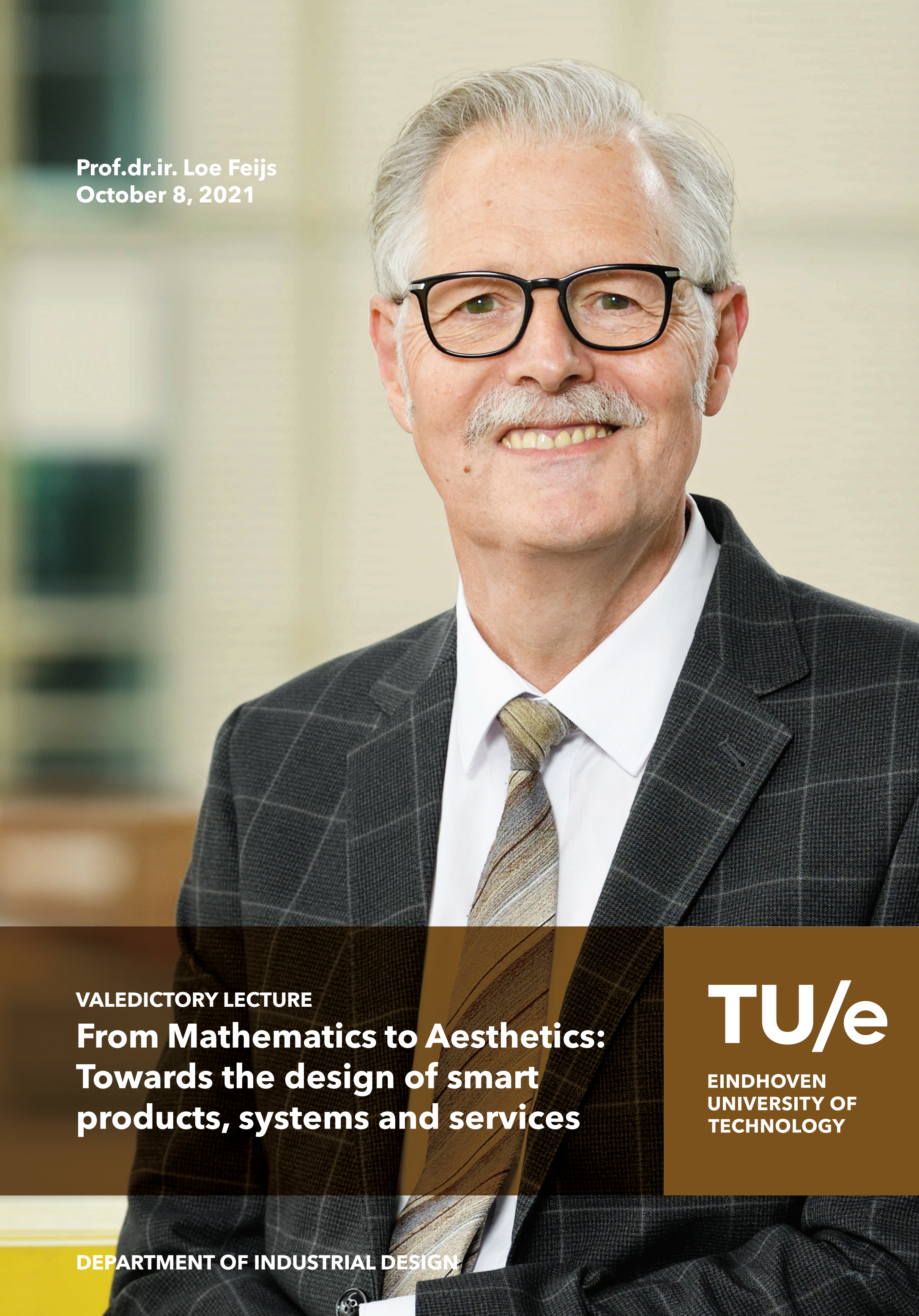
From Mathematics to Aesthetics



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October 8, 2021

VALEDICTORY LECTURE

From Mathematics to Aesthetics: Towards the design of smart products, systems and services

TU/e EINDHOVEN UNIVERSITY OF TECHNOLOGY

DEPARTMENT OF INDUSTRIAL DESIGN

VALEDICTORY LECTURE PROF.DR.IR. LOE FEIJS

From Mathematics to Aesthetics: Towards the design of smart products, systems and services

Presented on October 8, 2021
at Eindhoven University of Technology

Introduction

Dear Rector, members of the Executive Board of Eindhoven University of Technology, dear colleagues, dear family and friends, esteemed audience.

It is my great pleasure to find you all interested in listening to my valedictory lecture. From the title of the lecture, you can guess that it is mostly about industrial design. When I was asked to join a new Department of Industrial Design in the year 2000, I had little idea of the challenge ahead, but I said "yes".

Software research

My “yes” unfolded into a great adventure in Industrial Design, in teaching and in research.
First, let me go back a few years to explain what I had been doing before, because that does matter when it comes to what happened later in Industrial Design. Before Industrial Design, I was working in Philips Research Labs and in the TU/e Department of Mathematics and Computer Science. Let me tell you what my colleagues and I were trying to do at Philips Research Labs. It was all teamwork. I got great support from my teachers, Dr. Hans Jonkers, Prof. Frans Kruseman Aretz and Prof. Jan Bergstra. We looked at computer science through the lens of *language*. We wanted to understand what it means for a computer program to satisfy a specification and we insisted that such a specification must not be some kind of sketch but should be in a formal language. In order to work with such new languages, I had to learn about mathematical logic first. Philips supported us in cooperating with top researchers in logic from the universities of Utrecht and Amsterdam. This cooperation gave rise to new languages, which we applied to specify components, programs and protocols relevant to Philips.

What was relevant to Philips? For example, the embedded software in Philips television receivers, CAD software for Philips color cathode-ray tubes, production robots, mobile telephony protocols and entirely new classes of devices such as the Philips Kidcom, a computer for children. The images give you an impression

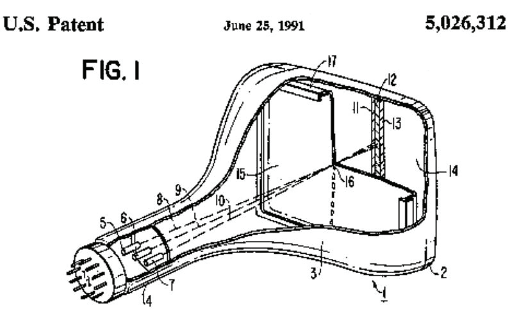

Figure 1. Examples of Philips components and products addressed in formal specification case studies: color cathode-ray tube shadow mask (image from patent 5,026,312, left) and Kidcom children’s computer, later renamed to In2It (right).

of these components and products; they ranged from classical electronic components to new devices no-one had ever heard of.

The methodology was performing case studies because although the languages and products may have been formal objects, the people working with them were not. The cycle of designing, building and testing was, and still is, key to finding out what works and what doesn't.

The products were interesting enough, but so were our new languages. These gave rise to interesting scientific problems, which appeared innocent at first but were harder than initially believed. For example, it is easy to write a program which pushes three objects onto a stack and then attempts to grab four. Of course, something can go wrong during the execution of that program, but we can still formally ask: what is the meaning of pop(empty)? Even a simple stack is not as simple as it appears. Hans Jonkers had proposed a new language called COLD [1], Common Object-Oriented Language for Design. In COLD, we could write a specification of the datatype of stacks in algebra style. Note the exclamation mark, a special symbol in COLD to distinguish the defined and the undefined.

```
CLASS

  SORT Item
  SORT Stack
  FUNC empty : -> Stack
  FUNC push  : Item # Stack -> Stack
  FUNC pop   : Stack -> Item # Stack

  AXIOM empty!
  AXIOM NOT pop(empty)!
  AXIOM FORALL u:Item # Stack
        ( pop(push(u)) = u )

END
```

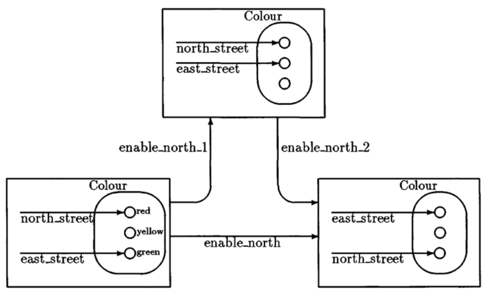

Figure 2. Formal specification in COLD (left) and state transition diagram of a class with colors and two variable functions (right).

The language-oriented paradigm insists that all well-formed expressions in the language have a meaning. Going beyond the algebra approach, other challenges concern state-based systems. For example, we can make an algebra-style specification of some sorts of colors, but we can also write procedures which perform state changes. The state-transition diagram shows some states and state transitions of a traffic light system, and we see that the datatype of the colors reappears in every state. How do we know that these are still the same colors and not a fresh copy?

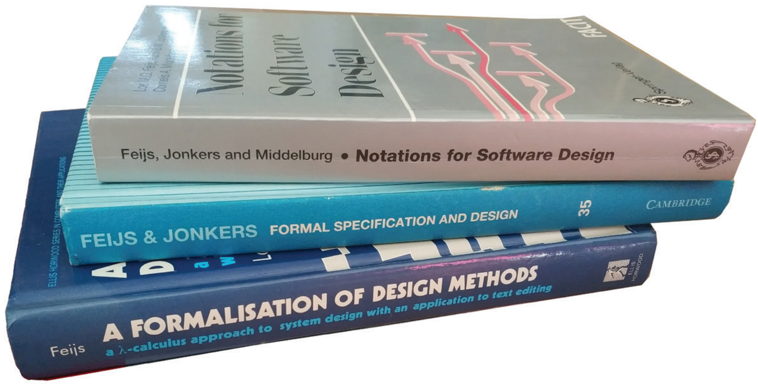

Figure 3. Books on COLD by Hans Jonkers, Kees Middelburg and Loe Feijs.

These are just some of the issues to be taken into account when designing and testing these new languages. As a highlight of all this work, I would like to mention the books which Hans Jonkers, Kees Middelbrug and I wrote at CUP and Springer.

After fifteen or twenty years of these developments, Philips had had enough of our formal languages, but that's not so strange considering that Philips also abandoned televisions and all of the other products I mentioned. But medical systems were still growing and software architecture, for example, became a hot topic [2].

In 1994, I was welcomed by the Formal Methods group lead by Prof Jos Baeten at TU/e, where we worked on similar problems such as software architecture, sequence charts [3] and software testing, but now also outside of Philips. The Nationale Testdag, which we organized, has been a yearly, industrially-relevant event ever since [4].

Together with industry, TU/e began an Eindhoven Embedded Systems Institute in 1998, nowadays a branch of TNO called ESI. My new job was in EESI and the goal was for the institute to do research for industry with computer scientists and electrical engineers working together. We pioneered the Embedded Internet [5], which we now call IoT, the Internet of Things. The internet had already existed for decades, but the World Wide Web was born in 1994. It was an immediate success. This web was mostly about information documents which linked to other information documents. But in 1998, Peter Peters, Johan Lukkien and I developed the vision that the web could be much more. That all kinds of devices, the so-called

Embedded Systems, would go online too and have their own webpages which would allow users to see what was going on (even when not at home) or to operate their devices remotely. In the EESI institute, we built prototypes that pushed the software technology and also built easy-to-understand demonstrators to explain the implications for everyday life. One demonstrator was about watching an aquarium and feeding the fish; another was about an internet-enabled coffee machine. We had to dig deep in our archives to find the images of the user interfaces (for the internet-enabled coffee machine, I could only find a black and white scan).

Many persons we talked to in those days felt there was no need for such "solutions of a non-problem", but others showed interest. For example, the National Dutch Television program *Jeugdjournaal* came to see our project in Eindhoven and paid attention to the new possibilities. Looking back, I would say that the vision was correct and that building demonstrators was not 'window dressing' but part of our job of paving the way for new things to come, notably the Internet of Things.

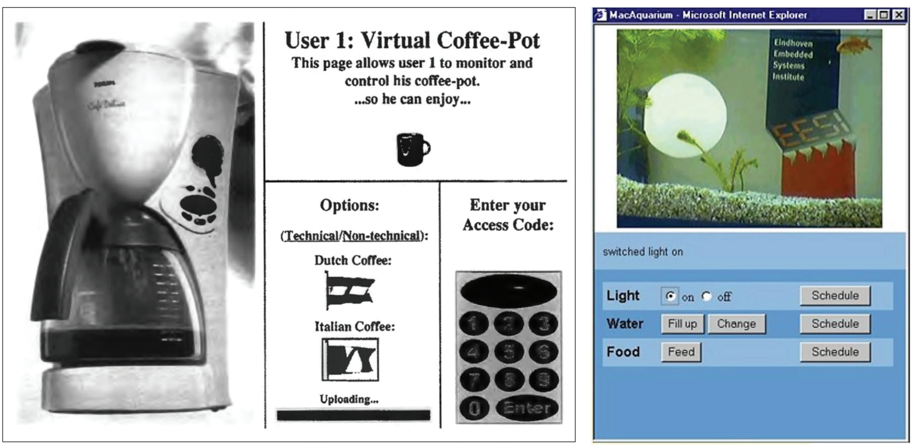

Figure 4. Experimental user interfaces for a web-enabled coffeemaker and a web-enabled aquarium realized at the Eindhoven Embedded Systems Institute.

The work on Embedded Internet was continued by my colleagues for many years after. Johan Lukkien and his group developed new architectures, taking care of both internet safety and the real-time requirements of the embedded system itself. Peter Peters translated the results into teaching so that students could develop new applications of the emerging technology.

A new department: Industrial Design

The idea that products would be computerized was gaining more and more ground. The board of TU/e then understood that this called for a new discipline called Industrial Design of Smart Products and they launched a new department for this. The TU/e board did a thorough job in checking whether there was industrial support for this plan, which they found to be the case indeed (only the board of Delft University of Technology expressed its doubts). My information comes from the October 2020 business plan of TU/e [6]. The diagram shows the position of the new department in a space which has two dimensions: the level of technology content (horizontal) and the level of societal aspects (vertical). As the diagram shows, TU/e was then run in the Dutch language; nowadays, it is in English, but I present the original diagram without translation. IO means Industrieel Ontwerpen: Industrial Design (as a verb).

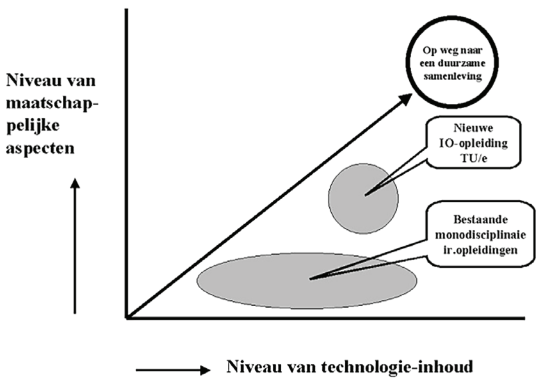

Figure 5. Vision from the TU/e IO business plan for a new Industrial Design education program.

Prof. Jeu Schouten, the new dean, had seen our internet-enabled coffee machine, the aquarium and other demonstrators and I think that those demos were one of the reasons why I was asked to join the new department. For sure, I had no training as an industrial designer – neither had Jeu Schouten or education innovator Han Smits – but fortunately there was help from Philips Design and from the Design Academy Eindhoven. We managed to attract fantastic people, including from Delft (the group led by Prof Kees Overbeeke) and from the Eindhoven Institute of Perception

Figure 6. Interior design of the space for Industrial Design within TU/e Hoofdgebouw in 2001, designed by Bert Staal and based on a camping and caravans theme (today, collegezaal 0.820 / 0.825 in Atlas).

Onderzoek (the group led by Prof Matthias Rauterberg). I have two images here. The first shows the space created for the department – an inviting interior design but as you can see, it was empty by early 2001, both people-wise and content-wise.

I would also like to show you a diagram from a PowerPoint presentation that Jeu Schouten gave to the university board once the department had begun running. This diagram is still correct yet notice that we still had an outsider's view of *what design is*. Design was defined by what would flow into it. Today, we have an inside-out vision; we can explain what design can offer to the outside world. I will come back to that.

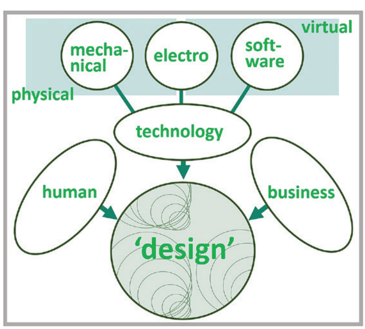

Figure 7. Example of a diagram used within TU/e around 2001 to clarify the relationship between design and other fields.

So, we began teaching and hiring staff, but despite the support of the board, many influential opinion leaders at TU/e were critical. The innovative teaching model with assignments and projects but no traditional courses and no exams was considered innovative but a bridge too far. And the scientific nature of industrial design was questioned too: is there a scientific core of industrial design? What is its basis?
The latter was a tough question worth paying attention to.

Product semantics, Semotion and DeSForM

By that time, I felt that I should make a contribution to the discipline of Industrial Design and I was fascinated by the problem of product semantics. Products speak to their buyers and their users through form, color and interaction. I knew the schematic diagram of a general communication system as proposed by Claude Shannon in 1948 [7]. Perhaps each designer works as a transmitter who codes messages into products and the user is the receiver decoding the messages. Claude Shannon had been very clear, however, that his theory was not about meaning, so something else would be needed in order to contribute to the theory of product semantics.

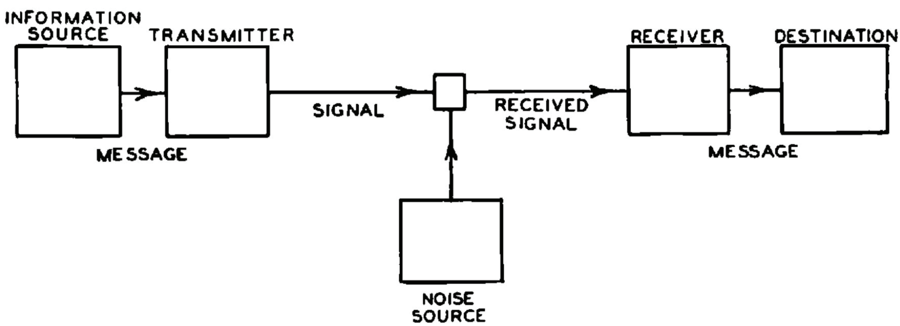

Figure 8. General communication system as proposed by Claude Shannon in 1948.

There were some books about product semantics, but the approach was mostly informal and anecdotic; there was no complete theory on how this worked. And products were growing more and more expressive; after all, the idea was to develop 'smart' products. Perhaps this was a problem for which my language-based lens could be helpful. I began working with the experienced designers around me, Richard Appleby and Steven Kyffin. We did several things.

The first thing was that we asked students to sketch new products which could express emotions such as joy, anger and so on. And in our new Eindhoven interpretation of Industrial Design, sketching meant making a working prototype [8].

For the Semotion = Semantics + Emotion project, this meant that there was a microprocessor inside each product which drove the emotion machine. This is where my knowledge of computer programming came in handy: for me, it seemed obvious, but most designers had no tradition of coding. Together, we did something new. I would like to show you an example of a prototype object which could show an emotion and was called 'Crack the angry vending machine' ([8], Section 5.2). It was designed by student Rombout Frieling, who was given the design brief that the object should work like a vending machine: its task was to deliver something small (a nut) to the user. Although Rombout made sure that the machine looks angry in its form and color, the behavior was even more interesting. It would make small menacing movements at first and then finally burst open and *throw* the nut towards the user.

Figure 9. An example of Semotion (semantics and emotion). Crack the angry vending machine by Rombout Frieling, made in 2005.

The next thing was a natural consequence of this, as we needed an outlet for these results. Just publishing articles would not convey what was going on and a demo alone was too meagre. Steven Kyffin, Bob Young and I decided that we would launch a conference series in which demonstrators and papers would go hand in hand: the DeSForM conference on Design and Semantics of Form and Motion. The conference began in Newcastle and was then held in Eindhoven, then Newcastle again. Here are the covers of the first three books, after which the team grew. The conference went to Offenbach, Taipei, Lucerne, Wellington, Wushi, Milano, Delft and Boston. By now, it has been organized in four continents and it will happen again in 2022 in Hong Kong.

Figure 10. Covers of the proceedings of the first three DeSForM conferences.

I also tried a third thing, a formal linguistic approach to product semantics. I called it CPS, commuting product semantics, as the formalism builds networks of commuting diagrams [9]. This formalism was not picked up at all, however, and I abandoned this work at some point. But I later found out that I had rediscovered Relational Frame Theory [10] and had written an axiom system for it. This system is shown in the figure, which is a semantic network full of commuting diagrams. The diagrams explain how the red and green signs on a Nokia phone of those days got their meaning: by having the same colors as traffic lights, by similarity (indicated as ≈), by opposition (indicated as ≠), by memory (μ), by human action (α), by physics (φ) and so on. In such a diagram, I could combine the existing theories proposed by Charles Peirce, Umberto Eco and the Offenbach school of product language. But the product design community was not waiting for my formalism; it did not resonate. I realized that the time window for contributing to product semantics was over. In fact, as more and more products became media – carriers of content – most design scholars felt that it would be arrogant for a designer to decide upon meaning. Products should be open as carriers for users who could load them with their own meanings through their own rituals.

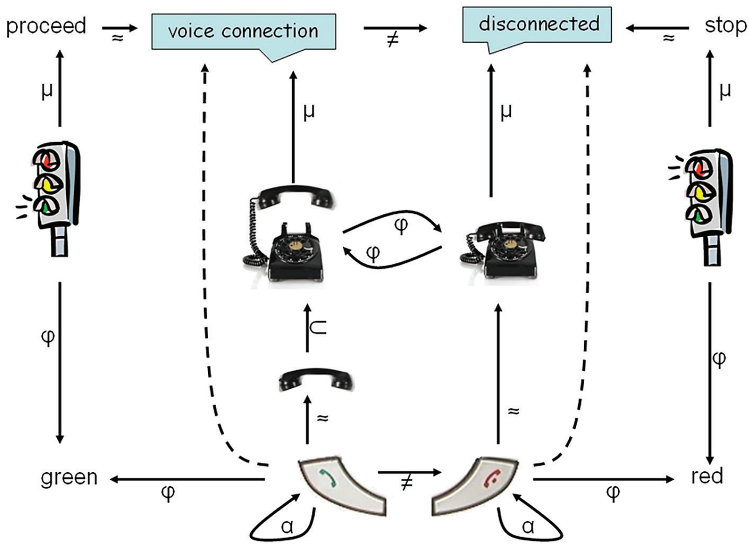

Figure 11. Commuting diagram of Nokia phone signs as an example of Commutative Product Semantics.

So, my contribution to the new field of industrial design was not in the language approach I tried but in the way I helped teach microcontrollers, servomotors and simple sensors – technology which I did not consider very new or very deep, but it was a step forward after all. This direction resonated with the research of my colleagues such as Stephan Wensveen and Joep Frens, who wanted to design for rich interaction. The approach also enabled us to become visible internationally. Besides DeSForM, I would like to mention the Cultural Patina workshops in China, organized by Jun Hu [11]. These workshops, which implemented rich interactions in a culturally rich setting, made our department famous as a place where design and prototyping technology are fully intertwined.

Industrial design has the power to touch people, convey emotional messages, attract people, impress them or scare them off. This is particularly true in preventive healthcare and medical clinics. I will present several examples of projects.

Design for well-being and healthcare

First, let me tell you about biofeedback for coping with stress. Under normal circumstances, you breathe in and breathe out in a regular pattern and your heart responds to that, taking care of all kinds of healthy internal feedback loops. Under daily stress and under chronic stress, these patterns change, but you wouldn't notice: humans have no good sensors for their own heart rate and heart rate variability. Exercises exist to train personal control over breathing and heart rate, which is healthy and restores balance. However, the devices are ugly. They produce scientific plots, which look scary rather than peaceful. We formed a team – Jun Hu, Geert Langereis, Mathias Funk, Rong-Hao Liang, Bin Yu and Mengru Xu – to create new visualizations and soundscapes which were personal, beautiful, practical and useful. We worked with Tilburg University, TU/e Electrical Engineering, Studio Rogier Arents, PSV and Kempenhaeghe to show what Industrial Design can contribute. One outcome was the Heart Bloom visualization system [12]. Heartbeats are recorded by a simple finger clip and then shown in real time. One way to show the heartbeats is on the wall by means of an innovative wallpaper. Bin Yu worked together with Studio Alissa + Nienke, who design beautiful decorative walls using laser-cut paper and other refined materials [13]. These materials can be moved by tiny silent motors which in turn move in the rhythm of the breathing as decoded from the heartbeats. This is beautiful, relaxing and so much more interesting than plain old wallpaper.

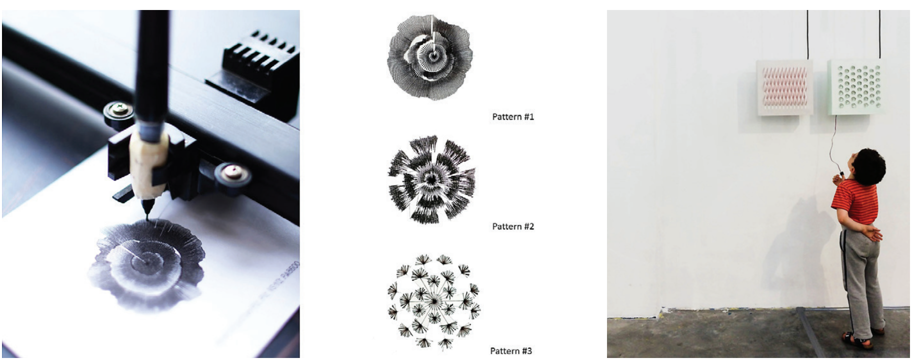

Figure 12. Real-time production of Heartbloom plots by Studio Rogier Arents and Bin Yu (left), Biomirror by Studio Alissa + Nienke and Bin Yu as shown during Dubai Design Week 2015 (right).

In the medical clinic, good design can also make a difference. I was invited by Prof. Jan Bergmans of Electrical Engineering to join a cooperation program with Máxima Medical Center, which has a specialization in *perinatology*. Máxima takes care of newborns, premature newborns, mothers and families. One success story is the smart jacket project aimed at monitoring premature babies. Instead of sticky electrodes, we explored textile electrodes, which hide the ugly wires and bring parents back into the loop. There is a new technology called 'conductive yarn', namely yarns which are not just cotton or polyester but which have a silver or steel coating such that the yarn can conduct electricity. This can be used in a special jacket for a baby. By properly sewing pieces of conductive fabric inside the jacket, the ECG – an electric signal coming from the baby's heart – can be picked up and shown to doctors and to the parents too [14]. Sibrecht Bouwstra designed the first jacket; we did several more projects and I had fantastic cooperation with neonatologists Prof. Sidarto Bambang Oetomo and Dr. Peter Andriessen. It is very useful to monitor the heart rate variability of a baby as the monitor will warn doctors and nurses when the baby needs urgent help. Heart rate variability has also been used by PhD students Rohan Joshi and Deedee Kommers to improve our understanding of the benefits of kangaroo care. This smart jacket is not on the market but was a research prototype which showed the way ahead and which gave rise to new products (and more research). Sidarto and Fabian Bambang Oetomo began developing the Bambi Belt, triggered by our smart jacket.

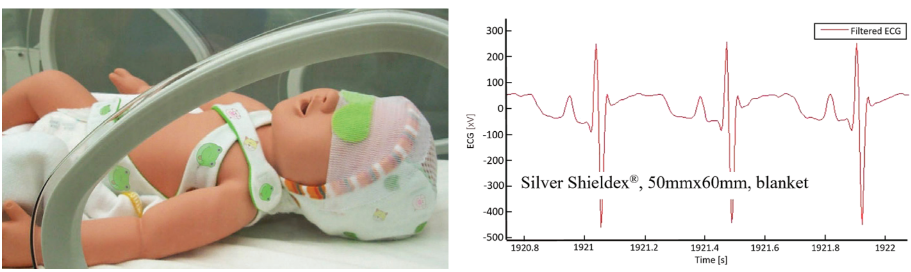

Figure 13. Smart jacket design for neonates by Sibrecht Bouwstra (left) and the ECG signal obtained while using the jacket (right).

We also developed manikins for training purposes (resuscitation training) and we exploited the advances in 3D printing and other methodologies from Industrial Design. Prof. Guid Oei of Máxima argued that doctors, midwives and nurses should train more using simulation. Guid Oei wanted to improve the simulation technology and he also got us enthusiastic. The first successful PhD project

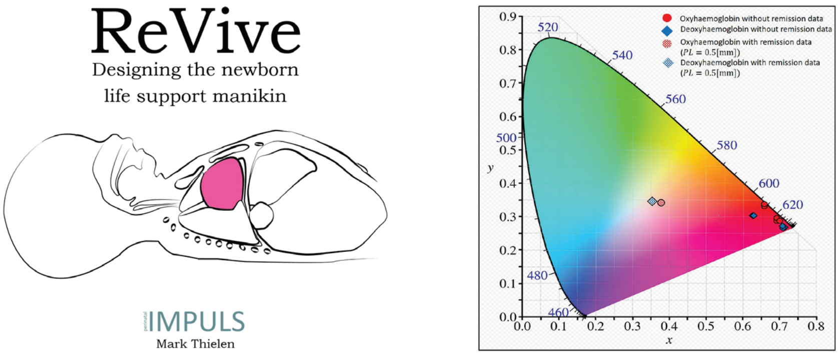

Figure 14. Design of a newborn life support manikin by Mark Thielen (left) and research into the colors of newborn cyanosis by Nur Fatihah Azmi (right).

on baby manikins was by Peter Peters [15]. This project was very ambitious: he designed the entire baby with provisions for checking muscle tone, breathing and so on. Later, we realized that although the baby manikin is tiny, building a good manikin is a huge task. Frank Debressine and I therefore changed strategy. The next PhD students, Mark Thielen and Nur Fatihah Azmi, focused on one theme each: heart resuscitation [16] and the baby's color [17]. We had to dive very deep into color theory; don't think pink is simply 'pink' and blue is 'blue'. Color theory is a patchwork of loosely connected theories, as we found out the hard way.

Today, the work on medical simulation contributes to a large European project on Perinatal Life Support. There have been several commercial developments, such as Bambi Belt, Medsim and Juno.

Another development which took inspiration from the baby projects was to again use the textile electrodes to measure the internal state of the human body, in this case the arousal level. We can measure galvanic skin response and estimate the arousal level and pain level of clients with visual and severe or profound intellectual disabilities. The goal is to support the professional caregivers of these clients. Stress and communication impairments are major causes for the occurrence of challenging behavior. This again involved teamwork: PhD students Kyra Frederiks and Helen Korving worked with Prof. Paula Sterkenburg of the VU, Dr. Emilia Barakova and Prof. Panos Markopoulos of TU/e, and Stichting Bartiméus. The client's stress can be detected by a smart sock, as developed by Kyra [18]. Once stress is detected, this information is shown to the caregiver by means of a flower app – beautiful yet efficient and helpful for the caregiver's sensitive responsiveness.

Aesthetics and Interaction

What I should explain here is that I interpret the term 'aesthetics' in a broad sense, not just pure art or just add-on decoration. The *beautiful* and the *good* go hand in hand. If the baby's ECG sensor hurts, then it is ugly. If the parents cannot bond with their child because it is amidst a mess of wires, this not good, it is unaesthetic. Digital therapies must be attractive; they should not just appear to be nice through advertisements but must be attractive and pleasant during daily usage, otherwise the patient will give up after a while. Note that it is not a matter of outer decoration; nowadays, it is mostly about interaction, understandability, the user experience and the built-in value system. Several of our PhD students did fundamental research on these notions: Philip Ross, Joep Frens, Eva Deckers, Bram van der Vlist and Gerrit Niezen. I have no time to explain all of that work. By way of example, I would like to show you the experimental lamp designed by Philip Ross [19]. It has no buttons but is operated by touch gestures. Using this lamp is a real pleasure (I am the proud owner of a genuine Fonckel lamp). The design methodology is as innovative as the lamp itself; it began with theories of rich interaction and human values.

Figure 15. Interactive lamp by Philip Ross as an example of ethics and aesthetics in intelligent product and system design.

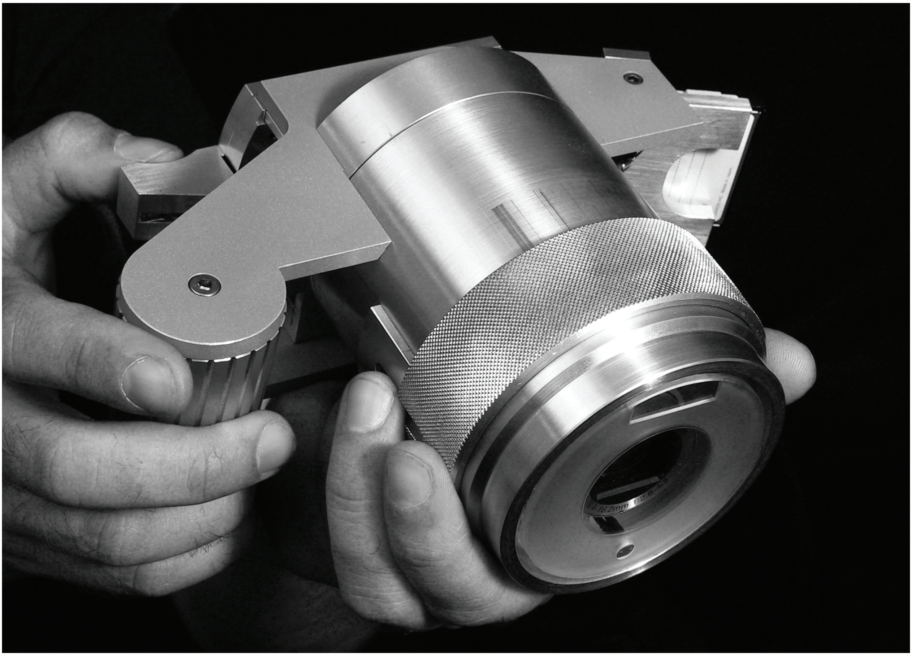

Figure 16. Camera designed by Joep Frens, designing for rich interaction: integrating form, interaction and function.

And as a second example, I present the research camera by Joep Frens [20]. It is not meant as a product but rather a laboratory to explore new forms of interaction: whether to use buttons or not, whether to hide buttons and when and how to show the camera's state. Even if these examples go against today's trend in which the smart phone's screen seems to be the main interaction device, people do still have full bodies, two hands and five or more senses. The potential for rich interaction must be used – if not now, then later, such as in medical design and experience design. I believe that our group created very valuable design knowledge.

Besides the healthcare and the medical projects, we also worked on robotics, gaming and adherence to sleep medicine. Perhaps I bit off more than I could chew, but I was lucky to have excellent colleagues whom I could rely on as promotors and co-promotors.

Reconnecting to Mathematics and Coding

The original idea of *smart* products, which was the basic idea of our new department, was a bit naïve. The idea as such is correct, but there are so many ways in which the computer and the internet have an effect on product design. This means that we have to distinguish between all kinds of 'smartness'. I already spoke about embedded systems, how tiny computers control the behavior of products. That's why we teach Industrial Design courses such as Creative Programming and Creative Electronics. These courses empower future designers so that they can build working prototypes and these prototypes act in terms of space, time and interaction. Moreover, the products talk to other products, sensors and websites, so the future of design is about systems and services, not just products.

Another way in which computers come in is that software is a tool for design. Traditionally, the designer works with editors such as Photoshop, Illustrator, Rhino and Solidworks, which have various geometric algorithms under the hood, mysteriously written by programmers elsewhere. The designer sees a What-You-See-Is-What-You-Get tool. I tried to challenge that view. I claim that mathematics and coding will be a source of innovation and a driver of design. If TU/e aims for the highest ambitions, I recommend embracing this claim. Not just in obligatory courses, but in projects where emergent behavior, fractals, additive manufacturing and systems thinking come together, for example. During the last ten years, I have been exploring this, sometimes making excursions into fashion and art - small projects without much funding but with enthusiastic colleagues: Jun Hu, Mathias Funk, Marina Toeters, Frank Delbressine and Troy Nachtigall. Let me give three examples of projects in that direction.

In the Mondrian generator project, I programmed tools to generate Mondrian-like compositions and I found that this is a new way of studying this famous Dutch-French-American artist. I did not forget all of my formal method experience as I formalized the paintings and grouped them into distinct composition types. A first publication in Leonardo [21] appeared in 2004. Later, I combined generators and statistics and I could measure one of the parameters for classifying Mondrian's paintings, as shown in the diagram [22].

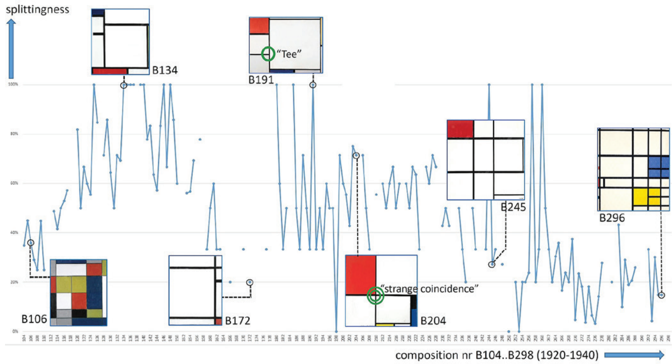

Figure 17. Classification of Mondrian's 1920-1940 paintings based on 'splittingness'.

In 2013, Gemeentemuseum in Den Haag and a media-lab setup in Utrecht launched a Call for Code competition. The challenge was to recreate Victory Boogie Woogie by code. Mondrian painted Victory Boogie Woogie in 1944, but it was very complex and he could not finish the work. The vision behind the 2013 competition was that programming is *the* craft of the twenty-first century. By reusing my knowledge about Mondrian and his work, by reusing code from my earlier Mondrian coding project, through hard work and with luck, I won that competition. The photo shows the jury members and the four nominees at Gemeentemuseum. It was an explosion of creativity. I could see connections

Figure 18. Jury members and the four nominees of the Call for Code competition at Gemeentemuseum in Den Haag, April 21, 2013.

between Mondrian's philosophy, the code and the aesthetics of Mondrian's art; all in all, it was very rewarding. And the cherry on top was that I could write an article about my code in the academic and peer-reviewed Journal of Mathematics and the Arts [23]. This won a best paper award.

The take-away message from the Mondrian generator project is that coding and aesthetics form a powerful combination.

In the Solemaker project, I was invited to contribute by Troy Nachtigall, who did a project about customization of shoes. We focused on the soles first and we made a prototype user interface through which the end-user could choose the grid pattern of her or his own shoes. The grid pattern is not only an aesthetic thing; it also determines how the sole will fold, how the shoes will walk. Here, our idea was to give the user a powerful yet unconventional WYSIWYG interface, but behind that was an optimizing shoe-sole compiler, somewhat like a silicon compiler used in the chip industry. Inside, there were algorithms for the G-code which goes to the 3D printer [24]. I would like to show you the sole as it comes out of the 3D printer and a dataflow diagram of the data structures and algorithms under the hood. In the project, we found evidence that new product-service systems call for designers who can work with algorithms, specifications and code.

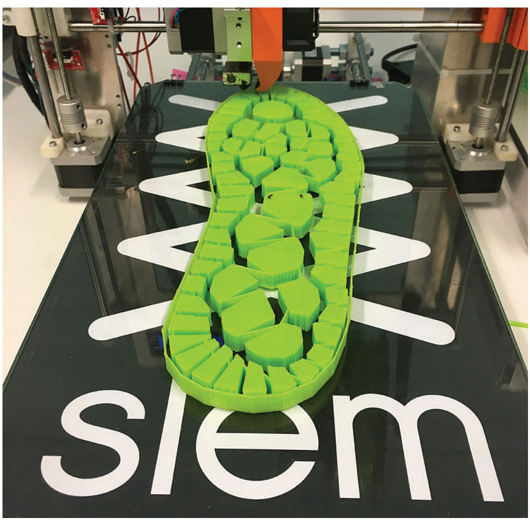

Figure 19. Shoe sole being 3D printed from G-code generated by the Solemaker system based on a personalized design.

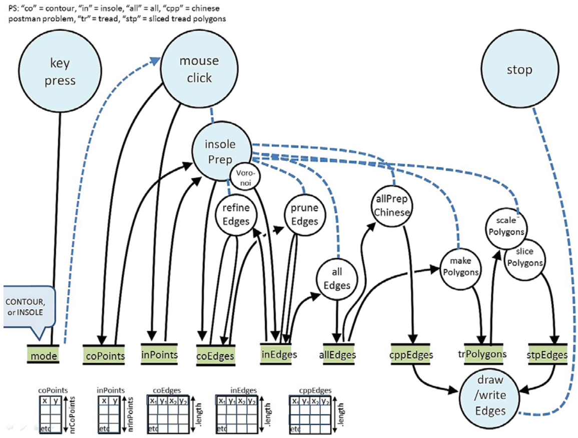

Figure 20. Dataflow diagram of data structures and algorithms inside the user interface and the G-code generator of the Solemaker system.

In the Pied-De-Poule project, actually a series of ten smaller projects, we looked for innovation within a classic fashion motif: pied-de-poule, or houndstooth as it is called in the UK. It is amazing how often this weaving pattern is printed and copied over and over again to 'create' new fashion. We showed that there is plenty of room for real innovation. Working with fashion innovator Marina Toeters, we created fractal versions of the motif [25,26] and cellular automata versions of the same pattern [27].

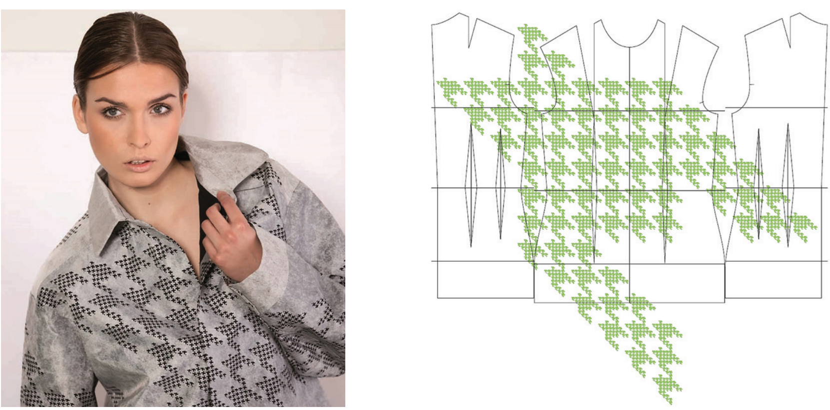

Figure 21: Shirt with laser-cut fractal pied-de-poule pattern (left) and generated pattern (right).

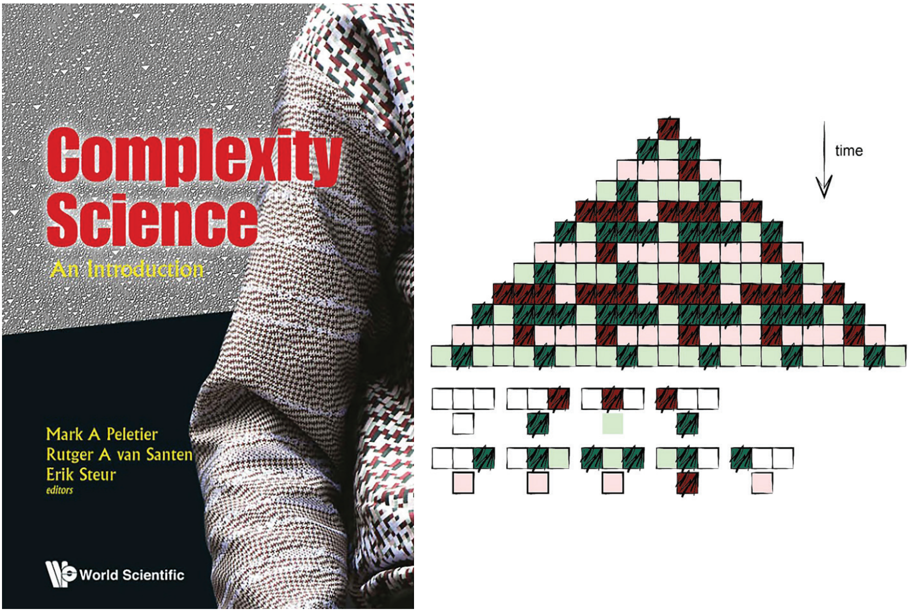

Figure 22. The book Complexity Science with the generative design using cellular automata on its cover (left) and the development of a cellular automaton (right).

The garment which appears on the cover of the book by Rutger van Santen, Mark Peletier and Erik Steur [28] is not only a puppytooth pied-de-poule; it illustrates the three essential concepts of modern complexity theory: emergence, chaos and resilience. These concepts always appear when systems are complex and it is important to bring this message to a wider audience. Industrial design is not supposed to produce the fundamental technology breakthroughs, but design mediates between the technological and the human.

The Future

What is the future of the Department of Industrial Design? In my view, it looks bright because society and industry need well-trained academic and techno-enabled designers. As more complex technologies are developed, there is an ever more urgent need to package them and make them meaningfully and transparently available to people. This is what Industrial Designers do. I have always enjoyed teaching and coaching students and the students have been very friendly to me. Now that the department has many graduated designers working in the field, I can see that the innovative elements in the education program did work out well: freedom of choice during the program, more projects, fewer exams and more real-life challenges. The entire university can benefit from these early explorations of industrial design.

New challenges are on the horizon: as technology pushes forward, the nature of Industrial Design changes . . . again. I could mention some of the challenges. How to work with big data and artificial intelligence? How to strengthen the theoretical and experimental core of the ID field? And how to better contribute to solving major global challenges, such as better health and a cyclic economy? Industrial Design cannot solve these global challenges on its own, but it can help significantly when working together with other disciplines. Working together is important: inside a group, inside a department, inside the university. Looking back on my many projects, I notice that the projects where I worked in a team had a much greater impact than any of my solo projects. Coming back to the question of what Industrial Design can bring to other partners, design has two special powers:

1. Sketching possible futures (so that we can see possible futures before choosing).
2. Making products, services and experiences usable, attractive and beautiful.

There will be new breakthroughs in synthetic biology, quantum technology and artificial intelligence, as explained by Robbert Dijkgraaf here in this room four weeks ago. But the genes, the atoms and the bits are not at a human scale; there are many design steps between the breakthroughs and their practical use in society by humans. To make sure that these design steps lead to good and meaningful results, the special powers of Industrial Design are indispensable.

I have great confidence in the strategic leadership of the dean, Prof. Lin-Lin Chen, and the talents of all colleagues and staff in the department.

What is the future of *my* design activities? Perhaps I have a few more years to do interesting projects and cooperate with the creative people I am already working with. I should let go of all the very serious and medical projects as they need more than what an aging emeritus can give. But I can play around with the meaningful combination I established, defined by art, fashion and mathematics. I found this niche, as you heard from my examples, while working in the department. Continuing to work in this niche, I am a regular guest of Fashion Tech Farm and of TU/e and I have my own brand, which I call LAURENTIUS LAB.

Figure 23. Infinity of the Artificial Skin designed by LABELEDBY, 3D printed on fabric.

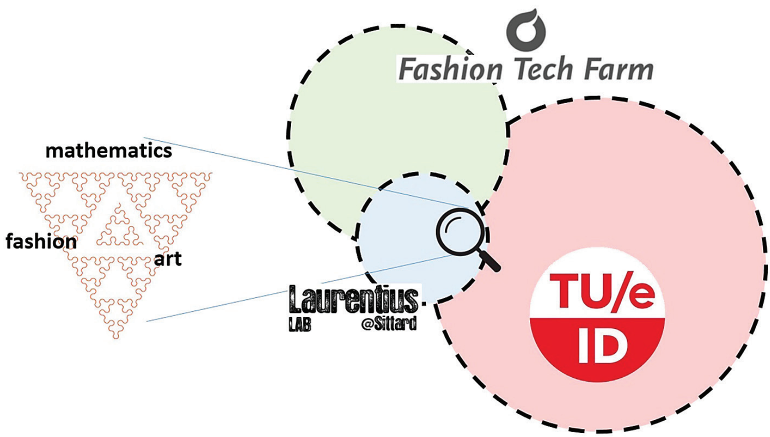

Figure 24. An ecosystem for my art-fashion-mathematics activities

In fact, after my formal retirement in December, I began working that way despite corona. As a very recent example of what can happen in this niche, I would like to show two experimental garments designed by Fabienne van der Weiden and Jessica Joosse of LABELEDBY in a project called Infinity of the Artificial Skin, work which is executed in the Fashion Tech Farm in Eindhoven. This is about innovation, 3D printing, craftsmanship and local production in the fashion system. In this project, I wrote code to generate Sierpiński curves, a kind of fractal which is morphed into fashionable patterns. In the background, there is in fact a third garment, a long dress in which the code itself is printed onto the garment. LABELEDBY embraces the view that mathematical coding, design and aesthetics are not opposites but that they can go hand in hand.

Thank you

I would like to thank many people. Although I did not turn out to be a capable manager, both Philips and TU/e were very friendly in adapting to what I could and could not do. In both organizations, I was lucky enough to meet people who encouraged me to develop myself, both as a person and as a scientist. Deans Jeu Schouten, Aarnout Brombacher and Lin-Lin Chen, managing directors Sabine van Gent and Jos Hermus, group leaders Jaap van der Heijden, Jos Baeten, Matthias Rauterberg, Jun Hu and Berry Eggen: thank you. All of the colleagues mentioned and not mentioned, the secretaries, the technical staff, the professors, the students, the TU/e board, the medical staff and the industrial partners: thank you. My teachers, Dr. Hans Jonkers, professors Kruseman Aretz and Jan Bergstra, thank you. I thank Danielle Roex, my trainer, my coach and my friend.

Also, it was not always easy for my family: this work needs so much time, it took a heavy toll on family life and I am afraid I neglected most of my friends. But I was lucky. My children – Mike, Katinka, Suzanne – you were always enthusiastic about what I did here at TU/e. And to my wife, Awaz: thank you for your love and your patience. And *thank you* to all my family, friends and colleagues present today, here in the auditorium and online, who took the effort to come here and celebrate this event with me.

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Curriculum Vitae

Prof.dr.ir. Loe Feijs was appointed part-time professor in the Department of Mathematics and Computer Science on June 23, 1994 and appointed full-time professor in the Department of Industrial Design on April 1, 2001 for the chair of "Industrial Design of Embedded Systems".

Loe Feijs was born in Sittard and studied Elektrotechniek at the TH in Eindhoven where he graduated in Information Theory in 1979. He joined Philips Telecommunication Industries in Hilversum, and in 1984 he moved to the Philips Natuurkundig Laboratorium in Eindhoven to research Formal Methods for software engineering. This was also the topic of his PhD thesis which he defended at TU/e in 1990. In 1994 Feijs was appointed part-time professor at TU/e in the formal methods group at the TU/e department of Mathematics and Computer Science. The work on software engineering ranged from formal specification towards software architecture and testing.
From 1998 to 2000 Feijs was scientific director of the Eindhoven Embedded Systems Institute, which later developed into ESI, now inside TNO. In 2000, when the TU/e decided to begin a new department Industrial Design with an innovative teaching model, Feijs was appointed vice-dean for five years with the task to develop the research program of the new department. Loe Feijs has supervised and co-supervised 26 PhD theses and is author and co-author of over 300 scientific publications.

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