It is a great pleasure to present the first edition of “PhD defences at the Faculty of Engineering Science”, giving you an overview of the innovative work and results obtained by 167 PhD students who successfully obtained their PhD degree from our Faculty of Engineering Science at KU Leuven in 2014.

This booklet shows the vast amount of research activities in all kinds of engineering science disciplines, from algorithms to hardware, from fundamental long-term research all the way up to practical implementations. Each in its own way makes a contribution to improve future products, processes and life on our planet.

We are happy and grateful that much of this research work could be performed thanks to the many supporting companies, research institutes or European and national research funding agencies such as ERC, FWO and IWT. We do sincerely hope that this document gives you an impression of the top research activities in the departments associated with our Faculty of Engineering Science and that it will inspire further research activities and collaborations.

Of course many thanks again to all the PhD researchers who contributed to this present collection. The Faculty of Engineering Science congratulates them with the obtained results and wishes them a successful professional career as innovative researchers or as frontline engineering practitioners.

Sincerely yours

Michiel Steyaert                      Jan Degrève
Dean                                 Chair Doctoral Committee
Faculty of Engineering Science       Faculty of Engineering Science
A probabilistic design methodology for building performance optimisation
An application to low-energy dwellings

Introduction / Objective
Building performance calculations often use deterministic simulations. Since many influencing parameters are generally inherently uncertain, this may lead to unreliable predictions of design impact and hence excessive deviations between design and reality. Such excessive deviations of building performances are usually undesirable: clients want guarantees that their investments have the desired impact. Hence, the overall aims of this research are (1) the development of a probabilistic robust design methodology to incorporate these uncertainties for building performance analysis and optimisation and (2) its illustrative application on the thermal design of comfortable and affordable robust low-energy dwellings.

Research Methodology
This thesis develops and illustrates a probabilistic design methodology for building performance optimisation as follows.
- The fundamentals of the global methodology (uncertainty quantification, sensitivity analysis, meta-modelling and multi-layered sampling) are explained based on references in literature and simple illustrations.
- The actual probabilistic design methodology is described in further details and the different steps are illustrated on a low-energy dwelling case study.
- An extensive illustration is provided in which design measures for affordable and comfortable robust low-energy dwellings are selected.

Results & Conclusions
The following results were obtained:
- A probabilistic methodology is developed to quantify performance spread and to use that in design, while taking uncertainties into account.
- Robust design principles are incorporated in a very intuitive way by the effectiveness $\varepsilon$ and robustness $R_P$ indicators.
- Design options that are (almost) optimal in all future situations can be selected to overcome potentially bad future performances.

Fig. 1 Monte Carlo principle for uncertainty quantification

Fig. 2 Effectiveness $\varepsilon$ and robustness $R_P$ indicators (left) applied to 13 824 design options for a low-energy dwelling (right). The overall optimum over all considered user types and economic scenarios is indicated in red.

Major publication
Mitigating Chemical Degradation of Magnesia-Chromite Bricks in Contact With a PbO Based Slag

Introduction / Objective
Vessel integrity is a vital aspect in the production of metals, determining the efficiency and feasibility of pyrometallurgical production processes. The linings in the reactors are made of refractory bricks, ceramic materials used for their excellent chemical and thermo-mechanical properties at the operational temperature. Nevertheless, failure of the lining occurs over time due to a combination of thermal, mechanical and chemical stresses, requiring a timely and costly replacement of the lining. Reducing the refractory wear would lead to less standstills and thus a more cost efficient production process. The objective of this work is to investigate the in-situ formation of phases by reaction with the slag as a method to limit the chemical refractory degradation caused by PbO-SiO$_2$ based slags.

Research Methodology
The chemical degradation of porous magnesia-chromite bricks by PbO-SiO$_2$ based slags is caused by (1) liquid infiltration into the porous refractory brick and (2) dissolution of MgO from the refractory into this liquid slag. The used slag composition is modified to mitigate each of these mechanisms separately. The effect of the modified slag on the chemical wear is determined using lab scale experiments after which the samples are analyzed using both a SEM microscope and EPMA-WDS system for chemical analyses.

Results & Conclusions
- By modifying the slag composition it is possible to form a protective spinel layer between the liquid and the refractory brick sample, slowing down the dissolution rate of the lining as the refractory components have to diffuse through this new spinel layer.
- For deep infiltration slags, the liquid composition, and thus the chemical corrosion, changes inside the refractory brick and the protective spinel layer no longer forms deeper in the sample.
- The formation of forsterite is used to seal off the open pores in the refractory. This has been tested for refractory brick under isothermal conditions and under a temperature gradient.
- The ability to seal off the pores before complete infiltration depends on the ratio between the forsterite growth rate and the infiltration rate of the liquid.

Major publication
Client-Side Web Security: Mitigating Threats against Web Sessions

Introduction / Objective
As the point of gravity of web applications shifts towards the client side, so does the focus of attackers. A wide variety of attacks threatens the user’s browsing experience on a daily basis, which results in losing control over accounts, suffering financial losses, becoming the victim of identity theft, etc. In this dissertation, we focus on the security of web sessions and session management mechanisms, which are crucial to any modern web application.

Research Methodology
By providing security solutions on the client-side, we can ensure that users are able to protect themselves, even in the presence of vulnerable web applications. The main challenge of this approach is achieving autonomy from the client-side, without explicit operational support from the web application. Crucial aspects of the developed countermeasures are:

- Formally-verified security policy ensures effectiveness of the countermeasure
- Prototype-driven approach demonstrates applicability and supports extensive evaluation
- Autonomous mitigation techniques carefully balance usability and security

Results & Conclusions
In this dissertation, we have conceptualized and implemented four prototypes that counter a specific threat against web sessions and session management mechanisms:

- **CsFire** autonomously protects the user against cross-site request forgery (CSRF) attacks. CsFire is publicly available for Firefox and Chrome, and used by thousands of users on a daily basis.
- **Serene** autonomously prevents session fixation attacks from within the browser.
- **SecSess** is an end-to-end approach for secure session management on the Web. SecSess preserves the same flow of requests and responses as current session management mechanisms.
- **TabShots** autonomously detects tabnabbing attacks, a specific variation on a phishing attack.

We have also performed a security analysis of 13 next-generation Web standards for the European Network and Information Security Agency (ENISA), uncovering several threats and ambiguous features.

**Major publication**
INTRODUCTION / OBJECTIVE

The main research objective is to decipher the role of both water conditions and water conflicts in the interplay of the rural settlements and productive landscapes that constitute the Chia-Nan Plain, Taiwan. Consequently, the research considers Taiwan’s (r)urban design from three main perspectives: (1) rural water management; (2) vulnerable productive landscapes; and (3) fragmented peri-urban settlements. The research focuses on the challenges regarding the environmental and economic transformations of the rural areas in the Chia-Nan Plain.

RESEARCH METHODOLOGY

The research applies descriptive and interpretive mapping methodologies to review the patterns of interactions between cultivation behaviours and rural settlement morphologies in the Chia-Nan Plain. The research furthermore discusses the crucial logics behind the formation of settlements in this region as a result of rural-urban interactions. Hence, three layers (water, productive landscape, and scales of production) in the productive surface, that are critical to the spatial environment, are highlighted in the research. The research employs two case studies to discuss two different water-related productive landscapes (paddy and aquatic landscapes), and explores how innovative urban design propositions and water management measures in these territories can be adapted to benefit the environment.

The two case studies are initiated by historical analysis and the deciphering of contemporary projects, via-a-vis layered narratives and contested territories of specific sites.

RESULTS & CONCLUSIONS

In short, the research uses “research by design”, and it explores spatial strategies that aim to have the potential to meet the changes of contemporary society and steer necessary environmental transformations.

MAJOR PUBLICATION

The Effect of Medium Structure Complexity on Microbial Growth in Food Biopolymer Systems: Combining a macro- and macro-scale approach

Introduction / Objective

In order to predict microbial growth in food products, the response of microorganisms on environmental factors encountered in food must be investigated. In this research, the effect of the factor food structure, induced by the presence of food biopolymers, on bacterial and yeast growth was investigated. As food biopolymers are mostly present in mixtures that often show phase separation, the phase-separating gelatin/dextran mixture was used. Micro-scale and macro-scale, i.e., population behavior was studied.

Research Methodology

Phase-separating mixtures of different ratios of gelatin (G) and dextran (D) were studied. The resulting microstructure and the location and morphology of *E. coli* and *S. cerevisiae* colonies was observed with confocal laser scanning microscopy.

The macro-scale growth dynamics in the mixtures were obtained by performing growth experiments and determining the microbial load via plate counting. Results were compared with those obtained in broth and in singular gelatin or dextran systems. Experiments were performed with and without salt to test the effect on macro- and micro-scale behavior.

Results & Conclusions

- Regardless the microstructure or the addition of salt, *E. coli* and *S. cerevisiae* cells were always present in the dextran phase (Figure 1). The combination of electronegativity and hydrophilicity favors the distributions of the cells in the dextran phase.
- Biopolymers can interact with the added salt, leading to lower apparent salt concentrations and hence a lower stress level. This can lead to an enhanced growth behavior compared to growth in broth.
- To predict microbial behavior in a biphasic biopolymer mixture, using results of experiments performed in liquid or in the preferential phase, i.e., dextran, alone are not sufficient, especially when a stressing factor is present (Figure 2).
- Medium composition in terms of biopolymers, i.e., gelling agents, and the resulting medium structure complexity cannot be ignored when predicting microbial growth behavior.

Major publication

Introduction / Objective
Risk prediction models for diagnostic or prognostic outcomes are useful tools for clinical decision support. Most commonly, a dichotomous outcome (e.g. a benign or malignant tumor) is considered. Especially in diagnostic problems, however, a differential diagnosis often includes more levels than categorization of subjects as ‘diseased’ versus ‘non-diseased’ (e.g. a benign, borderline or invasive tumor).

Methods for updating existing risk prediction models have already been suggested for dichotomous models but do not yet exist for multinomial models. Closely related, the aspect of calibration of multinomial risk prediction models, i.e. how reliable are the predicted risks, has not been studied extensively. Therefore, this PhD aims to extend calibration statistics, calibration plots as well as updating techniques to prediction models for nominal outcomes.

Research Methodology
- Calibration tools for dichotomous outcomes were extended towards polytomous outcomes modeled via a multinomial logistic regression model.
- A non-parametric or generic recalibration framework, using vector splines, was proposed to visualize and quantify the lack of calibration for multiclass risk prediction models irrespective of the adopted algorithm.
- Updating methods to recalibrate, revise or extend risk prediction models for dichotomous outcomes were adapted to polytomous outcomes based on multinomial logistic regression.
- Case studies concerning the diagnosis of ovarian tumors, the accurate prediction of resected residual mass of testicular cancer and the prediction of the outcome of pregnancies of unknown location were considered for illustration.

Results & Conclusions
- Calibration plots visualize the agreement between predicted probabilities and observed proportions for each outcome category.
- Calibration measures, such as calibration intercept, calibration slopes and estimated calibration index (ECI) quantify the lack of calibration and are easier for comparing but less informative and interpretable.
- Updating methods for dichotomous logistic regression are successfully adapted to multinomial logistic regression models.

Major publication
Natural gas in the energy transition
Technical challenges and opportunities of natural gas and its infrastructure as a flexibility-providing resource

Introduction / Objective
In the light of the energy transition towards a more sustainable energy economy, the energy system faces radical changes. The natural gas system can play an important role in the energy transition as it is robust and reliable, natural gas can be used for a flexible backup of intermittent renewable energy generation, the gas network allows a defossilisation through the injection of green gases and the gas network can even act as a buffer for superfluous renewable electricity converted to gas through the “power to gas” conversion.

However, these changes can bring challenges for the natural gas system which can be of, e.g., technical, economical, operational and/or organisational nature. The challenges for the gas system should be studied carefully in order to safeguard the reliability and efficiency of the gas system. The possible changes studied here are a massive introduction of gas-fired small-scale cogeneration units and “power to gas” conversion. The thesis focusses on technical operational effects, but also reflections towards economical effects are made.

The energy transition does not only lead to challenges, it can also provide new opportunities for the gas system in that it can be further optimised. An opportunity studied here is active gas demand response, aimed at a more efficient use of gas transport capacity and a more optimal use of flexibility for gas balancing.

Research Methodology
The main methodology is operational research with rule-based and techno-economic optimisation models.

Results & Conclusions
The most important findings of the research are:
- The impact of small-scale cogeneration units on the gas demand and network is generally limited, but this depends on the reference loading state of the gas distribution network. The capacity of the thermal storage that accompanies the cogeneration units is important for the resulting gas demand profile. Larger storage capacities lead to lower gas demand peaks.
- The “power to gas” conversion transfers flexibility and capacity related issues from the electricity network to the gas network, originating from intermittent renewable electricity generation. While the power to gas conversion is an interesting option to make use of superfluous renewable electricity, it may increase gas costs.
- There is an interesting potential for active gas demand response to “reshape” gas demand profiles to make better use of transport capacity and to optimise gas flexibility usage for gas network balancing. Thermal storage can be used to decouple the gas demand from the heat demand. The most interesting option is to combine the use of thermal storage tanks between active gas demand response and other thermal systems, such as solar thermal collectors.
Interfacial dynamics of phospholipids and lung surfactant

Introduction / Objective

Lung surfactant lines the surface of the alveoli and prevents their collapse by lowering surface tension. Prematurely born baby’s lungs often lack surfactant, causing possible fatal breathing problems. Instillation of a few ml of natural surfactant derived from animal lungs saves many lives. Although many synthetic surfactants have been developed with a similar surface tension as natural surfactants, none of them is as efficient. This indicates that there is more to lung surfactants than just surface tension. As a result, in this work the dynamics of natural lung surfactants and their main phospholipid, DPPC, are investigated to get a more fundamental knowledge about the real function of the lung’s surfactant.

Research Methodology

- Mimic surface tension during breathing with a natural lung surfactant extract in a Langmuir trough.
- Characterization of the interfacial shear rheology of DPPC, HSA and 3 different natural lung surfactant extracts (Survanta, Curosurf and Infasurf)
- Quantify the effect of the interfacial rheology on thin film mobility by observing a drainage flow by interferometry both on a plain geometry and covered with lung epithelial cells.

Results & Conclusions

The surface tension of Curosurf, a natural lung surfactant extract, appears to be much lower in the alveoli than the surfactant’s equilibrium surface tension. This is caused by slow desorption and fast adsorption kinetics combined with a key feature of human breathing, sighing. The repeated large expansion-compression maintains a metastable state.

As the surface tension in the upper airways is much larger than in the alveoli, a natural driving force for Marangoni flow is present throughout the lung. The interfacial viscosity of the most successful lung surfactant replacements is very low and drainage experiments indicate that even small surface tension gradients can have a significant effect on lung surfactant flow.

From the results it can be concluded that lung surfactant is a self-regulating system. Due to significant surface tension gradients in the lung and the low interfacial viscosity, a slow Marangoni flow can act as the natural removal mechanism of the surfactant that is produced non-stop. Additionally, if this removal is too large and the low surface tension is at risk, the driving force for Marangoni flow will disappear, protecting the low surface tension condition which is crucial for breathing.

Major publications

E. Hermans and J. Vermant, *Deep breaths and metastability of pulmonary surfactant*, PLOS ONE, (Submitted)
Datamining of Imaging Mass Spectrometry Data for Biomedical Tissue Exploration

Introduction / Objective

Imaging Mass Spectrometry (IMS) is a powerful molecular imaging technology that enables the simultaneous analysis of hundreds to thousands of different biomolecules throughout a tissue section. This makes it an immensely valuable technology for explorative research, however, an IMS experiment commonly leads to several gigabytes of complex data for a single examined tissue slice. In this thesis we therefore focus on the development of the datamining methods necessary to explore these data.

Research Methodology

We concentrate on three computational challenges:

- Feature selection and dimensionality reduction of IMS data using the Discrete Wavelet Transform (DWT) as a dimensionality reduction tool. We further improve this analysis through incorporation of spatial information.
- Differential analysis of IMS data from multiple tissue slices using Group Independent Component Analysis (GICA), which allows for an in-depth comparison of a large number of IMS datasets.
- Data fusion of IMS data with an anatomical atlas, the Allen Mouse Brain Atlas, which allows for guided exploration of the complex IMS data.

Results & Conclusions

We show that computational methods can greatly facilitate the processing and exploration of IMS data:

- Incorporation of spatial information into the DWT-based feature selection process allows for improved conservation of biologically relevant features.
- GICA allows for efficient comparison of IMS data from different tissue slices, allowing retrieval of differential biomolecular patterns that are expressed in biologically relevant areas for the disease under study.
- The explicit linking of ion abundance with curated anatomical labels enables a more exhaustive investigation of the roles of anatomical structures and aids in interpretation of the IMS data.

Major publication

Introduction / Objective

Molecular transport phenomena underlie many of the processes that regulate cell behavior during skeletal growth and development. Biomimetic tissue engineering (TE) research, aiming for the repair of skeletal tissue damage by recapitulation of embryonic tissue development, therefore strongly depends on imaging technologies for transport quantification. Gradually, these tools are becoming integrated in the field, but the need for novel technologies remains high. In this PhD research quantitative luminescence-based techniques, microbead technology, and mathematical modeling were combined with the aim of better understanding mass transport phenomena in TE constructs and a central focus on the role of oxygen transport.

Research Methodology

Three main technologies were applied in this research project to study mass transport phenomena in TE constructs:

- Photoluminescent oxygen sensitive microbeads (OSB)
- Fluorescence recovery after photobleaching (FRAP)
- Quantitative bioluminescence-based reporter cell imaging (qBLI)

A methodology was developed for integration of the OSB in cell spheroids, i.e. mimics of skeletal cell condensations. A strategy was defined to measure oxygen concentrations in turbid constructs. FRAP measurements were performed in TE constructs making use of surrogate tracer fluorophores. Mathematical modeling was used to quantitatively describe the emitted photon flux from bioluminescent reporter cells.

Results & Conclusions

The microbead oxygen sensors were successfully calibrated in normal and turbid media, showing their applicability for a wide range of experimental setups. The use of an avidin-biotin-based binding method enabled the robust, non-interfering and non-invasive integration of these microsensors within a cell spheroid. Measurements of oxygen tension within chondrogenic cell spheroids indicated the presence of a peripheral region that had a beneficial effect on cartilaginous matrix synthesis.

Presence of cells within a TE construct had a significant influence on solute transport, as quantified from FRAP analysis and confirmed by release-kinetics experiments. Established oxygen concentration gradients within TE constructs clearly interfered with the emitted bioluminescence signals. Using a model-based approach, oxygen-independent bioluminescent intensities could be obtained that were shown to be a more reliable and accurate representation of the active reporter cell population within the construct. Mass transport phenomena therefore not only control skeletal development, but also strongly influence bioluminescent based assays.

Major publication

Security Primitives for Protected-Module Architectures Based on Program-Counter-Based Memory Access Control

Introduction / Objective
Our society increasingly depends on computing devices. Customers rely on laptops and mobile devices to access security sensitive applications such as online banking. Security of computing devices is paramount and various security measures have been developed that raise the bar significantly for attackers. However, vulnerabilities in such systems still exist and are frequently exploited successfully. In this thesis, we developed a new approach where a fixed set of security primitives that can be used to build secure software module:

*A program-counter based access control mechanism, providing strong isolation between the module and a possibly malware-infected memory
*A capability-mechanism enabling modules to restrict access to their interface
*A fast and practical state-continuity algo. enabling modules to store their state securely on disk. Even in the event of a crash or loss of power, modules can resume their last state. Attackers cannot provide stale states as being fresh nor can infer any information when the system crashes at any point in time.

Research Methodology
The developed program-counter-based access control mechanism formed the basis for many research results:

*Fides: A hypervisor-based implementation showed that the isolation mechanism can be implemented on commodity x86 architectures
*Salus: A kernel-based implementation showed that the access control mechanism can also be applied to isolation potential attack vectors from likely attack targets
*Sancus: A hardware implementation showed that the same access control mechanism can also be implemented efficiently on low-end processors

Results & Conclusions
Relying on a fixed set of security primitives can significantly increase the security of a system. Intel announced recently that it will implement a similar mechanism in future generation CPUs

Major publication
Introduction / Objective
While understanding natural language is easy for humans, it is complex for computers. The main reasons for this can be found in the structural nature and the inherent ambiguity of natural language. Correctly interpreting language therefore requires one to take into account the necessary context. In order to perform natural language understanding by means of machine learning techniques, an appropriate representation is required that takes into account this relational information and integrates the necessary background knowledge into the learning process.

Research Methodology
Statistical relational learning (SRL) is well-suited to represent this structural information, and to incorporate the necessary context and background knowledge for natural language understanding. Furthermore, its inherent probabilistic nature offers opportunities to deal with linguistic ambiguity. This thesis investigates the promise of SRL for natural language processing (NLP) and provides evidence for the utility of this approach.

Results & Conclusions
From the obtained results, we can conclude that the distinguishing characteristics of SRL offer several advantages that prove particularly useful for natural language learning, namely:

- Its relational representation proves to be well-suited to represent the structural and relational features that are important for current (semantic) NLP tasks;
- the high-level declarative specification of the domain offers an increased expressivity of the domain model and interpretability of the results;
- the declarative approach also offers the opportunity to encode additional background knowledge;
- its inherent probabilistic nature offers opportunities to deal with linguistic ambiguity.

Major publication
Cross-border cost allocation: Application of beneficiary pays principle to electricity transmission investments

Introduction / Objective
- Massive electricity transmission investments needed to achieve the energy and climate policy objectives of the European Union.
- Key challenge: The alignment of national and European interests in investments
- New developments: Introduction of Projects of Common Interest (PCI) and innovative offshore grid designs
- Regulatory trends: Adoption of the beneficiary pays principle (BPP) to solve cross-border cost allocation problems
- Research questions (a) suitability of existing cost allocation methods to apply BPP (b) congestion revenue as part of the cost allocation solution

Research Methodology
- Welfare impact analysis approach
- Transmission investment & economic dispatch models
- Cost allocation frameworks to apply BPP
- PCIs and offshore wind interconnection projects simulated to test proposed cost allocation framework.

Results & Conclusions
- Existing cost allocation methods leave open questions regarding compensation for welfare loss & the benefit indicators that should be used to allocate investment costs. This calls for a framework to apply the BPP to cross-border electricity transmission investments.
- Using congestion revenue in a compensation logic increases the likelihood of realizing investments and allows for an ex-post adjustment to the ex-ante cost allocation.

Major publication
S.Y Hadush, C. De Jognhe, R. Belmans (2014). The effect of welfare distribution and cost allocation on offshore grid design. IEEE transactions on sustainable energy: Special issue on regulatory schemes for large scale RES integration (Accepted for publication)
Active control of turbulent axisymmetric jets using zero-net-mass-flux actuation

Introduction / Objective
A topic of major interest in jet-flow control is increasing the mixing rate between the injected fluid and stagnant ambient fluid around the jet, with, e.g., possible applications towards cleaner combustion with less carbon emissions, or more efficient pollutant and waste-water discharge. An effective way to enhance mixing is using unsteady actuation with zero-net-mass-flux (ZNMF) actuators. The main challenge for the applicability of these actuators in jet flow control is the intricate interaction of the control means with the main jet flow. The understanding on control effects resulting from this interaction is still very limited. Therefore, this study aims to increase the understanding of basic control mechanisms with ZNMF actuators, and explores the optimal control configurations for better mixing performance.

Research Methodology
A numerical flow control and optimization framework is developed in the open-source CFD toolbox OpenFOAM, and ZNMF-actuated axisymmetric jets are extensively studied using high-fidelity flow simulations on high-performance clusters of Flemish Supercomputer Centre (VSC). Thanks to the efficient use of high-performance computing, we carried out:

- a very detailed analysis of underlying flow phenomena using three-dimensional visualizations and flow statistics.
- a novel optimal control study that employs an adjoint method in combination with high-fidelity simulations in a generic flow code.

Results & Conclusions
- Control mechanisms in ZNMF actuation are identified.
- The frequency regime for efficient large-scale mixing is found.
- The frequency regime that suppresses jet turbulence is found.
- Benefits of multi-frequency actuation in overall mixing performance are demonstrated.
- New scientific challenges in optimal control of turbulent flows are revealed.

Major publication
Optical characterization and modeling of bulk scattering and luminescence

Introduction
In lighting, display, and photovoltaic applications, bulk scattering and luminescent materials are frequently used. Bulk scattering materials are used as diffusers to create a homogeneous source area or a specific radiation distribution. Luminescent materials are used to convert short wavelength radiation to longer wavelengths and may also exhibit bulk scattering. The light propagation through these materials is described by the radiative transfer equation (RTE), given in Eq. 1. In this doctoral research, the effect of luminescent down-shifting layers to enhance solar cell efficiency was investigated.

Research Methodology

Methods to solve the RTE
- Ray tracing: probabilistic method, any geometry, time consuming.
- Adding-doubling (AD): numerical method, layered geometries, fast.

Determination of optical properties (parameters RTE)
- Absorption and scattering: absorption coefficient ($\mu_a$), scattering coefficient ($\mu_s$), scattering phase function ($\phi(s,s')$)
- Luminescence: emission spectrum ($w_M$) and quantum yield ($QY$)

Application: luminescent down-shifting (LDS) for solar applications
- Solar cells have typically low efficiency at short wavelengths (Fig. 1)
- Converting short wavelengths to longer wavelengths by applying LDS layer
- Screening and optimization of LDS layers requires adequate modeling tools

Results & Conclusions
- Determination of absorption, scattering and luminescent properties of LDS sheet and reflectance and internal quantum efficiency (IQE) of solar cell
- Prediction of the external quantum efficiency (EQE) of the module using AD method
- Measurement of EQE module
- Validation of AD method as modeling tool (Fig. 2): NRSMD < 0.02.

Major publication
**3D phase-field simulations of sintering and coarsening in polycrystalline multi-phase materials**

**Introduction / Objective**

The microstructure of many polycrystalline materials consists of more than one phase. Controlling the microstructural evolution during processing of multiphase materials is a huge challenge due to the large number of variables that must be understood and controlled. In this PhD work, the effect of interfacial energy, volume fraction and diffusional mobility in each phase on the evolving microstructure of multi-phase materials is studied using a 3-D phase-field model.

**Research Methodology**

An appropriate multi-phase multi-component phase-field model was developed. The accuracy of the developed model was verified by implementing the model for small scale systems in 2D using MATLAB. In order to perform 3D large scale simulations, an advanced implementation method called Bounding-box algorithm was developed using C++ object-oriented programming language. The advanced implementation offered faster calculation and lower storage requirement. The developed software was used to study the effect of interfacial energy and diffusivity of elements on the evolving microstructures in three solid phase systems and the effect of solid volume fraction and interfacial energy in two phase solid-liquid systems. In order to verify the simulation results, the microstructural features of a liquid phase sintered NbC-Co cermet were measured in 2D and 3D using the 2D and 3D Electron Backscattered Diffraction method. The obtained results were compared with the simulation results.

**Results & Conclusions**

For three solid phase systems: depending on the interface energy between grains of the same phase and grains of dissimilar phases, different phase arrangements resulted. For all cases, a growth rate exponent of $n = 3$ was measured implying long range diffusion controlled growth. The growth rate of each phase was found to be a function of the diffusivity of elements and phase arrangement. For two phase solid-liquid systems: the growth rate, shape and number of particle-particle contacts were found to be a function of the interface energy between solid particles and liquid phase. With increasing particle-particle contacts, the growth rate exponent decreased indicating a change in the coarsening mechanism from particle coarsening to grain growth. The mean dihedral angle was measured using contiguity and connectivity measurements. The measured microstructural features from the EBSD measurements agreed well with the simulation results.

**Major publication**

Robustness is a key performance indicator to evaluate railway systems. Therefore, the question is raised to develop principles and techniques to make a railway system more robust. Inspired by the observation that large and complex station areas are the main sources of delays, the main objective is to improve the robustness of a railway system in these bottlenecks.

Research Methodology

First, the essence of what robustness is about is detected. A railway system is defined to be robust against daily occurring, small disturbances when it optimizes the travel time in practice of all passengers. To improve the robustness, the problem is split in three problems that are solved step by step: the selection of a route for each train, the timetabling that determines the order of trains and the departure and arrival times, and the platform allocation problem. An internal timetabling phase is added to avoid conflicts and exploit the potential of changes.

Simulation is used to evaluate the obtained solution. It is shown that the robustness of the system is improved with a considerable reduction of delays as a consequence. Other results are a reduced interaction between trains in switch zones, better spread arrival times, and more balanced platform occupations.

All together, this enables a much more efficient use of the limited capacity in the various considered bottlenecks and under varying circumstances.

Major publication

Performance of NiTi Shape Memory Alloys after Various Heat Treatments

Introduction / Objective
NiTi shape memory alloys, which show shape memory effect and superelasticity, are attracting increasing interest for applications. The transformation behavior and mechanical properties of NiTi alloys, which are essential factors affecting the practical applications, are susceptible to the microstructure. The objective of this work is to modify the microstructure using heat treatments, and thus to tailor the performance of NiTi alloys.

Research Methodology
Various heat treatments (e.g., aging treatment, post-deformation annealing treatment) were conducted to modify the microstructure (e.g., grain size, precipitates) of NiTi alloys. Electron back-scattered diffraction (EBSD) and transmission electron microscopy (TEM) were used to characterize the microstructure. The transformation behavior and mechanical properties were characterized using a differential scanning calorimeter (DSC) and a dynamic mechanical analyzer (DMA), respectively.

Results & Conclusions
- The grain size can indeed affect the aging microstructure and related transformation behavior. The frequently observed multi-stage martensitic transformation in aged coarse-grained Ni-rich NiTi alloys (Fig. 1a) is absent in the samples with small grains (Fig. 1b).
- Inspired by the above findings, a unique microstructure with small grains and homogeneously distributed nanoscaled Ni₄Ti₃ precipitates was obtained (Fig. 2a).
- The temperature-induced B19' martensite transformation is significantly suppressed by this unique microstructure, so that only the A↔R transformation can be detected (Fig. 2b).
- The A↔R transformation with improved functional properties (Fig. 2c), controllable transformation temperatures and large working windows was obtained.
- The improvement of functional properties associated with B19' martensite transformation was also achieved (Fig. 2d).

Major publication
The Status of Stone. Urban Identity and the Typological Discourse of Private Houses in the Antwerp City during the Long Sixteenth Century

Objective

Private urban housing in 16th century Antwerp is studied typologically, not by documenting features or constructive characteristics, but by specifically concentrating on functional aspects in a broad sense. Analysing structures from this viewpoint allows to understand the initial use and significance of types in relation to social identity and status and the discourse of a community. Function typology proposes a different approach, which, integrated with the currently applied morphological system, enables a more valuable treatment of historical houses and town structures.

Research Method

To analyze and reduce different structures to their essential characteristics, a multidisciplinary method was developed, processing a great number of archaeological and archival data and combining them with insight in construction. Each type is investigated by a number of case studies, establishing their commercial and domestic functions, identifying commissioners and users, their social ranking and status. Novel in this approach is, that instead of only considering the material and visual components, it searches for the contents and social significance.

Results & Conclusions

- The proposed ranking into four basic types reflects the main social groups of the Antwerp cosmopolitan society: cottages, shopkeeper houses, merchant houses, and elite residences, showing variations on the basic pattern.
- Antwerp types were persistent, perfectly answering to the needs of the citizenry: despite various opportunities and circumstances over the long and eventful century, they have not changed, nor have new types emerged.
- Only consequently to the massive exodus around 1585, the surplus of houses has introduced a typological shift.
- As the establishment of a glossary indicates, in the highest categories, differentiation in the use of space and its nomenclature increased, the discourse of which served social status, the same way as many visible features did.
- Treatises or Mediterranean foreigners have not affected the traditional spatial organization. Immigrants adopted the local living pattern.
- Principally, the proposed approach and method are applicable to any urban context.

Major publication

RECONFIGURATION OF ELECTRICITY DISTRIBUTION GRIDS WITH DISTRIBUTED ENERGY RESOURCES

Introduction / Objective

Renewable energy sources such as solar energy, wind energy etc. are environmentally friendly due to low carbon emissions during generation. These resources are distributed in nature and hence are called distributed energy resources (DERs). The presence of DERs is the characteristic feature that differentiates the present & the future electricity distribution grid from the traditional one. With the intervention of DERs, the unidirectional power flow has become bidirectional. This impacts several characteristics of the distribution system. The inherent uncertainty of the DERs is yet another challenge, making the assessment of DER power output difficult. This will affect the power loss in the grid and will also cause power quality issues like over voltage.

Research Methodology

This PhD research uses the concept of grid reconfiguration (GR) to minimize power losses and ensure power quality in an electricity distribution grid while taking into account DER uncertainty and switching cost

• GR is defined as altering the topological structure of distribution feeders by changing the open/closed states of sectionalizers and tie switches
• GR is formulated as an optimization problem

Major contributions of the thesis:

• Identifies the various factors that affect the benefits of GR
• Identifies & accounts for the effect of photovoltaic uncertainty in GR
• Develops three reconfiguration methods based on the concepts of scenario analysis and receding horizon control
• Develops a general methodology to determine the period of reconfiguration (PRC) in the presence of DERs

Results & Conclusions

• GR can defer grid investments
• The choice of PRC calls for a comparison of switching cost versus benefits of GR
• A longer PRC can be adopted if the network is less sensitive to a change in the DG output
• A shorter PRC has to be adopted if the forecast is inaccurate or even in the presence of accurate forecast if the network is sensitive to a change in the DG output

Major publication

1. P. Chittur Ramaswamy and G. Deconinck “Impact of varying photovoltaic penetration on minimum loss reconfiguration,” IEEE IECON, Vienna, Austria, Nov.11-13, 2013 (Won the best paper award of the session)
2. P. Chittur Ramaswamy, J.R. Pillai and G. Deconinck “Scenario analysis to account for photovoltaic generation uncertainty in distribution grid reconfiguration,” IEEE IECON, Vienna, Austria, Nov.11-13, 2013 (Won the best paper award of the session)
Atlass as Design / Designing Atlases
Two Cartographic Explorations of Implicit Urbanisms in Southwest Flanders

Challenging the Spatial Imaginations, Questioning the Plan Repertory
This research explores the format of the atlas and works on the expansion of its agency. Increasing problematics –
environmental, social as well as cultural– accompanying the global condition of planetary urbanization, are at the stake of it. Expanding cartographic formats is a way to increase the scope of our spatial imagination, which in turn challenges the way urbanists, planners and landscape architects look at the landscape, the way they conceptualize space, and consequently also the way they act on the territory.

Research by, with and through Mapping
Two extended atlases have been developed from start to end (Cattoor and De Meulder, 2011; Cattoor, 2013). Both are involved in the exploration of the territory as much as in the exploration of the format of the atlas itself. Each of both atlases is an exercise in de- and recomposing: decomposing the landscape into various maps and then recomposing these maps into a meaningful atlas structure, into an atlas whose format makes that it is more than the sum of its parts.

Both atlases, Figures Infrastructures (metamap above) and Chronologies of a (Sub)urbanized territory (metamap on the right) are re-cartographies of the Kortrijk Region in the south of West Flanders. This area can be considered emblematic of the dispersed urbanization of Flanders. It is characterized by the simultaneous presence of multiple spatial systems that overlap and, more often than not, conflict. Figures Infrastructures and Chronologies of a (sub)urbanized territory explore a selection of these spatial patterns that mostly remain implicit and reimagine them as territorial figures. The focus of the work is in this respect on gaining insights into complex and dynamic spatial structures that cross different scale levels, affect large territories, and that unfold over the course of extended time periods.

Major publications
Decomposition Approaches for Optimization Problems

Introduction / Objective
This dissertation encompasses the development of decomposition approaches for both real-world and fundamental optimization problems. Many optimization problems comprise of multiple interconnected subproblems, often rendering them too large or too complicated to solve as a single integral problem. Decomposition approaches are required to deal with these problems efficiently. By decomposing a problem into multiple subproblems, efficient dedicated procedures can be employed to solve the subproblems independently. Furthermore, often strong bounds on the optimal solutions can be derived by exploiting structures in the underlying subproblems.

Research Methodology
This work primarily focuses on analyzing and identifying problem components to decompose a problem into multiple, easier-to-solve, subproblems. The decompositions are realized through mathematical techniques such as Column Generation and Benders decomposition, thereby relying on Integer Programming, Constraint Programming, heuristic and combinatorial procedures to solve the resulting subproblems. Key aspects of a decomposition:

- Efficiency
- Robustness
- Scalability
- Quality assurance (bounds)

Results & Conclusions
Decomposition approaches have been developed for a variety of routing and scheduling problems, including problems related to school bus routing and concrete delivery, as well as variations on the Traveling Salesman Problem. For several of these problems, our decomposition approaches outperform alternative state-of-the-art methods. Furthermore, by decomposing a problem, techniques from various interdisciplinary domains have been combined into a single integrated solution approach. Correlations between the problems under consideration as well as the proposed solution methodologies provide insight as to the applicability, limitations and the intuition behind the various techniques.

Major publication
Kinalbe, Trick, A Logic Based Benders’ Approach to the Concrete Delivery Problem. CPAIOR 2014
Kinalbe, Wauters, Vanden Berghe, G. The concrete Delivery Problem, Computers & OR, 2014
Optimal Heat Sink Design for Liquid Cooling of Electronics

Introduction / Objective
Due to continued miniaturization and integration of transistors, the heat dissipation rate in computer chips has surpassed the limits of air-cooled heat sinks. Liquid cooling with microchannels is a candidate solution. The design of cooling channels in micro heat sinks is a challenging task due to complex physical interactions and the multiscale nature of the problem. Therefore, the objective of this thesis is the development of numerical optimization methods for the design of liquid-cooled micro heat sinks.

Research Methodology
Two approaches have been investigated:

- Shape optimization of parallel microchannels
- Topology optimization of the full heat sink

Results & Conclusions
Microchannel shape optimization has been performed by combining an analytical heat sink model with numerical optimization. The results (right) show a reduced thermal resistance or elimination of temperature variability.

Heat sink topology optimization is performed using a CFD model with adjoint calculation of sensitivity. Results display a network of branched cooling channels (below). Thermal resistance reductions up to 50% are achieved.

Major publication
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Parallel Algorithms for Optimization of Dynamic Systems in Real-Time

Introduction & Motivation
We target optimization-based methods for control and estimation of dynamic systems, with a focus on problems with long prediction or estimation horizons, and both linear and nonlinear dynamics. Such problems are of great practical interest for a variety of reasons including stability guarantees and control or estimation performance. Particularly in the pursuit of economic objectives their formulation can be a key necessity. We develop algorithms that exploit the inherent sparsity of these problems with a focus on concurrency of the major computational steps, so as to ensure parallelizability on current and future computational architectures.

Developed Methods
We propose a hierarchical re-linearization procedure for nonlinear model predictive control (MPC) that bridges the gap between linear and nonlinear MPC. We subsequently analyze sparsity-exploiting solution algorithms for the resulting structured quadratic programming problems (QPs), resulting in an improved, reduced-complexity condensing algorithm and a novel, dual-decomposition based semismooth Newton strategy that combines sparsity-exploitation characteristics from interior-point methods with warmstarting capabilities from active-set methods. We propose tailored numerical implementation of the algorithm that pushes the state-of-the-art in QP solution approaches by factors of more than ten in computation time on a variety of benchmark problems and examine generalizations of this dual Newton idea to distributed quadratic programming and to Nonlinear programming.

Contributions
We summarize important contributions of this thesis in the following:
- A hierarchical update scheme for nonlinear MPC
- A structure-exploiting, parallelizable active-set method for QP
- An efficient open-source QP solver for MPC and MHE
- A structure-exploiting, parallelizable nonlinear programming method
- A real-time feasible high-fidelity nonlinear MPC for autonomous driving

Steps of the dual Newton strategy in the space of the multipliers of the coupling constraints

Computation time comparison of the dual Newton approach with the established condensing approach in nonlinear MPC
Methods and Algorithms for Scalable Systematic Biologically-Inspired Design

Introduction / Objective
Biologically-Inspired Design is popular because of the proven performance of nature's solutions, the potential for developing more sustainable products and the potential for discovering leapfrog innovations. The state-of-the-art in methods and tools to support Systematic Biologically-Inspired Design struggles with scalability, meaning that only a fraction of human's knowledge about nature can be leveraged. In order to overcome this common challenge, the need for interactive work for each biological strategy during database expansion requires elimination.

Research Methodology
Three supporting algorithms are proposed that form essential building blocks for the development of Scalable Systematic Biologically-Inspired Design (SSBID) approaches:

- A webcrawler that autonomously collects biological strategies from the Internet
- Mention and focus organism detection to determine which organism is the focus of a biological paper
- Multi-word product identification to identify product descriptions in technical patents

Two approaches for Scalable Systematic Biologically-Inspired Design are proposed:

- Scaled AskNature: scaling a popular existing approach
- SEABIRD: a new scalable approach

Results & Conclusions
- The feasibility of automatically populating the existing Biomimicry Taxonomy with natural-language biological strategies was demonstrated for both AskNature's reference strategies used as golden key and for strategies collected by a webcrawler.
- SEABIRD (Scalable sEarch for systemAtic Biologically-InspiRed Design) is a new SSBID approach that leverages both a patent and biological paper database to link products and patents (problems) to organisms and biological strategies (solutions).

Major publications
Ultra-Low-Voltage Design of Energy-Efficient Digital Circuits

Introduction / Objective
Nowadays, energy-efficiency is becoming more and more a decisive parameter for digital systems, driven by the ever increasing number of portable applications. Mobile phones are an obvious example, but many other portable electronic devices are emerging which have less stringent speed requirements but even more critical energy requirements. Since their stand-alone time is dependent on the fixed available energy budget, research towards significant improvements in energy consumption per operation is paramount. Operating digital systems at extremely low supply voltages can result in significant energy savings and is therefore the focus of this PhD.

Research Methodology
However, ultra-low-voltage circuits pose many challenges as well: decreased speed, increased sensitivity to variations and reduced robustness. To provide answers to these challenges, a comprehensive design methodology is developed, which:

- Goes from transistor-level design: investigating ultra-low-voltage functionality of circuit topologies, enhancing existing logic families, defining basic building blocks, etc.
- Up to architecture-level recommendations: exploring the advantages of a fully differential implementation, time borrowing, latch-based deeply pipelined architectures, etc.
- Obtains high energy-efficiency combined with high variation-resilience and MHz-speed.

Results & Conclusions
This ultra-low-voltage design strategy is effectively validated by the design and measurements of four prototypes in bulk CMOS technologies. These four prototypes consist of three datapath elements, i.e. a logarithmic adder and two multiply-accumulate units, and a full JPEG encoder in 90nm and 40nm CMOS. The prototypes have successfully obtained the research goals:

- Operation at ultra-low supply voltage to obtain high energy-efficiency.
- High variation-resilience to guarantee sufficient yield.
- Operating frequencies well beyond 10MHz.
- Applicable for all types of signal processing applications.
- Study of the influence of technology scaling.

Major publication
Efficient Design of MIMO solutions for Software Defined Radio

Introduction / Objective
Software Defined Radio (SDR) baseband solutions employ programmable processors, so that the same hardware can be used across various wireless standards by changing the software only. The drawback is that the algorithm design to support various wireless standards becomes very challenging. On top of that, the support for Multiple Input Multiple Output (MIMO) antenna schemes is increased with each new wireless standard to meet the high data rate requirements of users. The high data rate offered by MIMO systems comes at the expense of a high implementation complexity in the receiver. In MIMO-SDR receiver design, existing solutions implement relatively simple receiver algorithms that cannot achieve optimal communication performance with high area and energy efficiency in hardware. In this thesis, we apply an algorithm architecture co-design approach to design a MIMO-SDR receiver that can achieve near-optimal BER performance.

Research Methodology
SDR platforms offer flexibility and programmability, which is usually the main cause of lower energy efficiency. However, this flexibility can also be used as an advantage to compensate for the energy inefficiency by implementing scalable algorithms that adapt to the dynamically varying wireless channel so that the algorithms can be operated in different modes. First, we use an architecture aware algorithm design approach, to enable run and design time scalable algorithms for the MIMO receiver (cfr. Fig.1). Afterwards, a C-programmable ASIP template is proposed for MIMO detection. The template is designed such that it can be re-configured to support various MIMO antenna configurations.

Results & Conclusions
A scalable ASIP template is proposed for implementation of both hard and soft-output MIMO detection algorithms.

- The proposed implementation can be configured to operate in different modes, with BER performance ranging from SIC to near-ML to near-Max-Log MAP, providing BER performance/energy trade-offs (cfr. Fig.2).

- The proposed implementation delivers peak throughputs of 3.6 Gbps and 2.05 Gbps in case of hard and soft-output MIMO detection, with only 13.03 mW and 22.99 mW respective power consumption, for a 4x4 LTE system with QAM-64.

Major publication
Introduction / Objective
Aggregate bandwidth requirements for I/O in advanced CMOS chips and stacked DRAM packages are expected to reach the level of multiple TB/s in the near future. In order to fulfill the power and bandwidth density demands, silicon photonics has been identified as a prime technology enabling cost-efficient short-range optical interconnect. This work is focus on the design of low power and high speed CMOS circuits to control the photonic devices and the demonstration of the optical link between packages.

Research Methodology
Enabling optical I/O and scaling into the TB/s regime within the voltage constraints of advanced CMOS puts several requirements on the CMOS control electronics. A low supply voltage headroom and strict power constraints lead energy efficient design:

- Novel driver circuit with an asymmetric and differential output
- High speed and low voltage transimpedance amplifier

To optimize the CMOS design, the accurate models of silicon ring modulator and photodiode were developed allowing co-simulation with the CMOS circuitry and enabling optical link benchmarking.

Results & Conclusions
To demonstrate optical transmission, silicon photonics die with co-designed CMOS transceiver chip were integrated using convectional flip-chip techniques. The characterized energy efficiency was in very good agreement with the simulations:

- 10Gb/s: TX: 250fJ/bit + RX: 350fJ/bit
- 20Gb/s: TX: 1300fJ/bit + RX: 580fJ/bit

Major publication
Recovery of valuable resources from wastewater using a fluidized pellet reactor and electrodialysis

Introduction / Objective
Due to the scarcity and depletion of natural resources, wastewater has been recognized not only as a needed resource but also as a “renewable” resource. The objective of this thesis is to propose a feasible integrated system to reclaim water from reverse osmosis concentrate, to regenerate acid/base from industrial wastewater and to recover phosphorus as calcium phosphate from municipal wastewater to achieve sustainable development.

Research Methodology

Results & Conclusions

Major publication
Towards an Integrated Area Development Approach for Nairobi Metropolitan Region Analyses of Community-based Organisations and their Development Strategies Against Social and Spatial Polarisation

Introduction / Objective

This PhD research examines, on the one hand, development strategies that are reinforcing social and spatial polarisation in the context of one of Kenya’s rapidly urbanising areas - the Nairobi Metropolitan Region. On the other hand, it examines how communities through their community-based organisations are countering socio-spatial polarisation through their role in social and spatial transformation.

Research Methodology

To analyse the inter-related aspects of socio-spatial polarisation and socio-spatial transformation, two methodological approaches were combined:

- a theoretical - historical approach guided by the theory of Africa’s moral economy/economy of affection linked with Regulation theory’s perspective of uneven development and Social innovation’s perspective of spatial development. The integrated analytical framework was mobilised to examine the interaction between Kenya’s economic development and the ensemble of institutions represented by the state and civil society actors in the production of development strategies that have significantly shaped the Nairobi Region’s spatial structure, during the pre-colonial, colonial and post-colonial periods.

- an empirical case method focusing on the social and spatial transformation strategies of Nairobi’s Eastleigh Somali entrepreneurial and non-Somali street vending communities, as well as those of Kajiado’s Maasai pastoralists. In addition, the state’s role in the interaction with each of the socio-occupational communities was considered.

Results & Conclusions

- The research found that the unevenness in Kenya’s and Nairobi Region’s spatial structure, is produced and maintained through political (colonial and post-colonial) as well as socio-economic dynamics.

- In Nairobi’s Eastleigh Commercial Centre the dynamics of empowerment within the Somali entrepreneurial community have interacted with Nairobi City Council’s privatisation and exclusionary urban development model (public-private partnerships) to produce market-driven informal urban development. Meanwhile, the struggle for urban inclusion among the non-Somali street vending community continues.

- In Kajiado North, changes in Maasai traditional coping mechanisms have resulted in increasing landlessness and poverty. A socially-innovative community-driven approach towards integrated land use planning and sustainable regional development has been developed to address the increasing land fragmentation in the area.

- Nairobi Region is therefore in need of a community-centred, environmentally-acceptable, bottom-linked, integrated development and governance approach.

Major publication

Middleware for shared and always-on embedded devices

Introduction
This dissertation focuses on supporting the software life-cycle of concurrent applications on shared and always-on resource constrained environments; environments that are prone to disruption and faults resulting from dynamic software reconfiguration and resource competition. Specifically, it contributes software frameworks and a distributed execution environment that ensure application integrity, improve resource efficiency and reduce development effort during the deployment and co-execution of applications.

Research Methodology
The research was conducted following a systems oriented and applied approach. Research during which systemic problems were identified. The scope of the research included several industrial projects in varied domains from logistics to the internet of things. The final evaluation was realized on a realistic approximation environment, deployed in the CS building, that allowed for the in-depth and long term analysis of our proposed solutions.

Results & Conclusions
We have proposed a systematic approach for sharing in resource constrained environments. Three key principles lay at the foundation of our approach: The first, state management delegation allows the middleware to control, configure and dynamically modify each application. The second, an internally generated model of system state that allows the middleware to optimize resource management. Finally, admission control allows the middleware to eliminate overutilization of critical resources. We evaluated our middleware through the incremental deployment of 8 applications and one year of their co-execution on a real world smart office WSAN. Evaluation results demonstrate that our middleware eliminates disruptions and faults, while improving resource efficiency.

Of particular importance is that: First, the approach is realizable in unobtrusive implementations that are applicable on practically any reconfigurable modularization technique. Second, that the models are generated based on locally scoped annotations on component implementations and on explicitly specified application constraints. For which, the component programmer and application developer do not need cross functional expertise or inter-application coordination.

Major publication
Soil Modeling, dynamic refinement and shared memory parallelization within SPH

Introduction / Objective

The Smoothed Particle Hydrodynamics (SPH) method is an alternative to traditional mesh-based techniques like FEM and Finite Differences, and has a wide range of applications for simulating complex phenomena. This work extends the applicability of SPH in two ways: by applying and validating the method for the 3D computation of cohesive soil, and by increasing its computational feasibility (i.e. dynamic particle refinement and shared memory parallelization).

Research Methodology

**Soil modeling.** The model used for the 3D computation of soil considers an elastic-perfectly plastic stress-strain relationship with the Drucker-Prager yield criterion. Attention is paid to avoid numerical instabilities that normally appear when simulating cohesive soil in SPH. The results are validated with simulations obtained with FEM.

**Dynamic Refinement.** The resolution of the discretization is locally increased by refining particles according to a defined criterion. A selected particle is refined by replacing it with smaller daughter particles. The properties of the new daughter particles are assigned so that the refinement error is reduced, and possible numerical instabilities are avoided.

**Parallelization.** The parallel implementation addresses efficiency issues that arise from complex memory hierarchies that feature Non-Uniform Memory Access (NUMA). The software combines domain decomposition and the use of a space filling curve to avoid NUMA-unfriendly memory allocations, reduce data races and allow efficient calculation of inter-particle forces.

Results & Conclusions

SPH has great potential for soil simulations, it can handle large deformations and post-failure flow without difficulties. The parallel implementation features an efficient and inexpensive load balancing algorithm. However, surface to volume ratio can be far from ideal in some cases.

Application of the dynamic refinement procedure allows to obtain a given accuracy using significantly less computational resources.

Possible application: Soil-tool interaction.

**Major publication**

Introduction / Objective
Technology roadmaps for Photovoltaic (PV) foresee a decrease in solar cell wafer thickness from 180 μm to 25 μm. Thin wafers are flexible and tend to break easily (Fig. 1). Thus, special handling solutions are required during device manufacturing. In this thesis, a handling solution is proposed, which is bonding the thin wafer to a thick glass by means of polydimethylsiloxane PDMS (silicone) prior to processing (Fig. 2). The interactions between glass, silicone and the process of amorphous silicon (a-Si:H) surface passivation are studied. At the same time, the influence of these interactions on the device performance are investigated and solutions to eliminate it are developed.

Research Methodology
The interactions between glass and silicone and the process steps necessary for the a-Si:H surface passivation, i.e., wet cleaning and a-Si:H Plasma Enhanced Chemical Vapor Deposition (PECVD), are investigated separately. The quality of the passivation is analyzed in terms of minority carrier effective lifetime ($\tau_{\text{eff}}$) and $\tau_{\text{eff}}$ uniformity, and the interactions are proven by chemical analysis of the samples (chromatography, XPS, FTIR and WCA).

Results & Conclusions

Influence of Glass
- Cleaning: no effect.
- PECVD: shift in wafer temperature and electric potential. This influence has negligible effect on device performance.

Influence of silicone
- Cleaning: introduction of contamination on wafer surface.
- PECVD: thermal and plasma-induced degradation of silicone. This influence is detrimental for a-Si:H passivation (Fig. 3).

Solution
A treatment to increase the silicone resilience and eliminate its negative influence on the passivation is developed. This comprises of:
- silicone outgassing;
- plasma treatments in RIE reactor;
- specifically wet cleaning sequence.
In this way, high-quality passivation comparable to reference is re-established (Fig. 3).

Major publication
Towards sustainable operation in the (bio)chemical industry: a framework for computer-aided multi-objective decision-making

Introduction / Objective

The manufacturing industry is faced with the challenge to constantly improve its processes, e.g., due to more strict environmental policies and increased societal awareness. Moreover, globalization and market saturations induce highly volatile prices and lower profit margins. Hence, this work aims at providing a framework to allow for the sustainable operation of existing processes and units. In this context, every day numerous decisions have to be made in industry while trying to meet a variety of possibly conflicting KPIs (e.g., increase production, reduce emissions and reduce operational risk). Consequently, decision makers worldwide are faced with the challenge to make sound and reliable decisions in real-time under uncertainty. However, these decisions are still (too) often based on intuition and heuristics.

Research Methodology

Advanced numerical methods have been developed to enhance real-time decision-making for the sustainable operation of large-scale dynamic (bio)chemical processes with uncertainties. The following tasks have been accomplished:

- **Task 1** Introduce interactive multi-objective algorithms for dynamic non-linear systems.
- **Task 2** Devise a user-friendly Graphical Unit Interface (GUI) for high-dimensional problems.
- **Task 3** Develop a robust multi-objective optimal control framework to systematically account for uncertainty.
- **Task 4** Test the proposed methodology and optimization framework to solve industrially relevant case studies.
- **Task 5** Acknowledge the intrinsic multi-objective nature of Nonlinear Model Predictive Control (NMPC).

Results

A screenshot of the proposed framework for computer-aided multi-objective decision-making for dynamic systems under uncertainty is reported here for the optimization of a five-objective fed-batch reactor: maximization of (i) product P, (ii) product E and (iii) operational safety αT, minimization of (iv) waste product G and (v) batch time. On the left the Pareto front in five dimensions is shown while on the right the states and controls profiles for the selected points are depicted.

**Major publication**

Numerical methodologies and algorithms for optimal experiment design in the (bio)chemical industry

Introduction

Process models are valuable tools for the analysis, design, control and optimization of dynamic processes. Before these models can be used in practice, they often need to be calibrated. More precisely, model parameters have to be estimated such that the model predicts experimental data as accurately as possible. As experiments are often cost and/or labor intensive, optimal experiment design techniques can help to systematically select a limited set of experiments which contain the most information and from which the parameters can be estimated with a high accuracy.

Research Methodology

The different research objectives:

- The first objective is the development of a novel computational method for the quantification of the parametric information content/uncertainty. This novel approach is shown to be faster than the corresponding state-of-the art approach.
- The second objective is the quantification of the uncertainty in the information content and in the system constraints. This uncertainty is quantified and a novel framework to incorporate it in the optimization formulation is presented.
- The third objective is a general procedure to investigate multiple interesting and possibly conflicting criteria for optimal experiment design.
- The fourth objective is the development of a solution strategy that circumvents the choice between some criteria. This approach has to guarantee an increase in information content irrespectively of the selected information measure.

Results

Major publications


The Second Law of Thermodynamics in Applied Engineering Science
Illustrated with Electronics Cooling Examples

Introduction
The Second Law of thermodynamics has inspired many scientists over the past century. Also in the field of engineering it has found applications like for example exergy and entropy generation minimization (EGM). This dissertation aims to assess these applications by questioning their usability in engineering design.

The Second Law of thermodynamics is half a conservation law because entropy can be created but not destroyed. This is mathematically expressed by an inequality sign:

\[ dS \geq 0 \]

From a modelling point of view, this inequality sign is inconvenient. Therefore engineering sciences often uses the equality sign to set a benchmark on reality (exergy) or minimizes the gap between reality and the reversible benchmark (EGM).

Unfortunately reversibility is infeasible. It is the inequality sign which describes reality on macro scale, not the equality sign used as a benchmark. This inherent discrepancy urged us to start a quest for the added value of the Second Law in engineering design.

Methodology
We start with a general acquaintance with the Second Law. Subsequently we offer three new perspectives on the Second Law as it is applied in engineering. These perspectives serve as a framework to assess current literature on applied Second Law based analysis and design. After pinpointing trumps and pitfalls, we illustrate when and how the Second Law can bring an added value to engineering design. Finally we put the work itself in a broader context.

Objective - Results
This thesis has the ambition to change the reader’s perception on the use of the Second Law in engineering and proposes new methodologies to design complex thermohydraulic systems with the Second Law of Thermodynamics.

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Time-Based Energy-Efficient Sensor Interface Circuits

Introduction / Objective
A new electronic revolution is arising: the smart environment. This means that sensors and sensor systems are becoming ever more important in today’s society. There are however still obstacles that need to be tackled for this to become a reality. This thesis focuses on tackling the electronic hardware challenges of the sensor interface, such as the power consumption, robustness and cost. As an alternative to traditional amplitude-based sensor interfaces, in this work a time-based sensor interface that offers scalability, robustness and energy efficiency is proposed and analyzed. The theoretical analysis is validated by several chip implementations in Silicon CMOS and Carbon NanoTube (CNT) technology.

Research Methodology
In the search for scalable, robust and energy-efficient sensor interfaces, two major research paths have been followed:

- The investigation of new sensor interface architectures and topologies: a novel time-based sensor interface architecture based on a digital phase-locked loop is presented, analyzed, modeled and validated through chip implementations.
- The search for new and improved technologies than what is currently available: the Silicon CMOS technology itself will eventually limit the performance fundamentally. Therefore, the search for new and improved technologies is necessary. CNT technology is an excellent candidate for this matter. Several design implementations have been done in the CNT technology from Stanford University.

Results & Conclusions
Three different chips have been implemented and measured in Silicon CMOS technology. With these three chips, the following objectives have been achieved:

- Robustness; by improving the supply-voltage sensitivity for resistive sensors in a Wheatstone bridge.
- Scalability; by implementing sensor interfaces in nanometer CMOS technology, up to 28 nm.
- Integration; by integrating external (Me:Me) sensors in on-chip time-based sensor interfaces.
- Energy efficiency; by employing the proposed highly-digital interface architecture, which results in a low supply voltage and a low power. Two chip implementations have been done in CNT technology. These chip implementations demonstrate that:
- CNT technology is indeed a viable technology for future sensors and sensor systems.
- The proposed sensor interface architecture is ideal to be implemented in a not yet fully mature, variation-sensitive technology.

Major publication
Territorial dispersion patterns of residential areas.

Introduction / Objective
This research deals with the territorial dispersion patterns in the expansion of residential areas, i.e. urban sprawl, conceived as an outcome of governance processes. Urban sprawl, as a type of land use transformation, originates from the decisions over land management carried out by certain actors, hence an appropriate theoretical framework is proposed and empirically implemented. Such effort is particularly relevant because, in the international literature on urban sprawl, political and planning factors are only limitedly focused on.

Research Methodology
Urban sprawl is defined as a predominantly residential phenomenon, and it is measured in hectares by the use of land use data. The analysis focuses on the land use transformations occurred in Barcelona and Milan as case studies, and how such transformations connect with governance processes of land management. First, residential urban sprawl is examined through different spatial scales (administrative boundaries, metropolitan delimitations, Larger Urban Zones, Urban Morphological Zones and NUTS 3 level or provinces) for a period of approximately 50 years (1950s-2000s) in both Barcelona and Milan. Second, the analysis of quantitative (i.e. employment and demographic data), and especially qualitative data (interviews, documents and planning regulations) allows to propose an explanation for the occurrence of urban sprawl, in both Barcelona and Milan, as an outcome of territorial, multi-scalar and multi-actor governance processes and dynamics.

- Descriptive analysis of land use data inventories (AMB, DUSAF and Corine Land Cover surveys), 1950s-2000s.
- Analysis of a total of 30 in-depth interviews to planners, politicians, key informants in Barcelona and Milan.
- Document analysis on the main plans and land use regulations in both case studies, 1950s-2000s.

Results & Conclusions
The comparative analysis reveals that the residential areas of the Barcelona case are relatively more compact than in Milan.
- Urban functions (industries, services and housing) have been de-centralized from the city center to the metropolitan areas and regions of Barcelona and Milan.
- Urban sprawl consists of land use micro-transformations carried out by local authorities to obtain a competitive edge with regard to the other municipalities located within the metropolitan boundaries.

The different territorial dispersion patterns in the expansion of residential areas in Barcelona and Milan, the built-up form of Barcelona being relatively more compact, is connected with the decisive role that the metropolitan and regional governments play with regard to land management strategies. In particular, the predominant position of the regional government is key for land containment.
Study of crack propagation for the fabrication of ultra-thin silicon solar cells

Introduction
Silicon based photovoltaic technology is the main candidate to respond to the ever increasing energy demand without spoiling the environment. However, to make it competitive with traditional energy sources, its cost per watt peak has to be further reduced. To achieve this goal, researchers have proposed in the past to manufacture solar cells from thin (<100 μm) silicon foils produced by mechanical separation from thick substrates. To make this technique viable, though, the separation process must be understood in depth. In this research, the analysis of the detachment process is provided and the quality of the produced thin foils is investigated.

Research Methodology
Two techniques were investigated to detach the thin foils. A first technique (SLiM-cut technique) wants to initiate and control the propagation of a crack inside the bulk of a silicon wafer through a stress-inducing layer. In a second technique (porous silicon (PS)-based layer transfer technique), a weak PS interface is first formed to trap the propagation of the crack. The question addressed in this work are:

SLiM-cut:
- Investigate different stress inducing layers;
- Characterize the detachment surface;
- Investigate quality of the produced foils.

PS-based layer transfer:
- Characterize PS morphology and reorganization;
- Evaluate PS mechanical properties;
- Investigate quality of the produced foils.

Results & Conclusions

SLiM-cut:
- Identified candidates material for the stress-inducing layer by FE simulations
- Demonstrated low temperature SLiM-cut
- Roughness of the crack surface investigated by profilometry, causes identified and solution to reduce it proposed
- High quality of the foils demonstrated by ESR and PL measurements

PS-based layer transfer:
- Characterization of PS morphology through different methods
- Proposed new theory to explain the reorganization of PS at high temperature
- Mechanical properties as function of the porosity investigated by FE simulations, SAM and nano-indentation
- High quality of the foils demonstrated by ESR and PL measurements

Major publication
Optimization of the Energy Conversion Starting from Low-Temperature Heat
Application to Geothermal Binary Cycles

Introduction / Objective
Low-temperature (100-150°C) heat sources are widely available, but they are hardly used. The problem is that the efficiency of the conversion of the heat to electricity is low due to the low temperature (Carnot). The consequence is that the gross electricity output of a low-temperature power plant is low, much water or electricity is consumed for the cooling and that relatively large equipment is needed for the small electricity output. The combination of these effects of the low conversion efficiency with the high costs of deep geothermal wells, makes it hard to design a profitable electric power plant, powered by low-temperature heat.

Research Methodology
Two areas of research can be distinguished in the open literature. First, work is done to find the optimal cycle to convert low-temperature heat into electricity, while neglecting components or modeling them very simplistically. On the other hand, researchers are optimizing components without looking into the system in which the components are used. The goal of this research is to combine the optimization of the cycle and of the components and perform a system optimization in which the cycle and all the components (heat exchangers, cooling system and turbine) are optimized together. In this way, the components are optimal to work together and optimal to be used in the optimized cycle.

Results & Conclusions
The system optimization is applied to a proposed deep-geothermal project in Belgium. The main conclusions are:
- For mild climates, water cooling results in much better economics than air cooling, due to the high investment cost in air-cooled condensers (ACC) versus a wet cooling tower (WCT). Only when water is very expensive, air cooling can be a good option.
- With the current technology and current electricity price, it is economically not interesting to use the geothermal heat for electricity generation only. Combining electricity generation with delivering useful heat is needed, but the heat delivery can have a strong influence on the electricity generating part.

Major publication
CMOS Transformer-Based Doherty Power Amplifiers

Introduction / Objective

Modern wireless communication standards such as LTE, WiMAX, WiFi use complex modulation schemes to increase the data rates. Consequently, the power amplifiers operate at power back-off and demonstrate low efficiency. The efficiency of the power amplifiers play an important role in the battery life time of a mobile device. In this Ph.D work, a novel circuit technique is developed to enhance the linearity and the back-off efficiency of the power amplifiers in modern mobile communication devices.

Transformer-Based Doherty Operation

In this work, the power amplifier is constructed by combining several small amplifier blocks. The major properties of the proposed topology can be summarized as:

- The number of working amplifiers can be adjusted depending on the required output power level. Therefore, power consumption can be minimized.
- The linearity of the overall amplifier can be improved by combining amplifiers with different distortion characteristics.
- Combining the output voltages of low voltage power amplifiers enables high output power levels in nanoscale CMOS technology.

Results & Conclusions

The proposed transformer-based Doherty topology is validated by using analysis and transistor level simulation results. Then, five different power amplifiers are designed, fabricated and measured for LTE, WLAN and mm-wave applications. The die microphotograph (left), continuous wave measurements (middle) and LTE measurements (right) of the LTE power amplifier is shown below. The PA satisfies the LTE requirements at 23.4 dBm output power with 23.3% PAE. The PAE is still as high as 18.4% at 6 dB back-off and 11.1% at 12 dB back-off from the maximum output power.

To conclude, this work demonstrated that complex and flexible circuit topologies can be used to overcome the challenges in the modern communication systems.

Major publication

Industrialization of Selective Laser Melting for the Production of Porous Titanium and Tantalum Implants

Introduction / Objective

As the number of orthopedic surgeries is increasing, so is the need for implants that not only can reconstruct a mechanical stable joint, but also serve as bone replacement material. Already more than two decades porous metal implants have been a solution to address this need since they can exhibit mechanical properties close to human bone and thus provide sufficient implant strength and stability while at the same time they allow for bone to grow inside the pores, ensuring a long-term implant fixation. Only now, with the introduction of additive manufacturing or 3D printing techniques like selective laser melting it has become possible to manufacture on an industrial scale porous metallic structures in a controlled and reproducible manner. In this dissertation three types of porous metallic implants made by selective laser melting have been evaluated: porous implants made from Ti6Al4V, tantalum and pure titanium.

Research Methodology

In order to allow for further industrialization of the selective laser melting technology for the production of porous implants, these topics have been studied in detail:

- The porous implant design: the porous architecture and the implant material;
- The characteristics of the SLM process: overall reproducibility and the build orientation;
- Post-processing operation: heat treatments and bio-functionalizing surface treatments;
- Production cost: lower cost by increased productivity.

Results & Conclusions

The investigation of these topics have led to some general achievements that haven’t been reported before:

- Porous architecture: Both the structure relative density and the unit cell design alter the mechanical properties.
- Implant material: Porous tantalum showed excellent in vivo performance and a very high fatigue resistance while porous pure titanium implants have a higher fatigue strength compared to the statically stronger Ti6Al4V.
- Overall reproducibility: The mechanical properties have standard deviations of less than 5% of the mean value.
- Build orientation: Improper selection can result in inferior mechanical properties (up to 30% less strength).
- Heat treatments: A stress relief heat treatment increases the yield strength (15 to 25%), a HIP treatment increase the elongation at fracture by up to 70%.
- Bio-functionalizing surface treatments: Growth factors and surface treatments can speed up the process of bone regeneration and implant fixation.
- Production cost: Significant productivity improvements have been achieved (1.6 to 4.2 times faster).

Major publication

Awareness support tools
From team to community, from small personal to large public displays

Introduction / Objective
The growth of content available on the Internet makes users feel more pressure to be aware of the flood of information, but humans have a limited capacity to store and process information. People would like to be aware of relevant content based on their needs and preferences and discover useful content.

The main topic of this thesis is to investigate how technology can support awareness for teams, groups, and communities. We focus on supporting awareness as a process, in a work-related context, and as a product, in a community engagement context.

Research Methodology
With a number of case studies we have designed, developed, deployed, and evaluated awareness support tools. With the aim to augment people's lives, the different tools were created following a design oriented research methodology.

Results & Conclusions
- Design and evaluation of an awareness support tool that enriches presentations from academic events with information provided by Web2.0 sources.
- Design and evaluation of an awareness support tool that makes researchers aware of what their peers are reading, using them as social filters of relevant content.
- Design and evaluation game design elements and personal information management (PIM) concepts to engage researchers in sharing their reading activities.
- Design and evaluation of an interactive public display to increase community awareness. We have adopted a structured method to quantify the different engagement phases.
- Evaluation of an interactive public display in different contexts using a structured method to compare results.

Key publications
Multi-scale modelling of spatial variability in textile composites
Uncertainty quantification based on experimental data of internal geometry

Introduction / Objective
The advantages of using composites for design, manufacturing and during operation are well known. Though, the introduction of composites is hampered by the relatively high cost of raw material and the uncertain quality of high-performance composite structures. An improved assessment of the quality of any composite part is achieved by identifying the irregularity in the tow reinforcement. Once the composite microstructure is identified, a reliable computational model can be established that forms a direct link between the irregularities in the reinforcement structure and the stochastic material properties.

Research Methodology
This dissertation provides a generic multi-scale framework for generating realistic virtual textile specimens. It is a first step towards a systematic modelling approach for textile composites where powerful simulation procedures are applied in combination with experimental data, both on the short-range (meso-scale) and long-range (macro-scale). Three main steps can be distinguished:

- Collection of experimental data and statistical analysis
- Stochastic multi-scale modelling of the reinforcement
- Construction of virtual specimens in the WiseTex software

Results & Conclusions
This framework is demonstrated for a carbon-epoxy 2/2 twill woven composite, produced by RTM, with main conclusions:

- Substantial differences in warp and weft direction are quantified from experiments, attributed to the manufacturing process.
- The Monte-Carlo Markov Chain method is appropriate to simulate auto-correlated (along the tow) tow path parameters.
- Series Expansion techniques are applied to generate auto- & cross-correlated (between tows) tow path parameters.
- Experimental and simulated trends have good correspondence for all tow properties, and target statistics (standard deviation and correlation length) are reproduced with high accuracy.

Major publication
A supply-side oriented analysis of urban (re)development in China by way of Smith’s Rent Gap Theory

Introduction / Objective
Urban redevelopment has emerged in contemporary China since the late 1990s and became a significant research area. The existing researches on this topic often share a demand-side approach. This approach, however, does not fit very well with Chinese contexts mainly because of special land tenure and planning systems in China which place landowners/land suppliers in a leading position in urban (re)development. In this PhD thesis, an alternative supply-side explanation of China’s urban (re)development was given and Smith’s Rent Gap Theory was elected as the privileged tool.

Research Methodology
This PhD research, which is paper-based, reinterprets China’s urban (re)development from a rent gap perspective in general and from a rent gap approach in particular.
- The 1st and 3rd papers adopt a predominantly supply-side perspective on rent formation in the process of urban (re)development and validate Smith’s RGT for China’s large-scale urban development projects and urban village (re)development projects respectively.
- The 2nd paper presents a logical inference that the larger the rent gap is in an area, the higher the probability that the area will be redeveloped and tested it using 2004-2011 Wuhan data.
- The 4th paper provides a broader discussion of rent production & distribution in China’s urban redevelopment.

Results & Conclusions
The rent gap on collectively-owned land and administratively allocated land cannot be considered as conceptually identical to Smith’s Western rent gap. In more specific terms, China’s land tenure systems have imposed restrictions on the use and exchange of use rights of collectively–owned land and administratively allocated land, thus reshaping the rent gap for these two types of land.

As the table shows, when the rent gap decreases, the corresponding FCI%/CA% also has a downward tendency, with two exceptions. This result basically confirms the inference we proposed, i.e., the larger the rent gap is in an area, the higher the probability that the area will be redeveloped.

Major publication
A computational framework for prioritization of disease-causing mutations

Introduction / Objective
Approximately eight percent of total population is affected by one of more than seven thousand identified genetic disorders. Causes of many of these disorders are poorly understood, which complicates disease management and, in some cases, increases morbidity and mortality. At the same time, rapid development of high-throughput technologies in the past few decades gave a considerable boost to the biomarker discovery in general. Among these techniques, the exome sequencing appears to be especially promising approach for identification of novel genes causing inheritable diseases. However, each individual genome typically harbors thousands of mutations, hence detecting the disease-causing ones remains a challenging task, even when the majority of the putatively neutral variation is filtered-out beforehand. Several computational methods have been proposed to assist this process, but most of them do not display satisfactory precision to be used in real-life environment.

Research Methodology
We propose a novel, genomic data fusion based method for prioritization of single nucleotide variants which implements several key innovations. First, it blends together conservation scores, haploinsufficiency and various impact prediction scores, practically subsuming all the other major algorithms. Second, it is the first of its kind to fully exploit phenotype-specific information. Third, it is directly trained to distinguish rare disease-causing from rare neutral variants, instead of using common polymorphisms as a proxy. We also describe several strategies for aggregation of predictions across multiple phenotypes and explore how each of them affects the prioritization under different levels of noise. In addition, we formulate a simplified version of the model to increase the interpretability of the decision-making process, as well as to reduce a storage demand and a computational burden induced by the system. Finally, we identify a bias originating from the hierarchically granular nature of the problem's data domain and develop a sampling-based way to bypass it.

Results & Conclusions
Application of our methodology in realistic usage scenarios have resulted in 10-fold increase of precision compared to the rest of state-of-the-art, without degrading recall. Moreover, we have showed how this result can be further improved by the utilization of an appropriate score aggregation scheme. Finally, we have demonstrated how the removal of hierarchical bias translates to a considerable additional increase of the system's performance. The framework implementing our complete methodology has been deployed as a free web tool and also as a stand-alone computer application.

Major publication
* equally contributing first authors
Shear capacity of prestressed and reinforced concrete members
Modeling and experimental validation

Introduction / Objective
Despite more than a century of nearly continuous research effort, the problem of determining the shear capacity of a structural concrete member remains open for discussion. Current codes of practice therefore adopt highly conservative design equations, specifically in the case of prestressed concrete elements. The present research aims to optimize design and analysis procedures for shear-critical prestressed concrete beams.

Research Methodology
This work assesses the mechanical behavior of shear-critical prestressed and reinforced concrete beams based on
- Experimental research, refer to Fig. 1
- Nonlinear numerical simulation
- Analytical modeling

Results & Conclusions
The following results were obtained:
- An extensive data set of full-scale experimental results on shear-critical prestressed and reinforced concrete beams was obtained.
- The application of advanced optical measurement methods was found to be valuable in assessing the mechanical behaviour of the test specimens.
- The experimental results reaffirmed the inapplicability of current Eurocode 2 (EC2) design guidelines in predicting the failure load and failure mode of the reported test specimens.

Major publication
Passive Hypersonic Boundary Layer Transition Control Using Ultrasonically Absorptive Carbon-Carbon Ceramic with Random Microstructure

Introduction
Laminar to turbulent transition in high-speed boundary layers leads to a significant increase in wall shear stress and wall heat flux which strongly affects the performance and the thermal protection system of hypersonic vehicles. The increase in the laminar portion of the boundary layer is of critical importance to the design and optimization of these vehicles. The present study investigates a passive hypersonic laminar flow control concept applying for the first time a porous material with random microstructure which additionally has the potential to be used as thermal protection system.

Research Methodology
Three 7° half-angle cones with various nose radii and a total length of 1100 mm were tested at zero angle of attack in the High Enthalpy Shock Tunnel Göttingen (HEG) of the German Aerospace Center (DLR) at Mach 7.5. One model was equipped with an inhouse manufactured ultrasonically absorptive carbon-carbon ceramic insert. The ultrasonic absorption properties of carbon-carbon ceramic (C/C) were assessed theoretically by means of the quasi-homogeneous absorber theory and experimentally by means of direct reflection coefficient measurements at varying ambient pressure levels.

Results & Conclusions
A distinctive attenuation of the ultrasonic boundary layer instability waves and a delay of laminar to turbulent transition on the ultrasonically absorptive carbon-carbon insert was found by means of e.g. fast-response surface pressure measurements and high speed schlieren visualization.

Major publication
A. Wagner, K. Hannemann, M. Kuhn. Ultrasonic absorption characteristics of porous carbon-carbon ceramics with random microstructure for passive hypersonic boundary layer transition control. Experiments in Fluids, 2014, 55
On generating tool paths for laser cutters

Introduction / Objective
Given a set of parts nested on a metal sheet, the objective of the laser cutting tool path problem is to generate a tool path that cuts all elements of these parts, satisfies all precedence constraints, and minimizes the total tool path execution time. The precedence constraints originate from inner-outer contour constraints and common cut constraints. This research explicitly considers the piercing time, the air move time, the sharp-angle macro time, and the pre-cut time.

Solution approach
The laser cutting tool path problem can be split into three different core optimization problems: tool paths for thin sheets, thick plates, and very thick plates.

High quality tool paths for thin sheets can be efficiently generated through generic construction and improvement heuristics, embedded in a tabu search metaheuristic.

For thicker plates, specialized construction heuristics are required and a new tool path representation is required to efficiently exploit the problem structure.

In the very thick plate problem, thermal effects have to be taken into account.
A finite difference method estimates plate-wide temperatures and a penalty-based multi-start heuristic is able to generate thermal feasible tool paths.

Results & Conclusions
- A set of construction heuristics proposed that generate tool paths that are more 30% faster than those used in commercial CAM software
- The tool path problem can be modeled as a PCGTSP
- New tool path representation proposed
- Thermal effects can be effectively taken into account using an penalty-based multi-start heuristic

Major publication
Gain-scheduling Feedback Control of Linear Parameter Varying Systems

Introduction / Objective
In many mechatronic applications, the systems exhibit dynamic behavior that can change according to the value of one of more parameters. In such systems, also commonly called Linear Parameter Varying (LPV), the relation between input and output signals is still linear, but changes according to the value of these parameters, also commonly referred to as scheduling parameters. The aim of this research is to develop practical controller design methods for such systems.

Research Methodology
Gain-scheduling control is using the measured or estimated value of the scheduling parameters in the controller in order to improve the efficiency and performance of the systems. The design procedure for gain-scheduling controllers can be categorized in two major classes.

Results & Conclusions
The overhead crane system shown on the right, is composed of a cart and a load which is attached to the cart via a cable. Since the dynamics of the system are dependent on the value of the cable length shown by $\ell$, this system is considered as an LPV system. Gain-scheduling controllers from both categories are implemented on

- Interpolating gain-scheduling controller provides satisfactory performance for slowly varying parameter $\ell$.
- LPV gain-scheduling controller is more conservative, yet it guarantees the stability and performance for fast variations of the cable length $\ell$.

The experimental overhead crane test setup (left) and the schematic diagram of the system (right).

Major publication
Development of ductile stainless steel fibre composites

Introduction / Objective
Advanced structural composites such as carbon and glass fibre-reinforced polymers have a limited ductility. This is due to intrinsic brittleness of the high performance fibres.

The composite ductility can be enhanced by choosing fibers with a higher strain-to-failure, but most known ductile fibres (e.g. some natural and polymer fibres) have a low stiffness. The aim of this work was to investigate a new fibre type for application in composites – annealed stainless steel fibres. The unique property of these fibres is that they combine a high stiffness (±193GPa) with a strain-to-failure which can be tailored up to 20%. The strain-to-failure is as high as that of a silk fibre and up to 10 times higher than that of a carbon fibre.

Research Methodology
An extensive experimental program, supported by modelling investigations, was performed to understand the mechanical behaviour of polymer composites made of these fibres. The influence of the matrix ductility, fibre architecture and interphase properties on the damage development and composite properties was investigated. Additionally steel fibre hybrids in combination with carbon fibres, glass fibres or drawn polypropylene tapes were studied.

Results & Conclusions
The ductile stainless steel fibres delivered composites with a high stiffness and a high strain-to-failure. The strain-to-failure can be up to 22%, which is much higher than a typical carbon and glass fibre composite. Steel fibre composites with ductile matrices showed the highest strain-to-failure and a distinctly different failure behaviour, compared to a steel fibre composite with a brittle matrix. In both cases the strain-to-failure could be further improved using a silane treatment which increased the adhesion strength.

By replacing low amounts of steel fibres by carbon or glass fibres, the composite strength increased, but with a significantly lower strain-to-failure. Adding steel fibres to self-reinforced polypropylene increased its stiffness and, also its specific stiffness despite the high density of steel. In contrast to hybridisation with a brittle fibre, no loss in strain-to-failure in a tensile test was measured.

Major publication
Electrospinning of polymer solutions: Jet stability and novel applications

Introduction / Objective
Electrospinning is a technique in which electric field is used for producing nanometer scale fibers. It gained a lot of attention in the research world with the increased interest in nanotechnology. However, the advance towards a complete comprehension of the process is slow. The main reason for this is the large number of interconnected parameters that influence the electrospinning and the produced mats. This work investigates the effects of the rheological properties of the solution on the jet stability, as well as the influence of the polymer polydispersity and the environmental conditions. Moreover it indicates new areas where the electrospun fibers can be applied.

Research Methodology
The study was conducted in four steps:
- Volumetric controlled jetting experiments were used to study the effects of rheological properties on jet stability.
- A study with well characterized polymers was conducted in order to investigate the influence of polydispersity on the electrospinnability of the solutions.
- The next step was a detailed experimental study on the effects of environmental conditions on the electrospinnability and the fiber properties of aqueous polymeric solutions.
- Finally, the electrospun fibers were used to produce conductive wires and selfpropelling particles.

Results & Conclusions

An operating space for jetting/dripping; it indicates how a given fluid will behave when leaving the nozzle in a volumetric controlled process.

Effect of increased relative humidity on the morphology of the fibers.

New scaling law relating the minimum polymer concentration for electrospinning and the molecular weight of the polymer.

Nanorods created by electrospinning self propelling in the direction normal to their long axis.

Major publication
Functional Polymers for Microsystems: Micromachining and Applications

Introduction / Objective
This dissertation aims at further broadening the know-how of using polymer materials for MEMS applications. Two types of polymers have been studied in this work, namely epoxies and hydrogels.

Research Methodology
For epoxy materials, two photopatternable epoxies under the brand name of EpoClad and EpoCore have been investigated due to their promising optical properties.

For hydrogel materials, a Pluronic hydrogel has been chemically modified. Specific functioning groups have been covalently attached to the backbone of the hydrogel, making the Pluronic hydrogel photocrosslinkable and electroactive.

Results & Conclusions
An EpoClad/EpoCore optical platform has been designed, fabricated and tested. This optical platform consists of optical waveguides, suspended movable mechanical parts and a built-in fiber clamp system. Optical variable attenuators based on thermo-optic and opto-mechanical principles have been fabricated and tested using this proposed EpoClad/EpoCore optical platform. An optical accelerometer has also been realized within this optical platform.

A MEMS fabrication process has been developed, successfully patterning the hydrogel at micro scale. Therefore, the swelling behavior of the hydrogel micro structures could be characterized. In order to benchmarking different hydrogels in a realistic usage environment, a MEMS platform has been presented in this work. The MEMS platform is also capable of delivering thermal and chemical stimuli to test the environmental sensitivities of the hydrogel sample. The swelling and shrinking behaviors of the hydrogel can be monitored by visual methods as well as by an embedded conductometric sensing mechanism.

Major publication
Introduction / Objective
The research studied the integrated development and design of open - unsealed - space in the rural-urban fringe of Brussels, Belgium. In the contemporary hybrid spatial environment, integration is increasingly considered a prerequisite for qualitative development. Although seemingly fashionable, the presence of integration as a concept within planning theory signals there is more than meets the eye. The concept has however only been explored to a limited extent from a theoretical point of view. The research therefore aimed to contribute in expanding the knowledge about this concept. In order to understand the integration concept fully, at least three aspects needed to be taken into account: the meaning of integration, why (or when) it is called upon, and how it is or can be established. Therefore, the dissertation looks into the what, why and how of integration within spatial development. It thereby hypothesizes that (1) spatial design as a creative medium plays a role in establishing certain forms of integration, and (2) that design and planning approaches that start from the ‘open’ rather than from the ‘urban’, have a larger capacity to achieve the ‘holy grail’ of integration.

Research Methodology
This qualitative and experimental research involved a combination of design workshops, landscape and spatial analysis, urbanization history, and several other methods in order to answer the research questions. As this concerned a case study research, the highly complex context of Brussels’ fringe was studied in particular.

An empirical focus was placed on open spaces in fringes for two main reasons: first, since the calls for integration resound especially loud in these environments at the frontline of development; and second because open spaces are increasingly considered crucial and strategic assets to deal with a wide range of environmental, social and economic challenges. Open spaces within a fringe context often experience a multi-layered development problematic, arising from their position in between spatial entities, policies and functional uses. They are not just literally in the fringe, due to their location at the edge of a dense urban core, but metaphorically as well, concerning perception, valuation and policy attention. As a result of this context, integration is often called upon.

Results & Conclusions
The research showed that integration is multifaceted and always needs to be related to something else, namely that which is being integrated. Within the context of spatial development, integration can be a goal, a process as well as a product. It points at either substantive issues and/or the development process, indicating a linkage of spatial, societal or institutional elements, or a combination thereof. An integrative act usually aims to bring such elements together into a coherent and qualitative whole, a spatial solution, or design. Ideally, integration does not erase the characteristic differences of the combined variables. It nevertheless still implies being selective. Establishing actual integration thus is no easy task, nor a guarantee for quality. Clarifying questions, such as whose integration is it? what is the strategic agenda behind the concept? and why is integration used? are crucial to avoid an integrative act that is merely post-political consensus. Furthermore, the research provided important clues on how design research on open space can be mobilized successfully in spatial policy-making processes by making conflicts explicit and visual. Moreover, it discovered the importance and power of the ‘land development’ instrument for open space planning.

Major publication

Ultra low power high speed SRAM design

Introduction / Objective
Modern mobile applications such as smartphones, tablets and laptops are becoming more and more advanced and powerful and need ever larger memory sizes. As battery capacity does not increase sufficiently to achieve long stand-by times for these applications, it becomes very important to limit both the active energy usage and the stand-by power of the integrated circuits in these devices. Conflicting specifications such as high speed and low cost make the design of memories very challenging. This work investigates different circuit techniques to achieve this goal.

Research Methodology
First, the parts of a memory consuming the most energy or causing the most leakage power are identified. The contribution to the total memory delay of each building block in the memory is determined as well. This leads to an in-depth understanding of the different trade-offs in a memory design. In a first design phase, active energy use is reduced by eliminating as much unnecessary activity as possible by switching off unneeded circuits as early in the memory cycle as possible. This is made possible by dividing the memory in different sections which can separately be activated. In a second phase, advanced data transfer techniques are developed to reduce energy use even further. Leakage is reduced without compromising speed by using high threshold voltages and increasing the supply voltage at the same time.

Results & Conclusions
Different circuit techniques to reduce energy consumption or leakage power, to increase speed or to increase reliability were investigated. These techniques have been successfully tested on silicon. Three prototype memories were designed and fabricated. The first prototype reached a speed of 850MHz while only using 133fJ/bit/access. To achieve this, the following techniques were used:

- activity reduction by using fully divided word lines
- divided bit lines, dynamic cell stability
- a dual (low) swing data transfer technique
- a hybrid static-dynamic distributed decoder
A second prototype reached 454MHz while using 114fJ/bit/access with the following techniques:

- bit cells with a high threshold voltage
- a highly integrated on-chip charge pump
- segmented signal buffers to reduce the effect of wire resistance

Major publication
BLACK WATER – GREY SETTLEMENTS
Domestic Wastewater Management and the Socio-Ecological Dynamics of Jakarta’s Kampungs

Introduction / Objective
The general aims of this PhD research are to: i) explain the origins of disparities in access to water and sanitation; ii) assess the contemporary governance dynamics; and iii) open an alternative path for imagining and building a future in the provision of water sector infrastructure. The outputs of the PhD research are four papers that are presented as the main chapters. These are stand-alone papers yet thematically, theoretically and empirically interconnected. In each paper, the specific research aims are explained.

Research Methodology
This PhD research addresses the problems of wastewater management in relation to the fragmented spatial development practices within the informal cities of the Global South. Four theoretical bodies – Urban Political Ecology, Institutionalism, literature on Informality, and Social Innovation – have been put into dialogue with each other in order to develop a comprehensive analytical framework.

Results & Conclusions
Due to spatial fragmentation within the built environment, diverse socio-economic and fragile geo-ecological conditions in different settlements and the city as a whole, it is argued that Jakarta should adopt a decentralized approach to wastewater management. The research addresses the notion of decentralized wastewater management in a manner of searching multi-scalar development approaches to the interconnected household and city-wide sanitation problems, as well as of finding possible governance platforms for water and sanitation service co-provision that allows for an active role of communities in development. The study finds that informality, with varying forms of reciprocal dynamics as its foundation, is not only a survival strategy but also a source of creativity in connecting ecological opportunities, technologies – both traditional and contemporary – and modes of self-regulation to each other.

Major publication
A research into the spatial steering potential of an integrated regional public transport project for the Flemish diffuse city & A network of interconnected corridors as a strategy for the transformation of mobility and spatial patterns.

Introduction / Objective
The research aims to formulate an answer on the two following complementary questions:
1° Is it possible to design an adequately functioning public transport network within the strongly fragmented spatial structure of Flanders?
2° Can such a network act as a lever or a strategic instrument to steer spatial developments, and as such restructure the territory in the long term?

Research Methodology
The doctoral research looks at these two questions from the specific angle of a system-approach, in which the main emphasis lies on the mutual interactions between mobility, transport infrastructure and urbanization patterns. This implies a contextual approach: public transport is embedded in a spatial-physical context, as well as in an institutional and policy context. As a consequence, the answer to the research questions is not formulated as a ‘solution’, nor as a blueprint for an idealised resulting situation. Instead there is a search for strategies to intervene on the existing processes within the system. By nature, such a challenge transgresses boundaries of scale and disciplines, and uses combined research strategies such as case studies and research by design.

Results & Conclusions
The research has resulted into a concept for a spatially steering regional public transport system for the Flemish territory, of which the structural components are the formation of corridors and a nodal connectivity. Apart from this concept in itself, two main tracks are elaborated: on the one hand, the argument for this concept is built up from a critical analysis of current practice and theory, on the other the spatial implications of the concept are researched through design-related research.

Major publication
Simultaneous multi driving mode operation of a piezoelectric motor

Introduction / Objective
Recent developments in consumer product technology, such as semiconductor and optical elements, have pushed the required specification of production and inspection machines to nanometer and sub-nanometer level. One of the challenges in designing these machines is the limited selection of actuators that are capable of delivering the required nanometer accuracy. Furthermore in many applications a long operational stroke, more than a few mm, is required. One of the possible actuators for achieving these requirements is piezomotor.

A standing wave ultrasonic piezomotor typically has the ability to drive its load at relatively high speed, e.g. at more than 200 mm/s. These motors contain piezo stacks that are capable of delivering nanometer accuracy. However, the capability of fine positioning at the nanometer level of this piezomotor is not as performing as the fine positioning of a piezo stack. This research aims to combine the high speed performance of the ultrasonic motor with the nanometer positioning of a piezoelectric stage. The investigated motor is referred to as Multi-Drive motor, while the complete system solution is referred to as Multi-Drive system.

Research Methodology
To solve the challenge, in the first stage a study on the ultrasonic motor operation principle is conducted. This includes the study of the constitutive model of piezo stack and modelling of resonant behavior of the motor structure. In the second stage, the two modes performance are investigated through experiment. Third stage involves the design of the complete positioning system. A mechanical rotational system having nanometer resolution measurement is manufactured, a novel circuit which allows two different driving signals to be superimposed is developed, control system is devised for the setup, and finally the performance of the system is investigated through experiments.

Results & Conclusions
In this research the method to drive two independent positioning modes on one piezomotor structure has been developed. The experimental results on the developed system shows that the use of the fine positioning mode on top of the coarse positioning mode is beneficial to the system performance, resulting in lower trajectory error.

Fig. A. ultrasonic motor principle  
Fig. B. piezostack fine positioning  
Fig. C. point to point motion of the Multi-Drive system (notice that the steady state positioning error falls below 20 nm)
Polymer composite materials based on bamboo fibres

Introduction / Objective
This research presents the development of an environmentally friendly material as an alternative among other natural and synthetic fibre reinforced composites. The main goal of this research is to develop a bamboo fibre composite with high mechanical properties using technical fibres extracted from the Colombian bamboo Guadua angustifolia. For that, two main challenges need to be tackled. The first one consists in the extraction of long bamboo technical fibres that can meet the requirements established in the field of reinforcements for composite materials, while conserving the good intrinsic properties of the technical fibres at a competitive cost. The second aspect consists in optimizing the transfer of the good mechanical properties of the fibres into the composites performance, with both thermoplastic and thermoset matrices.

Research Methodology
The first step deals with the characterization of the extracted technical fibre. The second one consists of the preparation techniques and the manufacturing of high quality composites and their testing. The results are benchmarked with other studies of natural fibres and natural fibre composites in order to demonstrate the potential of this new material amongst well established composite materials. During this process, a methodology for dry fibre bundle testing applied to bamboo fibres was developed as well as, a novel approach to investigate the effect of fibre ends on the unidirectional bamboo fibre composites properties was investigated and benchmarked with a fully unidirectional fibre composites.

Results & Conclusions
- The modified length-based Weibull model, accurately describes the fibre strength distribution at various gauge lengths, showing low variation for the fibre strength according to the shape parameter.
- The mechanical properties of bamboo fibres reaches 92% for stiffness and 79% for strength of the ideal bamboo fibre epoxy composite properties. This points out the strong fibre-matrix interface present between fibres and epoxy matrix.
- Bamboo fibres present several ecological, environmental, technical and mechanical performance aspects concerning the production and use of bamboo technical fibres and their composites. They are suitable to fulfill the new worldwide requirements toward the use of renewable and sustainable materials at competitive price.

Major publication

Comparison between experimental strength and predictions of the modified and non-modified Weibull model.
Battery Energy Storage Systems and Distribution Grid Support

Introduction / Objective
A cost-effective and sustainable electricity supply depends on carefully balanced investments in all sources of flexibility. This dissertation deals with the complementarity of grid infrastructure and energy storage, with a focus on distribution grids and battery energy storage systems (BESS). If BESS technology is to be used, it must be designed and operated competitively. The main question throughout this work is how this storage technology may be approached most cost-effectively, considering both price signals coming from markets and signals on local grid constraints.

Research Methodology
The technology and cost structure of BESS requires new methods to assess their value as an asset in the power system. A number of technical challenges remain to be addressed. The main contributions are in the techno-economic modeling of BESSs which are used to provide multiple services. The modeling chapters deal with the optimization of control, design, sizing, and siting of BESS in distribution grids.

Optimization models for BESS are proposed, and results are calculated for case studies of realistic distribution grids. A first model deals with the combination of storage with photovoltaic generation, to mitigate the impact on the medium-voltage grid. Next, generation-source neutral approaches are developed. Here, battery storage is used to mitigate voltage and power issues in low-voltage distribution grids.

Results & Conclusions
The proposed methods determine the investment and variable costs corresponding to a required technical performance. It is shown that BESS in a highly loaded grids can postpone grid upgrades by providing peak power reduction and voltage regulation at the same time. Modeling a BESS purely as a finite source/sink of active power in a LV grid, strongly underestimates the potential because of the existing phase unbalance.

A photovoltaic (PV) system with batteries has multiple ways to limit the impact on the voltage in weaker grids: curtailment of PV, reactive power support or charging the batteries during overvoltage. Additionally, the batteries can be cycled to make use of electricity price variations. The optimization method determines the best solution given the local grid circumstances.

Major publication
Nonlinear Control Systems, A “State-Dependent (Differential) Riccati Equation” Approach

Introduction / Objective
Recently, the easy-to-implement state-dependent Riccati equation (SDRE) strategy has been shown to be effective for numerous practical applications, possessing collectively many of the capabilities and overcoming many of the difficulties of other nonlinear control methods. Due to the great similarity to SDRE, the newly emerged state-dependent differential Riccati equation (SDDRE) approach shares most of the benefits of SDRE and exhibits great potential from both the analytical and practical viewpoints. However, there is a lack of theoretical fundamentals to support all the successful implementations, especially the feasible choice of the possessed design flexibility (namely, the infinitely many factorizations of the state-dependent coefficient, SDC, matrix) with some predictable performance is still under development for both schemes. Regarding the general-finite-order nonlinear time-variant systems, we try to resolve several problems related to the flexibility, since they appear at the very beginning of the implementation of both schemes.

Research Methodology
The main results are verified by mathematical derivations, using
- Linear Algebra & Its Applications (e.g. Dynamical Systems)
- Nonlinear Optimal Control (e.g. Bellman/Pontryagin Principal)
- Matrix Analysis & Computation (e.g. solving Riccati equation)

Results & Conclusions
The proposed results are for the nonlinear time-variant systems with general finite orders, and are demonstrated to effectively continue the SDRE/SDDRE scheme, when the fixed SDC matrix produces no solution yet the presented solvability condition is satisfied, via several benchmark examples from textbooks and significant real-world applications. Specifically, we summarize the following:
- Necessary and sufficient conditions for the existence of feasible SDC matrices, such that the corresponding SDRE and SDDRE would result in solutions with properties of existence, uniqueness, and positive (semi-)definiteness.
- Easy construction/determination/parameterization of feasible SDC matrices, such that the corresponding SDRE/SDDRE would result in a solution with properties of existence, uniqueness, and positive (semi-)definiteness.
- Conditions on the optimal control recovery for both the SDRE and SDDRE strategies.

Major publication
Solidification of Al-based ternary and quaternary eutectic alloys

Introduction / Objective

With the increasing demand for stronger and better-performance materials in response to the limited energy supply and the finite natural resources, it is important to understand the microstructure formation in a multicomponent and multiphase alloys. Eutectic alloys are one of the interesting materials offering superior casting and advantageous mechanical properties. However, the current knowledge is only limited to binary and some ternary systems. Thus, the aim of this study is to expand the eutectic growth theory to higher order systems, including further investigation of a special divorced eutectic growth in a ternary alloy and the expansion of the knowledge of the coupled eutectic growth to a model quaternary system.

Research Methodology

Advanced processing techniques have been used to process an Al-base ternary alloy (Al-Mn-Si) in the European Space Agency Solidification and Quench Furnace (ESA SQF, Figure 1, top) installed on the International Space Station (ISS) and a model quaternary alloy (Al-Cu-Ag-Mg) in the advanced solidification processing facility (ASPF, figure 1, bottom) of Department of Materials Engineering, KU Leuven. Two types of 3D techniques (CT and serial sectioning using focused ion beam, FIB) have been used for the materials analysis.

Results & Conclusions

• Particles layer structure caused by symbiotic eutectic growth was obtained under both gravity (1g, ground reference GM) and microgravity conditions in space (μg, FM) as shown Figure 2. New mechanism for the particle pushing and engulfment (PET) was proposed for the complex Al-Mn-Si system.

• Quaternary eutectic structure in Al-Cu-Ag-Mg model system was studied in 3D (Figure 3) and eutectic spacing adjustment mechanisms of rod splitting and merging were identified to be different from 2D analysis in binary or ternary systems.

Figure 1 Solidification processing facilities: ESA SQF (top) and ASPF (lower), details in text.

Figure 2 3D particle layer structure reconstructed by CT: (1) 1g, (2) μg, detail in text.

Figure 3 3D eutectic structure obtained in Al-Cu-Ag-Mg quaternary eutectic alloy.

Major publication

Experimental and modelling investigations of structure-property relationships in nano-reinforced cellular materials

Introduction / Objective
Nowadays, the most important structural application of cellular solids is in light-weight sandwich structures where they are used as a core material. A better understanding of the properties of foam cores in relation to their structural organisation is essential for performance optimisation of existing cellular solids and for the development of new core materials. The goal of this PhD research is to systematically study the behaviour of popular core materials, such as balsa wood and PVC and SAN foams, and of novel nano-reinforced PP and PU foams.

Research Methodology
The study was carried out using experimental methods supported by modelling investigations. The experimental methodology included micro-CT image analysis, compression tests at micro- and meso-structural levels and fracture toughness evaluation. Some of the tests are not standardised and were designed specifically for this study. The modelling methods involved the homogenisation approach, the mechanics of honeycombs (models), the classical lamination theory and the computed tomography-based finite element analysis.

Results & Conclusions
- The correlations between the measured properties and the microstructure of the cellular solids were successfully established. Material behaviour trends were explained from the morphological point of view.
- The established structure-property relationships helped identify strategies that can be implemented to achieve, for a given density, higher Young's moduli in cellular materials.
- A positive “nano-effect” on the fracture toughness of the nano-clay-reinforced PP foams was observed.
- The stiffness prediction models of the studied cellular solids were developed. The homogenisation scheme has to be used with caution for the cellular solids, which microstructure is subjected to local bending deformations.

Major publication
Hardware-Backed Identity Management Systems

Introduction / Objective
This thesis tries to contribute to answering the question how hardware based security technologies, more specifically secure element and trusted execution environment technologies, can be applied to realize the diverse set of requirements inherent to identity management systems and technologies. This thesis focuses on the use of existing hardware-based security technologies rather than developing new hardware components.

Research Methodology
We apply commodity hardware security technologies to increase the security, privacy and user-centricity of identity management systems. They can provide an alternative to conventional security technologies or they can be used to realize complementary security properties. Two approaches are presented:
- Secure Element-Backed Identity Management.
- TEE-Backed Identity Management.

Results & Conclusions
Secure Element-Backed Identity Management
- Informed consent via trustworthy application
- Secure entering of PIN
- Selective disclosure with X.509 credentials
- Bind credentials to owner via biometrics

Secure Element-Backed Identity Management
- Controlled release of identity information
- Unlinkable user pseudonyms for each provider
- Offline use
- No profiling by IdP
- Attribute aggregation

Major publication
Numerical simulation of the mechanical behavior of ankle-foot orthoses to enhance the patients’ functional outcome.

Introduction / Objective
An Ankle Foot Orthosis (AFO) is commonly used in clinical practice to assist gait of patients with different pathologies. There is no methodology to predict the effect of an AFO on gait before the AFO is manufactured. Such a prediction would benefit clinical decision making and therefore functional outcome. The aim of this research is to develop a method enabling the prediction of the functional effect of a specific AFO on a specific patient. This requires both a quantification of the stiffness of the AFO produced with specific design characteristics and an evaluation of the functional effect of the stiffness of the AFO on gait.

Research Methodology
To quantify the stiffness of the AFO, a literature review is performed and the parameters that influence both the stiffness of golden-standard polypropylene (PP) AFOs and the stresses occurring in those AFOs, are identified. Furthermore, two FE-models are developed to investigate the influence of these parameters on the stiffness of the AFO.

Selective Laser Sintering (SLS) is introduced as a more consistent and controllable production technique compared to PP-AFOs. The effectiveness of an SLS-AFO on drop foot gait is assessed using gait analyses and a comparison is made between the clinical performance of SLS-AFOs and the clinical performance achieved using custom-molded PP-AFOs.

To evaluate the functional effect of the stiffness of the AFO on gait musculoskeletal simulations are used. Different formulations to allow a simultaneous change of the kinematic pattern and the muscle excitations during gait are proposed. Furthermore, an algorithm to optimize the stiffness of the AFO based on the prediction of metabolic energy during gait is proposed.

Results & Conclusions
Results show that:
- SLS-AFOs show a clinical performance that is at least equivalent to the golden standard PP-AFOs.
- Both single muscle compensation mechanisms (figure) and more convenient kinematic gait patterns can be suggested using these algorithms.
- Optimization of the stiffness of the AFO based on the prediction of metabolic energy during gait is possible, however the kinematic input remains of great importance.

Major publication
Characterization of Materials for Low Temperature Bonding of Miniaturized Interconnects

Introduction / Objective

In the novel type of device architecture, such are 3D Integrated Circuits, miniaturized interconnects play a large role. Sn and Sn based alloys are materials commonly used for the production of the micro-bump interconnects. Due to the decrease of the micro-bump size, solder is completely transformed into intermetallics upon bonding. These intermetallics are formed as the result of the solder-under bump material reaction (commonly Cu or Ni), and their mechanical properties are not well known. Within the scope of this study an attempt was made to extract some of the mechanical properties of the Cu-Sn and Cu-Sn-Ni based intermetallics. Apart from that, a thorough study of the phase transformations and growth of the phases by solid state diffusion was investigated in the selected samples. The obtained results have revealed the novel insight into the mechanical and microstructural response of these intermetallics under loading and/or increased temperature. By comparing the obtained results among various intermetallics investigated, a proper selection necessary for the future design of the micro-bumps is enabled.

Research Methodology

Due to their small scale, mechanical properties extraction of intermetallics in thin films and micro-bumps, was done by nano indentation. The results obtained in this manner were compared and correlated with the indentation test results on the same intermetallics obtained by Spark Plasma Sintering. To measure the values of toughness and get insight in failure mechanisms of the investigated intermetallics, the 3-point bending and compression tests were conducted on sintered samples.

Microstructural development occurring in the thin film and micro-bump samples, during solid state ageing, was mostly conducted based on the results of the: Scanning Electron Microscopy (SEM) results combined with Electron Dispersive Spectroscopy (EDS).

Results & Conclusions

- Mechanical properties of the Cu-Sn and Cu-Sn-Ni were extracted by different techniques and their failure mechanisms have been determined.
- Based on the values of mechanical properties, it was determined that Cu-Sn based intermetallics have superior properties compared to the Cu-Sn-Ni ones.
- Microstructural investigation of the thin film samples submitted to the solid state ageing have revealed that the phase transformation kinetics depends on the deposition (stacking) sequence and the thickness of the layers. Understanding of the occurring phase transformations is very important as the initial input for the further micro-bump design.

Major publication.

Efficiency analysis of innovative tuning methods for immunity testing in reverberation chamber and comparison to anechoic room. Application to civil and military testing in the RMA chamber

Introduction / Objective
The use of reverberation chamber (RC) for immunity testing to radiated electric fields is limited to military and some specialized standards. RC’s are not yet accepted as an alternative to semi-anechoic room (SAR) in civil standards. The objectives are, firstly, to conceive, design and evaluate the efficiency of innovative and less cumbersome tuning systems and, secondly, to compare the severity level of RC and SAR for immunity to radiated electric field testing.

Research Methodology
In order to perform a severity comparison of the immunity testing to electric fields between RC and SAR, a Canonical Equipment Under Test (CEUT, connected to its laptop with optic fiber, see Fig. 1) has been designed, developed and manufactured at the Royal Military Academy. It is an original realization with no equivalent in the EMC (ElectroMagnetic Compatibility) community. It consists of a coupling part, a sensitive electronic part and a remote control part. The aim was to be able to measure whether the electronics inside has been disturbed or not and to determine its susceptibility level in function of parameters like frequency, field strength and number of tuner steps. An unexpected development is that the CEUT has been accepted as reference material for Interlaboratory testing within ABLE (Association of Accredited Laboratories in Belgium). Moreover EMC testing laboratories in Germany and Japan have participated in this campaign.

Results & Conclusions
- Two new innovative tuning methods for RC are validated.
- New testing method for antenna efficiency measurement in RC.
- Conditions for equivalence between RC and SAR (Fig. 2).
- Experimental validation of Ergodicity in a RC (Fig. 3).

![Fig. 1: The CEUT (metallic box: 24.5x20x25 cm³)](image1)

![Fig. 2: Conditions for equivalence of immunity to radiated electric field testing.](image2)

![Fig. 3: Electric fields in a RC as an ergodic random process.](image3)

Major publication
Metaheuristics for the Orienteering Problem with Hotel Selection

Introduction / Objective
Routing problems are involved in many real applications in our daily life and an efficient solution to them can considerably improve the economic, social, and environmental aspects of our society. Some examples of these applications are in transportation and logistics as well as in tourism and healthcare systems. Although it is not straightforward to develop an effective method dealing with these types of problems, according to its wide range of interesting applications, it is worthwhile to explore and expand the knowledge of this field.

Research Methodology
Although there are some papers that consider intermediate facilities in node (and arc) routing problems, the hotel selection variant of the OP was not discussed before. No research was presented before with intermediate facilities and maximizing the total collected score, while the available time is not enough to visit all the customers.

For many of the NP-Hard optimization problems, exact methods are not able to solve instances of real word size in a computation time that is acceptable in practice. Depending on the practical application, this acceptable computation time can vary between a few seconds (e.g., on-line applications) or even several hours (e.g., strategic planning).

In this research, we have first introduced this new problem and its applications. Then, some (meta)heuristics are developed to calculate high-quality solutions in real time for this problem and a variant with time windows.

Results & Conclusions
A skewed variable neighborhood search (SVNS) as well as a memetic algorithm (MA) are proposed for the OPHS. A memetic algorithm (MA) and a two-stage heuristic (2ST) are developed for the OPHS with time windows. Benchmark instances with known optimal solutions are created to evaluate the implemented solution methods.

The results show that the memetic algorithm is a powerful metaheuristic that is efficiently compatible with the two-level structure of the OPHS.

Figures compare the quality of the results of applying the proposed algorithms on different sets of instances in terms of the average gap with the optimal solution.

Introducing and solving the OPHS and its variants such as the OPHSTW is certainly an added value to the literature of the field of routing problems (with profits). It is a challenging optimization problem with many interesting practical applications. From our experience, the OPHS inherits characteristics of the OP (combination of Knapsack problem and TSP), but due to the hotel selection level, an even greater effort is required when solving the instances. Moreover, in any proposed algorithm dealing with this problem, one should consider that in looking for a good quality solution, it is critical to find a good sequence of hotels.

Major publication
Overhoused People / Underused housed?
Towards a sustainable reassembling of the post war housing stock in suburban Flanders, Belgium

Introduction / Objective
After the Second World War, the privately owned, detached single family house became the dominant building type in Flanders. This PhD dissertation focuses on the widespread phenomenon of ‘underuse’: houses inhabited by fewer people than the surface and number of bedrooms would allow for. Today, the concerns about the sustainability of the underused suburban housing stock are growing. The research goal is twofold: gaining insight in the experiences of people living in underused houses and formulating appropriate policies for a transformation of the underused suburban housing stock.

Research Methodology
The research is based on an interdisciplinary perspective with material stemming from 61 home visits and interviews with 91 home owners – predominantly empty nesters – living in underused, detached single family houses in 10 municipalities geographically dispersed over the Flemish region, supplemented with 20 interviews with key informants.

Results & Conclusions
• The image of ageing home owners for whom life in the underused house is problematic can be refined. These houses fulfill an important role both in the lives of the empty nesters and in the extended family life.
• The image of sedentary villa owners not willing to renounce their spacious dwelling can be refined. The desire for independence and self-sufficiency surpasses the emotional bond with the house.
• A public support analysis on different neighbourhood transformation strategies shows the largest support for a reconfiguration strategy consisting of incremental infill through house and plot subdivision.
• The suburban housing stock proves to be very ‘obdurate’ resulting of a complex entanglement of the materiality of the house, the meaning of home, the local home culture, real estate values, spatial policies, zoning plans, the legislative framework, taxes, and regional and local politics.
• This PhD dissertation advocates a ‘sustainable reassembling’ of the suburban housing stock based on a collaborative planning process, a spatially selective, integral and integrated approach, and a responsibilization of the involved actors.

Major publications
Thermo-Mechanical Study of Chip-Package Interaction Effects for 3D Stacked IC Technologies

Introduction / Objective
This PhD thesis finds its place within a particular field of microelectronics - three dimensional stacked integrated circuits (3D SIC). 3D SIC represents a technology with the potential to further increase the speed of integrated circuits and lower their power consumption.

The objective of this PhD thesis is to detect, describe and provide solutions for thermo-mechanical effects of 3D IC stacking and packaging on the Si die front-end-of line (FEOL) in order to improve 3D IC stack/package performance.

Research Methodology
The methodology can be split in several sections:

- Developing a stress calibration methodology to enable benchmarking of FEOL device stress sensitivities
- Providing fundamental understanding on the thermo-mechanical behavior of 3D IC stacks, in particular related to the underfill-microbump stress
- Developing FEOL stress sensors and using them to monitor and interpret stress development through 3D assembly processes – stacking, packaging
- Provide guidelines for mitigation of mechanical stress in Si caused by 3D assembly processes

Methods used include: the finite element method (FEM), 4-point bending, nano-indentation, opt. and mech. profilometry and X-ray diffraction

Results & Conclusions
Si in-plane and out-of-plane stress sensors were successfully implemented. The underfill-microbump stress mechanism was explained and resolved by introducing new materials and stack geometries. Packaging of 3D stacks preserves local stresses and introduces new global stress patterns.

Major publication
A robust approach to topology optimization accounting for geometric imperfections

Introduction / Objective

Topology optimization is a powerful design tool which seeks the best layout for a structure by optimizing the material distribution in a predefined design domain. The design obtained by classical topology optimization usually forms a very efficient solution for the structural problem at hand; however, in practice its performance might be strongly reduced by uncertainties in the system. More specifically, the optimized design often consists of slender members which are sensitive to geometric imperfections. Structural members under compression are particularly sensitive as the influence of initial imperfections is magnified by nonlinear effects and even the structure’s global stability might be affected. The main goal of this thesis is to develop a robust approach to topology optimization which takes into account geometric imperfections.

Research Methodology

- A density-based approach is used to formulate the topology optimization problem as a nonlinear programming problem which can be solved efficiently using a gradient-based optimization algorithm.
- A Total Lagrangian finite element formulation is adopted to incorporate geometric nonlinearities in the optimization.
- Geometric imperfections are modeled by means of random fields in a probabilistic framework.
- Robust Design Optimization is performed while using uncertainty quantification techniques (e.g. collocation methods or perturbation methods) to estimate the robust performance measure during the optimization process.

Results & Conclusions

The robust approach provides well-performing designs that are also insensitive to geometric imperfections.

Major publication

Introduction / Objective
The main challenge in automatic speech recognition (ASR) is robustness against the various sources of variability present in speech signals. Whereas humans excel in coping with this variability, the algorithms used in the current ASR systems still fall short. Two main sources of variability in the speech signal that deteriorate the performance of ASR systems significantly are environmental variability and speaker variability. In this thesis, we look at various methods to either model the variability or reduce the variability.

Research Methodology
The techniques used to handle the variability in a speech signal can be categorized in two major classes. Feature based (front-end) techniques rely a.o. on feature normalization steps to obtain features that are minimally affected by a source of variability. Model based (back-end) techniques are more difficult to implement but are intrinsically more potent since they extend the acoustic model with, sometimes rudimentary, knowledge on how the source of variability affects the observed speech signal. We investigated novel techniques from both classes:

- **parametric histogram equalization (pHEQ)** is a front-end technique which compensates for additive background noise;
- **non-negative matrix factorization (NMF)-based speaker adaptation** adapts the Gaussian mixture weights in the acoustic model;
- **NMF-based noise compensation** learns how the Gaussian mixture weights need to be changed in the presence of noise.

The proposed techniques are evaluated and analyzed on large vocabulary continuous speech recognition benchmark tasks. To investigate the impact of noise, different types of noise with different signal-to-noise ratios were added to the noise free data.

Results & Conclusions
The results show that the proposed algorithms can significantly improve the performance of ASR systems.

- **pHEQ** improves the performance of the speech recognizer when handling noisy input speech. Input from a noise tracker assures good performance when dealing with non-stationary noise, and future improvements to the noise tracker automatically improve the efficacy of pHEQ.
- **NMF-based speaker adaptation** can, due to the small number of degrees of freedom, adapt the acoustic model quickly to a new speaker, leading to improved performance. The technique is complementary to eigenvoice speaker adaptation, a known technique which adapts the Gaussian means instead of the Gaussian weights.
- **NMF-based noise adaptation** allows fast adaptation of the acoustic model to the instantaneous noise. The main challenges lie in obtaining a sufficiently accurate measurement of the instantaneous noise and in preventing an incorrect estimate of the noise from adversely impacting the accuracy.

Major publication
Amorphous metal-oxide semiconductor based thin-film electronic devices for RF applications on foil

Introduction / Objective
Low-temperature processed thin-film electronic devices represent an emerging alternative for applications where traditional silicon based technologies cannot be employed: in large-area, flexible, transparent and low-cost circuits. During this doctoral project, devices and circuits based on amorphous indium-gallium-zinc-oxide (a-IGZO) for Ultra-High Frequency (UHF) applications were developed, targeting energy harvester for passive RFID tags. It was shown, for the first time, thin-film technology based active devices and integrated circuits capable of operating at the UHF range.

Research Methodology
Thin-film based devices have intrinsically a lower performance than traditional silicon based circuits. Therefore, the development of integrated circuits based on thin layers of IGZO capable of operating at UHF represents a high technical challenge. This objective was successfully achieved by combining:

- Fundamental understanding of Schottky barrier formation and interfaces with a-IGZO.
- Developing and optimizing new processes to achieve stable devices and integrated circuits.
- Employing RF characterization methods that were not yet used within the thin-film community.
- Designing antennas and impedance matching circuits for the optimal circuit performance.

Results & Conclusions
- Demonstration of thin-film IGZO Schottky diodes with record cutoff frequency of 3 GHz at 0 V bias.
- Integrated IGZO rectifiers and RF-DC voltage boosters with functionality at the UHF range.
- Demonstration of a full energy harvester at far-field range.
- Plastic compatible processes for flexible UHF thin-film circuits.
- Direct measurement of a-IGZO subgap states.

Major publications
Understanding the effect of confinement on droplet coalescence in shear flow

Introduction / Objective
Polymer blending is an interesting route to create new materials with enhanced properties. These properties are dependent on the blend morphology. For a droplet-matrix type of morphology the final morphology is the result of two processes: breakup and coalescence. When polymer blends are used in microfluidic devices, effects of the walls (confinement) on the droplet coalescence are expected. Hence, in this work the effect of confinement on droplet coalescence is studied.

Research Methodology
Two model materials are used for this study: polydimethylsiloxane as droplet material and polyisobutylene as matrix material. Both materials are Newtonian, optically transparent and liquid at room temperature.

A counter rotating parallel plate shear flow cell is used to perform the experiments. The two plates rotate in opposite direction, creating a stagnation plane. Droplets in this plane can be easily visualized with a microscope.

The effect of several parameters on droplet coalescence is studied: initial offset (ΔY/2R), droplet size (2R), gap spacing (H), confinement ratio (2R/H), capillary number (Ca) and droplet to matrix viscosity ratio.

Results & Conclusions
- The critical conditions for coalescence are mapped out as function of initial offset and capillary number.
- Confinement induces a new type of trajectory at small initial offsets: reversing trajectories.
- Confinement promotes coalescence: it increases the critical capillary number and critical initial offset.
- Confinement increases the coalescence efficiency.
- The effects of confinement are similar for different viscosity ratios.
- With increasing viscosity ratio coalescence becomes more difficult.
- All these effects are qualitatively explained with the help of numerical simulations and a thorough investigation of the droplet trajectories.

Major publication
Event-driven Demand Response for Electric Vehicles in Multi-aggregator Distribution Grid Settings

Introduction / Objective
In the search to accommodate increasing shares of renewable energy into today’s electricity system, demand response has received renewed research attention. At the same time, the introduction of charging electric vehicles (EVs) at residential locations shows that current distribution grids were never dimensioned for the coinciding activation of such large loads. Solutions are needed that safeguard the state of distribution grids and at the same time allow large-scale demand response based on market objectives.

Research Methodology
In this work, first a multi-agent based coordination mechanism for large-scale demand response is developed. The mechanism operates at two distinct levels. At the market level, flexibility offered by the EVs is used in an optimization to find an optimal schedule, from a business perspective. At the real-time level, respecting technical constraints in distribution grids is the main objective, and interaction at this level takes place using event-based communication.

Results & Conclusions
The results show that the proposed event-driven coordination mechanism for EVs provides a suitable method for solving demand response problems, even in a multi-aggregator distribution grid setting. While the mechanism may be suboptimal compared to other proposed solutions, it provides very good scalability and low complexity, which is beneficial for large-scale implementations. Furthermore, even in the weak distribution grid configurations that were examined, the need for additional grid congestion management mechanisms beyond voltage droop control can be challenged.

Major publication
Contact Technology for the On-Chip Integration of Ge and III-V Compounds for Advanced Microelectronics Applications

Introduction / Objective

The focus in this PhD work is to contribute in finding solutions to produce low resistive, thermally stable ohmic contacts on III-As and Ge: these high mobility semiconductors materials are believed to enable further scaling and improved performance for MOSFET devices in the sub-20 nm CMOS technology nodes. Contacts should fulfill at the same time the strict requirement for integration in Si platform and deliver extremely low resistivity specifications for advanced CMOS.

Research Methodology

Typically ohmic contacts are formed by the deposition of a metal on a semiconductor surface followed by a thermal treatment which triggers reactions to form alloys between the two materials. For this PhD research, contacts were first investigated from a physical viewpoint (assessing the reaction upon annealing of different metals -Ni, Mo, Ti...- with the semiconductor surfaces); finally electrical characterization was carried out, extracting specific contact resistivity ($\rho_{ct}$) which describe the quality of an ohmic contact. Two main parameters determining good ohmic contacts are the active doping concentration ($N_D$) of the semiconductor and the Schottky barrier height (SBH) of the metal/Semiconductor interface. To achieve very low resistance high $N_D$ and low SBH are desired, however for n-III/As and n-Ge it is very difficult to achieve high $N_D$ values as well as modulate the SBH.

Results & Conclusions

- For n-III/As, Au-free contact schemes were studied checking thermal stability of solid phase reactions of Pd/Ge and Ni/Ge as well as single metals (Ti, Mo, Ni) and extracting their $\rho_{ct}$. Lowest values are obtained with Mo-based metallization ($5 \times 10^{-7} \ \Omega \cdot cm^2$), proving thermally robust up to 600 °C. A self-aligned (SA) integration ready contact scheme for III/As was proposed, using selective Ge growth and selective Ni germanidation (Fig.1).
- For n-Ge two approaches are compared to achieve high $N_D$: dopant segregation via germanidation and laser activation (LA) of doping: with LA samples $8 \times 10^{-7} \ \Omega \cdot cm^2$, with snowplow $2 \times 10^{-6} \ \Omega \cdot cm^2$ (Fig.2).
- For n- and p-GeSn alloy, Ni germanide contacts were compared with Ti-based metallization. Compared to n-Ge, our results on n-GeSn showed lower SBH: such materials can be used as stressor on Ge-channel MOSFETs, boosting mobility of the channel without compromising the parasitic components.
- Current and contact resistance was modeled in order to obtain indication on the values of SBH and $N_D$ needed to achieve the values indicated by ITRS roadmap for CMOS technology below 20 nm node (Fig.3).

Major publication

Wave Based Modeling Methods for Acoustic Inclusion and Multiple Scattering Problems in the Mid-Frequency Range

Introduction / Objective

The effect of sound on living quality is significant. Good acoustic properties are not considered luxurious for commercial products anymore, but necessary, which leads to the requirement of efficient and robust numerical simulation tools for acoustic problems. Whereas dedicated methods have been established for low- and high-frequency regions, such as the Finite Element Method, the Boundary Element Method, Statistical Energy Analysis, ray tracing methods etc., they fail to address mid-frequency region effectively. The Wave Based Method (WBM) has a potential to solve the mid-frequency problem, however it is restricted to moderately complex geometries. The main goal of this thesis is to assess and enhance the WBM and relax its geometrical requirements.

Research Methodology

Multiple scattering and inclusion problems are defined as the target applications. The available WBM technologies are applied on such settings and the method is further developed to efficiently tackle geometrically complex problems.

Results & Conclusions

Assessment and enhancement of the WBM and the Multi-level WBM:
- The WBM is assessed for a large-size problem in the mid-frequency range by a room acoustics case.
- Symmetric b.c. are derived for the ML-WBM for 2D and 3D problems.
- The ML-WBM is used in shape and topology optimization scenarios to exploit its numerical advantages.
- Innovative lens designs are proposed as a result of the optimization calculations.

Relaxing the geometrical requirements of the WBM:
- A hybrid Boundary Element – Wave Based Method is developed for 2D/3D inclusion and multiple scattering problems.
- The method’s efficiency is demonstrated by benchmarking against the FEM and the BEM.

Major publication

Dataflow-inspired parallel and distributed computing: Practical techniques and real-world use cases

Introduction / Objective
Key challenges in parallel and distributed computing include: development of concurrent programming models, deployment, scheduling, memory management and synchronization. We use dataflow-inspired techniques for organizing computation and data at a high level of abstraction, in order to address these challenges.

Research Methodology
In this thesis, we show how different challenges in parallel and distributed computing can be overcome for specific applications, chosen from different application domains and with different characteristics:
- High-performance computing, where we applied a dataflow-based model for programming stencil computations.
- Real-time embedded computing where we improved middleware support for dataflow models, focusing on optimizing schedules of applications on MPSoCs.
- Ubiquitous computing, where we apply dataflow-based modeling and optimization techniques, in order to deploy applications in ubiquitous environments.

Results & Conclusions
Our results show that programming stencil operations with dynamic task graphs reduces their synchronization overhead, resulting in an implementation that scales better than the state-of-the-art (figure 2). For mapping and scheduling applications on MPSoCs, we observe that modeling the inter-dependencies that enable tighter coupling between different aspects of the system i.e. computation, communication and memory, improves the energy efficiency and/or performance of the system (figure 1). The execution semantics of dataflow models play a key role in enabling this tightly-coupled scheduling. Use cases in the domain of ubiquitous computing demonstrate the usage of dataflow-based modeling and optimization techniques for the deployment and configuration of dynamic applications in highly heterogeneous and distributed systems.

Major publication
Zubair Wadood Bhatti, Roel Wuyts, Pascal Costanza, Davy Preuveneers, Yolande Berbers, Efficient synchronization for stencil computations using dynamic task graphs, Procedia Computer Science, volume 18, pages 2428-2431, ICCS, Barcelona, Spain, 5-7 June 2013
A mesoscopic study of gas bubbles in liquid metal in a Hele-Shaw cell

Introduction / Objective

High quality observations of gas bubbles in liquid metal are vital for a further development of pyrometallurgical gas injection reactors. The opacity of metals however enforces the use of indirect imaging techniques with limited temporal or spatial resolution. In this PhD study an innovative approach is explored to circumvent these restrictions and observe gas bubbles in liquid metal with an unprecedented resolution.

Research Methodology

Instead of considering gas injection in the bulk of a liquid, bubbles are studied in a thin layer of liquid metal entrapped between two flat and closely spaced parallel plates. The resulting quasi-two-dimensional multiphase flow phenomena in such a so-called Hele-Shaw cell can be fully captured from a single point of view, avoiding the need to apply tomography. Furthermore, by using a transparent cell material that is not wetted by the metal, bubbles contours can be observed directly, avoiding the need for radiography. Based on these principles a setup is developed to visualize bubbles with unprecedented resolution at temperatures over 700°C.

Results & Conclusions

The viability of the suggested approach is first demonstrated at room temperature by observing buoyancy driven nitrogen bubbles in liquid mercury. A detailed quantitative analysis of the hydrodynamics clearly shows the unique capabilities of the setup, yielding new insights with respect to flow properties, regime transitions and volume variations for bubbles in metals. Afterwards, the applicability for industrially relevant systems is confirmed by unique observations of nitrogen bubbles in liquid zinc at 700°C in a fused quartz cell.

Considering these results, the relative simplicity of the setup and the fact that the governing effects in a Hele-Shaw cell are similar for unconfined geometries, it is concluded that the suggested approach seems very promising as a first, easy accessible step in an experimental study of gas injection in liquid metals, supporting future developments in this field.

Major publication

Optimal Control of Traction Motor Drives Under Electrothermal Constraints

Introduction / Objective
Future requirements on electric traction drives are getting increasingly stringent. A reduction of cost, weight and volume is required, while an increase of efficiency, power density and reliability is necessary as well. Performance figures are not only determined by the properties of individual drivetrain components, but also in the way traction motors, power electronic converters and energy storage interact as a system. Because this interaction is (for a large part) determined by the applied control strategy, a large potential for improvement is situated in this area. This thesis investigates how advanced control algorithms can contribute to improve performance inside electrical and thermal constraints.

Research Methodology
Degrees of freedom that can be controlled include the motor current vector (angle and amplitude), switching frequency and DC-link voltage. These control variables all have an influence on losses and hence also on motor and inverter component temperatures. By taking the actual thermal state of the drivetrain into account (thermal model feedback), they can be controlled in such a way that peak torque/power of the drive is maximized for every operating condition, without violating electrothermal constraints of the components. Hence, a better, more efficient and more reliable utilization of the drivetrain hardware can be achieved compared to conventional control.

Results & Conclusions
The control strategy was validated on an 11 kW PMSM drive, coupled to a dynamic load emulation machine:
- Maximized overall motor and inverter efficiency over the entire operating range
- Reduced switching loss at low speed allows a higher standstill and starting torque
- Increased inverter lifetime due to reduced thermomechanical stress on IGBTs
- Power and torque maximization inside electrothermal constraints

Major publications
Introduction / Objective

Thanks to recent developments of Information Technologies, there is a profusion of available data in a wide range of application domains. The demand for real-time processing, mining and analysis of these data is experiencing an explosive growth because it can allow to make new scientific discoveries, design optimal business strategies, optimize industrial processes etc. In this thesis we have investigated how to detect interesting patterns present in the data and monitor their evolution over time through a dynamic cluster analysis.

Research Methodology

In order to unveil the evolving structure of the data under study we have developed new algorithms in the Least Squares Support Vector Machines (LS-SVM) framework. In particular, problems like community detection in evolving networks, fault detection in industrial machines and clustering in a non-stationary environment have been tackled. The main strategies that have been adopted are:

- Design of a novel model which incorporates the temporal smoothness between clustering results in successive timesteps when analyzing an evolving network described as a sequence of snapshot graphs.
- Construction of a new adaptive clustering method to process a non-stationary data stream, which is computationally efficient and allows to properly track the evolution of complex patterns over time.

Results & Conclusions

In what follows the main contributions of this thesis are resumed:

- We conceived a complete methodology to cluster big network data in a fast and efficient way.
- A new model is designed to handle evolving networks. Also new model selection criteria specific for the given application are introduced. The technique is compared to various state-of-the-art algorithms showing a competitive performance.
- We have developed a clustering model able to infer the degradation process affecting a packing machine from the vibration signals placed on the sealing jaws. The model is able to predict the need of maintenance actions due to the dirt accumulation in the jaws.
- We presented a new algorithm to perform online clustering in a non-stationary environment. The method is able to catch the dynamics of the clusters evolving over time by modelling merging, splitting, appearance, death, expansion and shrinking events, in a fast and accurate way.

Major publications

Sustainable materialisation of residues from thermal processes into construction materials

Introduction / Objective
Industrial processes operating at high temperatures generate solid residues (slags and ashes) and carbon dioxide as their main byproducts. These residues are often left unvalorised or are valorised for low economic value applications. The composition of these residues are promising in terms of their use as binders in construction applications. In this research, the fine slags form the stainless steel producing industries were used and their binding properties were investigated by using alkalis (alkali activation, AA) or treatment with carbon dioxide (carbonation). The mix compositions showing potential were then used to produce and test prototypes simulating masonry blocks.

Research Methodology

Results & Conclusions
- Continuous casting (CICs) and argon oxygen decarburisation (AOD) slag show potential for valorisation as construction materials in the presence of steam curing and alkali silicates as well as accelerated carbonation.
- The compressive strength of the specimen develop with the increase in temperature of steam curing during alkali activation and duration of curing during carbonation in a carbonation chamber (CC) or a reactor.
- The construction materials from the slag show potential for industrial application and have lower environmental impact than regular construction materials available in the market.

Major publications
Modeling and compensation of non-ideal effects in microwave circuits and systems

Introduction / Objective
Non-ideal effects, such as nonlinearity and memory, are present in every RF system. They can degrade the performance considerably, if they are not dealt with well. Compensation of these effects can be done at the circuit level or the system level. In this work we investigated system-level compensation of non-ideal effects by using signal processing techniques. Implementation of these techniques improve the accuracy, energy efficiency and spectral efficiency, which are crucial in emerging and future telecommunication systems.

Research Methodology
The research was conducted in three areas: characterization, modeling and mitigation of non-ideal effects. A method for characterization of intermodulation products and memory effects by using a novel multisine excitation is presented. In the area of modeling, a new Volterra-based model is proposed. The model is then used to mitigate non-ideal effects in power amplifiers, by using an FPGA-based setup. The research was not restricted to mitigation in the transmit band, but it also included characterization, modeling and compensation of non-ideal effects in the receive band caused by the emission from the transmitter in RF transceivers. A signal processing approach is also developed to compensate the non-ideal effects of RF signal generators in post-processing. All the proposed methods are supported by experimental evaluations.

Results & Conclusions
By using signal processing techniques, the performance of RF system can drastically improve. The improvement can be in accuracy, energy efficiency and spectrum efficiency. The techniques can be applied in both Tx- and Rx-bands. The figure on the right shows the accuracy of modeling the deterministic receive-band noise applied to the measured data. Signal processing can also improve signal quality of signal generators in post-processing, as shown in the figure on the left.

Major publications
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Development of tools for the analysis and prediction of the mechanical properties of glass fibre reinforced polyurethane foam sandwich panels

Introduction / Objective
This research focuses on the mechanical properties of a polyurethane foam sandwich panel and its different constituents. The sandwich panel was recently developed by Recticel nv. and can be found in automotive applications as a lightweight alternative for more traditional materials. Moreover, the characterization of the separate constituents is of importance for future PU-foam material developments in other domains as well. The main goal of the study is to build different tools to analyze and predict the mechanical properties of the aforementioned materials.

Research Methodology
A FE-model of the open cell PU foam was built by means of the following steps
- Characterization of the cellular morphology of the open cell PU foam
- Selection of an appropriate RVE for the FE-model (Kelvin and Weaire-Phelan cell)
- Construction of the FE-model and application of the boundary conditions
- Extraction of the eng. constants a.f.o. relative density and shape anisotropy of the cells.

Secondly the skin thickness, and the stiffness of the sandwich panel skins and core was determined. Since the skins and core of the sandwich panel are formed during the production process, special measuring techniques (e.g. X-ray micro CT) were applied.

Results & Conclusions
- The Weaire-Phelan structure represents the real foam structure better than the Kelvin cell.
- The minimal surface energy approach proved to be an efficient method to model the linear elastic properties of the open cell foam
- The different in situ, produced sandwich panel components were successfully characterized.
- An easy accessible software tool was built to predict the homogenised stiffness off the sandwich panel
- This facilitates future material developments

Major publication
Thinking Public Spaces through the Spatiality of Arab women. The case of Nablus, Palestine

Introduction / Objective

This dissertation is devoted to 'Women & Public Spaces'. The main objective is to conceptualize public spaces through the spatiality of Arab women, and to reveal the mechanism of actions shaping their urban experiences in modern Arab cities. The research provides a critical perspective towards the urban feminist theory by highlighting the limitations of its application in Arab contexts, and provides a culturally sensitive approach to gender planning in the Arab World that resonates with the social and urban lives of many Arab women.

Research Methodology

The theoretical argumentations on Arab women's spatiality were supported by empirical research conducted in Nablus, Palestine. The field work aims to analyze the spatiality of women in Nablus. A set of observations and semi-structured interviews were designed to examine the social and physical constraints affecting the everyday lives of more than 100 women in five urban settings: the city center, two urban neighborhoods; and two outdoor recreational spaces, the so-called mutanazahaf. The spatiality of women in Nablus is analyzed in relation to four components: cultural norms, space audience (namely men), space organization and spatial opportunities.

Results & Conclusions

Most interviewed women in Nablus demonstrated passive engagements with the examined outdoor public spaces for two reasons: the lack of spatial opportunities that meet their socio-spatial needs, and that Nablusi women are subjected to socio-cultural norms that limit their accepted public behaviors. To conclude, semi-public spaces are promoted as the first step towards the 'spatial justice' for women in Nablus, as their socio-spatial structures would enhance women's active engagement and facilitate claiming their 'spatial rights' in the long run.

The spatial presence of interviewed women increases when the publicness of spaces decreases. This classification of indoor spaces is based on their social status (i.e. their publicness in relation to space audience). Women's confinement to the private home is mainly due to the lack of convenient recreational spaces in Nablus.

Major publication

Manueline ribbed vaults - The innovation of João de Castilho

Introduction / Objective
This thesis examines Portuguese ribbed vaults from the Manueline period (end of the fifteenth and beginning of the sixteenth century), with particular reference to those of architect João de Castilho. Historical issues include the originality of the Jerónimos Monastery church vaults. Structural issues relate to the behaviour of the barrel forms, and the polemic surrounding the ribs function. The chief issue concerns architecture, the geometry used in elevation and in the creation of complex forms, as well as on a broader scale, the methods of design and construction of ribbed vaults.

Research Methodology
1. Analyses of the historical sources of João de Castilho’s vaults.
3. Study of the Manueline ribbed vaults. A typology of vaults was created based on the types of ribs.
4. Construction details and structural analysis of two barrel vaults, based on surveys and diagnostics in situ, finite elements methods and contemporary structural rules.
5. Geometry analyses and hypothesis of design and construction, in 40 mapped case studies, drawing primarily on works by João de Castilho, based on principles in use at the time.

Results & Conclusions
- The historical and architectural analyses confirm the authorship and originality of the Jerónimos Monastery church vaults. Identifies German and Spanish influences, particularly in the use of compound and curved ribs.
- The structural analyses emphasize the importance of construction details, especially the masonry. Contributes to understand the construction and structural function of straight and curved ribs.
- The architectural analyses identify and characterize João de Castilho’s vaults. Bring new ideas on the methods for conception and construction of ribbed vaults, specially for the creation of the form.

Major publication
Development of low-fouling Thin Film Nanocomposite (TFN) membranes

Introduction / Objective
The potential of tailoring the separation performance for specific applications makes Thin Film Composite (TFC) membranes of great interest. However, the main obstacle of using TFC membranes is that the top layer is prone to membrane fouling. The objective of this research is to design and develop a low fouling Thin Film Nanocomposite (TFN) membrane, mainly to acquire a fundamental insight in the effect of manufacturing conditions on structure and performance of TFC membranes, fixation of TiO₂ nanoparticles, membrane fouling, and enhancement of the membrane performance.

Research Methodology
- Investigation of the effect of manufacturing conditions on structure and performance of TFC membranes.
- Development of a procedure to enhance the stability and efficiency of nanomaterials in/on the membranes.
- Comparing structures, surface properties, permeability, selectivity, and antifouling performance of membranes to acquire a fundamental understand in the influence of each nanomaterial to the TFC membranes.

Results & Conclusions
A facile and versatile method to robustly bind TiO₂ nanoparticles on TFC membrane surfaces by using a novel “bio-glue” polydopamine is proposed. The dopamine can be self-polymerized on the surfaces of membranes and TiO₂ nanoparticles, and form a strong connection between them. Comparing with the traditional self-assembly binding method, polydopamine can irreversibly bind more nanoparticles on the membrane surfaces. This modification method showed a great anti-fouling performance both in visible light and dark conditions.

This binding procedure can be adapted for a variety of substrates to bind nanomaterials without a complex surface pretreatment. Using polydopamine to bind TiO₂ can easily introduce visible light photocatalysis to most of the substrate surfaces.

Major publication
Dynamic power management in content distribution networks

Introduction / Objective
The Internet was designed for communication between hosts but is increasingly used as a means to distribute content. Therefore, overlay networks are required for high-quality, highly available, and bandwidth-efficient content distribution. Such content distribution networks (CDNs) consist of cache servers deployed in data centers at the edge of the Internet close to the content consumers. The rapidly rising number of power-hungry cache servers fuels the unsustainable increase of data-center power consumption. We aim to save energy in content distribution networks.

Research Methodology
- Survey and analysis of power-reduction techniques for data storage systems to identify techniques applicable to CDNs
- Trace-driven CDN energy simulator to assess energy-saving techniques in content distribution networks
- Near-optimal offline heuristic greedy policy for combined server and disk power control to benchmark online policies
- Online load-directed threshold-based policy for combined server and disk power control that can be used in practice

Results & Conclusions
- Classification of power-reduction techniques according to impact on performance, dependability, and capacity
- Workload traces reveal cyclic load fluctuations resulting in energy waste because CDN is not energy proportional
- Near-optimal policy uncovers potential to reduce energy consumption by nearly 30% (even for minimally provisioned CDN)
- Online policy (LofoSwitch) realizes 85% of energy-savings upper bound and saves 30% more energy than state-of-the-art (Hibernate) while ensuring high availability (>99.999%) and high bandwidth efficiency (>99.9%)

Major publication
Towards a 3D GIS based monitoring tool for a Preventive Conservation Management of the World Heritage City of Cuenca

Introduction / Objective
Postponed interventions make large heritage restorations increasingly controversial, complex and expensive. The overall goal is to provide a sound scientific background for the preventive conservation paradigm shift and to demonstrate that a value-based monitoring system in a Geographic Information System (GIS) environment helps the prioritization of interventions and improves the cost-benefit balance in heritage management.

Research Methodology
This research started by the development of a conceptual framework for the value-based monitoring system for the heritage conservation planning of World Heritage Sites (WHS). To this end the proposed monitoring system deals with two essential aspects: 1) the definition of the heritage values as basis for the identification of the features to be monitored in WHS and, 2) the management of a wide range of information of the heritage objects documented with high geometrical and semantic precision. For this aspect the Delphi technique and semi-structured interviews were used to validate the Outstanding Universal Values of the case study (Cuenca - Ecuador). The Nara-Grid was the linking tool between the heritage values, valuable features and the monitoring system. The spatial semantic of the valuable features was supported by a data model, which was extended to the third dimension. The data model was based on the CityGML standard, which provides an open data model for 3D city representation and is focused on the semantic aspects of the model components.

Results & Conclusions
The work performed in the doctoral project offers a solid basis for the further development of fine-tuned multi-scale monitoring systems, enabling improved heritage management and the design of certified preventive conservation strategies. The extension of the CityGML data model for preventive conservation purposes is a major step ahead for the 3D modelling of heritage features and related disturbances and threats.

Major publication
A New Method for Analyzing Plasmonic Circuits Using Integral Equation Techniques

Introduction / Objective
Plasmonics has obtained significant attention in the last few years. Applications are envisaged in communications and information technologies, chemical and biological sensors, enhanced solar cells and so on. Reducing the production cost requires reliable and accurate solvers which are able to numerically analyze the structure before fabrication. Numerical methods that discretize current carrying bodies are enforced to use tiny segments in order to describe the volumetric polarization currents. Otherwise, the rapidly decaying fields inside the metals will not be modeled correctly. Therefore new numerical methods are required which can analyze plasmonic integrated circuits efficiently.

Research Methodology
The original problem is separated into two sets; interior and exterior. The interior problem is analyzed independent of the outer region and introduces a relation between tangential electric fields on the boundary and the equivalent surface electric current. This relation is called surface impedance boundary condition. In another step, this boundary condition is enforced on the exterior problem and the fields in the outer region are computed.

Results & Conclusions
The derived operator surface impedance is an exact method that theoretically can solve scattering problems with different shapes and material types. A technique for finding the proper Green’s dyadic is also introduced.

Major publication
A framework for integrated configuration management of distributed systems

Introduction / Objective
People and companies rely extensively on software services, that grow larger and more interconnected. This increases the complexity to correctly configure distributed systems. Configuration management tools can automate configuration management tasks but the current state of the art lacks: a high level of abstraction in their specification, integration of configuration management of all subsystems and devices, they cannot refine high level concepts to working applications and an incremental adoption for real systems: both physical and virtualized.

Research Methodology
We developed a framework for integrated configuration management. It offers system administrators the technology to:
• Model the configuration in a desired state configuration model.
• Integrate the configuration of the entire execution environment in an integrated configuration model.
• Create a modular configuration model that provides reusable configuration modules.
• Use multiple levels of abstraction in one model by using refinement.
• Generate deployable configuration artifacts for real world systems.
• Support incremental deployment of abstract configuration models.
• A framework that allows the integration of ad-hoc scripting practices that interface with the configuration model.

Results & Conclusions
A functional prototype (+ 56 configuration modules) of the framework was developed. This prototype was used in 3 case studies that show that the framework can: manage heterogeneous equipment, automated parameter allocation and allows integrated configuration management and iterative deployment of complex distributed systems on Cloud computing platforms.

To conclude, the framework contributes:
• Integrated configuration management.
• Model refinement to allow all abstraction levels in a single model.
• Deployment on real systems with real case studies.
• The tooling for a principled approach to describe complex configurations and make changes to it.

Major publication
Bart Vanbrabant, Thomas Delaet, Wouter Joosen, Federated access control and workflow enforcement in systems configuration, Proceedings of the 23rd Large Installations Systems Administration (LISA) conference, pages 129-143, Baltimore, MD, USA, 1-6 November 2009
Introduction / Objective
Software as a Service (SaaS) has been increasingly adopted by software vendors as their main software delivery model in order to benefit from the economies of scale. Multi-tenancy is a key enabler to leverage economies of scale by sharing resources among tenants (i.e. customer organizations). However, a high degree of resource sharing typically results in a one-size-fits-all approach, limiting SaaS applications in terms of flexibility and variability. Therefore, the goal of this research was to address this trade-off by introducing the necessary flexibility to customize shared SaaS applications at a per-tenant basis, without compromising the cost efficiency, performance and scalability.

Research Methodology
The approach used in this research is application-driven and started with the study of and hands-on experience with the current state of practice to identify the open challenges. On this basis, this research integrated and incrementally improved two research lines, respectively in the domain of software engineering and middleware:

- Software product line engineering to address the management complexity of many co-existing variants,
- Adaptive middleware to enable run-time composition and reconfiguration of these variants, scoped to a specific tenant

Results & Conclusions
- Comparison of representative PaaS platforms and gap analysis
- Middleware framework to support co-existing variants in multi-tenant SaaS, focusing on:
  - Efficient, run-time composition of software variants
  - Rapid, run-time enforcement of performance isolation
- Service line engineering method to introduce and manage variability in a cost-efficient and scalable manner

These middleware platforms, concepts, and methods have been implemented, validated, and evaluated in the realization of several prototypes based on industry-relevant application cases.

Major Publications
Removal of arsenic from groundwater using physico-chemical methods

Introduction / Objective
Arsenic (As) contamination of groundwater in several parts of the world is the result of natural and/or anthropogenic sources that have a large impact on human health. Since only membrane technologies or conventional technologies may not be sufficient to mitigate As related problems in drinking water due to several limitations and a combination of both technologies seems to be more effective to efficiently meet the drinking water quality. The objective is to explore new or emerging physico-chemical approaches to achieve an effective removal of As from contaminated groundwater.

Research Methodology
• Fundamental research in arsenic removal from water and its corresponding removal mechanism.
• Investigate the efficiency of forward osmosis (FO) for As removal.
• Examine the performance of FO, RO and NF for As removal in groundwater condition.
• Reduction of higher oxidation As species (III, V) in aqueous concentrate to lower oxidation state [namely As(0)] using zerovalent iron.
• Aiming an integrated/hybrid technology for a complete treatment of As contaminated water and remaining secondary waste fractions to solve the drinking water scarcity in developing as well as developed countries.

Results & Conclusions

Removal of individual ions by BW30, SWHR, NF90, and NF270 membranes

Major publication
Mondal, P., Tran, A.T.K., Van der Bruggen, B., Removal of As (V) from simulated groundwater using forward osmosis: Effect of competing and coexisting solutes. (Accepted 2014: Desalination).


Clinical Data Miner
Towards more efficient clinical study support

Introduction / Objective
Clinical diagnostic model research aims to optimize diagnostic procedures, by applying statistical and machine-learning techniques to patient data, for extracting models. Separate software packages handle different aspects of its workflow. Due to this lack of integration, this workflow requires considerable manual effort. Clinical Data Miner (CDM) therefore aims to offer an integrated software framework for Electronic Data Capture (EDC), data preprocessing and machine-learning.

Research Methodology
CDM is implemented in Java, using a Test-Driven Development (TDD) approach. Feature requirements were defined in collaboration with prof. D. Timmerman and dr. T. Van den Bosch.

Results & Conclusions
CDM is a user-friendly, multi-centric, web-based software framework, integrating EDC, data preprocessing, and machine-learning. The TDD approach has resulted in few software issues, hence high user satisfaction levels. In the context of the studies of the International Endometrial Tumour Analysis (IETA) consortium, CDM has collected over 3600 patient entries so far. The integration of data collection and data analysis vastly simplify the extraction of models. The functionality for generating learning curves enables study coordinators to assess whether to continue or to terminate data collection, avoiding both unnecessary data collection and weakly performing models, enabling more efficient clinical diagnostic model research.

Major publication
Middleware for the Inspection of Complex Software Systems

Introduction
With the increasing impact of computers on society, we are faced with the obligation of maintaining an increasingly complex ICT infrastructure. Unfortunately, the current software infrastructure is too complex to observe without specific inspection tools. This thesis aims to lay the foundation for the creation of such tools, that enable comprehension of complex software, by representing the running system in terms of the abstractions that the various stakeholders can understand.

Research Methodology
We have followed an incremental approach by studying four sub-problems; the solution of each of these problems has brought additional insight and know how, and has been demonstrated by creating and using relevant software prototypes.

Results & Conclusions
Apart from an overarching conceptual model, we have provided four innovative prototypes:
- **AODA**: a generic debugger for AspectJ like languages.
- **AOPS**: a run-time policy enforcement system for AspectJ.
- **QVTD**: a generic solution for agile run-time inspection middleware, capable of performing dynamic and selective state transformations.
- **MonArch**: an overarching framework for multi-abstraction inspection of large scale distributed systems. It allows information about such systems to be collected effectively. It also provides advanced support for transformation of inspection data, to convert the raw data to a format more suitable for human consumption. It enables sharing of inspection data between different stakeholders and provides a first step towards the application of even more advanced analytics.

Major publications
Interactions between cement and combined concrete admixtures
The influence on cement paste rheology

Introduction / Objective
The current lack of reliable engineering tools in traditional concrete production methods sometimes leads to inconsistent control of the concrete workability (e.g. right figure). Today’s advanced models, that try to capture the flow behavior of fresh concrete, keep facing problems which are linked to the agglomeration of the cement particles and to the implementation of combined concrete admixtures.

The objective of this work is to investigate the rheological mechanism in cement paste for the combined use of superplasticizer, retarder and accelerator. In particular, an effect on the particle agglomeration is aimed for in order to contribute to a more fundamental understanding of the concrete’s flow behavior.

Research Methodology
This fundamental research combines dedicated analytical methods and conceptual models to improve the understanding of particle agglomeration. To that end, a multi-disciplinary approach and new concepts were developed:

- Combined thermodynamic modelling and mineralogical investigations have been applied to identify the different rheological performance of two similar cements at very young age
- Physico-chemical analysis clarified the adsorption mechanism and repulsive functionality of sodium gluconate
- The agglomerative strength of particle clusters has been probed indirectly with the elastic modulus
- An agglomeration model was proposed to relate the macroscopic agglomeration rate and the measured agglomerate connectivity

Results & Conclusions
- The superplasticizer (SP) can change the hydrate morphology to such an extent that the interparticle contact forces are modified.
- The extra addition of retarder (SG) led to a densified polymer layer at the cement grain surface which contributed to the steric stabilization of the cement paste.
- For the extra addition of accelerator (CN), an interstitial structure was assumed to diminish the rheological effect of the polymer layer.
- Generally, the cumulative amount of hydrates within the agglomerates influenced the agglomerate stability and the amount of external hydrates determined the reagglomeration rate. The different relations are shown at the left for the three admixture combinations.

Major publication

Severe damage to the building due to dense steel reinforcement that congested the flowing concrete
Simulating luminance distributions of luminaires from ray files

Introduction / Objective
For luminaires with a non-uniform luminance distribution, glare evaluation should be based on luminance maps. These luminance distributions cannot be simulated directly for light source models based on experimental near-field goniophotometric data. To enable accurate simulations of these luminance distributions, the following research questions/objectives must be answered/met:

- Development of new simulation approaches enabling luminance distribution simulations of light sources characterized by experimental near-field goniophotometric data.
- Investigation of the influence of optical modeling of surface scattering of materials surrounding a light source on simulated luminance distributions.
- Development of a new innovative approach to minimize the instrument function characteristics of a surface scattering measurement device.

Research Methodology
- Optical ray tracing simulations using Monte Carlo techniques allowed to develop new sampling strategies for ray files, while enabling the validation of simulated with measured luminance distributions obtained with near-field goniophotometers.
- Similarly, the influence of a BSDF measurement instrument signature was simulated and compared with measured data. Minimizing this impact of the instrument signature through deconvolution methods was first performed on analytical and simulated data. Afterwards the approach was validated against measured data.

Results & Conclusions
- Development and validation of a ray file sampling technique allowing the simulation of luminance distributions from ray file data for planar and hemispherically shaped light sources.
- Research showed that BSDF data has a great impact on the accuracy of simulated luminance distributions.
- Successful deconvolution of BSDF data resulting in much more accurate luminance distributions.

Major publication
Microsystems encapsulation using nanoporous alumina

Introduction / Objective
The traditional IC packaging techniques based on metal bonding and plastic overmolding are not directly applicable to the growing variety of new microsystems (like MEMS) used in modern appliances like biomedical implants and smartphones. This research aims to develop a simple process for microsystems encapsulation, which will lead to more package miniaturization, improved reliability and increased functionality of state-of-the-art microsystems.

Research Methodology
- **Technology and materials:** An innovative Al anodization process is developed to create nanoporous alumina membranes featuring a high density of cylindrical nanopores of 10 to 20 nm diameters. These membranes are used to encapsulate microsystems at wafer-level in (vacuum) microcavities, sealed with an impermeable layer (e.g., silicon nitride or Al).
- **Design and modeling:** Analytical and finite element models are used to predict the thermomechanical and electromagnetic behavior of the micropackages and the encapsulated microsystems.
- **Performance and reliability:** The strength, hermeticity, reliability and RF compatibility of the new micropackages are evaluated using a comprehensive set of tests and experiments.

Results & Conclusions
A wide variety of on-wafer encapsulated microsystems (e.g., Al-based RF lines and Ni-based MEMS) with micropackages of different shapes and sizes are realized. Some micropackages have sufficient strength to survive an epoxy overmolding process (performed at 30 bar pressure and 175 °C temperature). A significant impact of the package structure and its sealing ring width on its hermeticity is further observed. The micropackages also show high reliability under extreme stresses including mechanical shocks, temperature variations and high humidity levels. Finally, micropackages with an improved design were proven to have no negative impact on the RF characteristics of encapsulated transmission lines.

Major publication
Relational Visual Recognition

Introduction / Objective

This thesis aims to contribute towards the idea that visual scenes and object grasping scenarios are best described using high-level representational devices that are based on semantically meaningful entities, such as graphs, and more generally using logical and relational languages. The main research questions it addresses are: can visual recognition benefit from SRL? and can we develop effective and real-world relational visual recognition systems?

Research Methodology

The key contribution of this dissertation is the use of several (statistical) relational learning techniques for different computer and robot vision problems. Different from early work in computer vision, relational representations have shown robustness to noise when combined with statistical techniques. This is an important step towards relational visual recognition and thus, closing the loop with the old literature. To achieve this goal, the thesis makes five main contributions:

- A relational distance-based framework for hierarchical understanding of images (application: house facades)
- The use of a kernel-based relational language for scene classification and scene tagging
- A probabilistic logic pipeline for task-dependent robot grasping
- A relational kernel-based approach to numerical feature pooling (application: robot graspable point prediction)
- The employment of state-of-the-art SRL systems for video sequence recognition (application: videos of UNO game)

Results & Conclusions

We can have real-world visual recognition systems that exploit SRL effectively:

- Successfully distinguished between indoor scene categories in cases where non-relational systems cannot.
- Visual scenes correctly classified by our relational system:

Object recognition results obtained with our SRL approaches are competitive with state-of-the-art while using sparser cues (house recognition in images of houses).

Major publication

Unsupervised Algorithms for Cross-Lingual Text Analysis, Translation Mining, and Information Retrieval

Introduction
With the ongoing growth of the global network and information influx in today’s increasingly connected world, more and more content becomes readily available in a plethora of different languages, dialects, unofficial and community languages. Considering the large amount of multilingual data which are typically unstructured but thematically aligned and comparable, there is a pressing need to build unsupervised algorithms which can deal with such multilingual data, and address the fundamental problems of meaning, translation and information retrieval in multilingual settings.

Research Methodology
The thesis presents four major contributions to the related fields of data mining, natural language processing and information retrieval:

I. Multilingual probabilistic topic modeling (MuPTM)
(an overview of the family of probabilistic graphical models inducing structured language independent representations from unstructured multilingual data)

II. A new statistical framework for inducing bilingual lexicons from structured high-quality parallel data
(the problem of translation)

III. MuPTM-based framework for cross-lingual semantic similarity and bilingual lexicon extraction from unstructured comparable data
(the problem of meaning and translation)

IV. MuPTM-based framework for cross-lingual and multilingual information retrieval
(the problem of information search and retrieval)

Results & Conclusions
Using MuPTM-based language independent representations of words and documents leads to
- a completely novel framework for modeling cross-lingual semantic similarity (out of context and in context)
- state-of-the-art performance in the task of bilingual lexicon extraction and suggesting word translations
- a completely novel framework for cross-lingual information retrieval and its state-of-the-art performance

Unsupervised algorithms - works for many language pairs!

Next step: From multilingual to multi-modal settings!

Major publication
Life Cycle Assessment of Biobased Fibre-Reinforced Polymer Composite

Introduction / Objective

Today, global environmental issues, such as global warming and fossil depletion, drive a paradigm shift in material applications from conventional fossil sources to renewable sources. In this thesis, the biobased alternative, i.e. flax fibre, which is one of the most widely used natural fibres, is studied as a glass fibre substitute from an environmental impact point of view. Moreover, a newly emerging biobased polymer, the wheat gluten, is analysed in the study; and it is compared to a conventional polymer and to a commercially available biobased polymer.

Research Methodology

The main question addressed in this thesis is whether there are general environmental advantages for the use of flax fibres over glass fibres, and for the wheat gluten polymer over petrochemical polymers. Although biobased materials are often perceived to be environmentally friendly, an in-depth analysis is still needed to answer this question. Life cycle assessment (LCA) is considered to be an appropriate tool for environmental impact quantification:

- A process-oriented DNDC method for field emissions estimation
- A Life Cycle Environmental Impact Indicator is proposed for material selection
- Both consequential LCA and attributional LCA are applied

Results & Conclusions

- The DNDC method leads to a reduction of 17% in the impact category of climate change per kg retted flax straw production in comparison to the level obtained from the IPCC method.
- Economic allocation is selected for the flax fibre extraction process
- Depending on the applied design criterion, the used reinforcement type and associated manufacturing processes, different conclusions were obtained concerning the environmentally preferable solution
- In the case of consequential LCA, different scenarios are presented. Wide ranges of impact results are obtained through different scenarios.

Major publication

The numerical solution of elliptic partial differential equations with fuzzy coefficients

Introduction / Objective

Uncertainty quantification is playing an increasingly important role in the mathematical modeling of physical phenomena. The classical approach to the modeling of uncertainties is to use probability theory. In some cases, it can, however, be argued that probability may not be the most appropriate mathematical representation of the uncertainty. One of the modeling alternatives is then provided by fuzzy sets. The main goal of this thesis was the development and analysis of numerical methods for solving fuzzy differential equations (DE), with the steady-state diffusion equation as our main model problem.

Research Methodology

Solving the fuzzy diffusion equation leads to a sequence of DE-constrained optimization problems over nested hypercubes. One of the approaches to exploit the shared information between those optimization problems is the response surface method. This boils down to constructing a response surface approximation of the solution to a corresponding parametric DE. The optimization problems are then solved by means of this response surface. We develop and analyze various numerical methods to construct the response surface efficiently and accurately. Second, we also propose an optimization strategy based on low-rank tensor methods for optimization over high-dimensional hypercubes.

Results & Conclusions

Discretizing the parametric DE by a Galerkin approach using finite elements in the spatial domain and a spectral basis of Chebyshev polynomials in the parameter domain results in a very large linear algebraic system of Kronecker product structure. We propose a center-based preconditioner and a multigrid preconditioner. Both preconditioners are shown to have optimal convergence properties.

Discretizing the parametric DE by a collocation approach leads to a sequence of similar linear systems. We develop two recycling strategies that reuse intermediate results or computations of previously solved systems to reduce the computational effort of solving the next system. Numerical experiments show they lead to a significant reduction of the computational effort.

The cost of optimizing a continuous real-valued function over a hypercube is known to scale exponentially with increasing dimension. The optimization algorithm based on low-rank tensor methods that we develop is shown to outperform state-of-the-art optimization algorithms in a numerical test with some challenging high-dimensional problems.

Major publication

Learning from structured EEG and fMRI data supporting the diagnosis of epilepsy

Introduction / Objective
In a significant ~30% of epilepsy patients the occurrence of seizures cannot be controlled by medication. Surgical resection of the region responsible for generating the epileptic seizures might offer remedy for these patients. This thesis aims at developing automated analysis techniques to support presurgical evaluation.

Research Methodology
Electroencephalography (EEG) and functional magnetic resonance imaging (fMRI) measure the changes of brain activity over time at different locations. As such, they provide valuable information on the nature, timing and spatial origin of the epileptic activity. The fundamental principle behind the proposed data analyses techniques is to exploit the characteristic spatiotemporal structure underlying epileptic brain signals.

Results & Conclusions

1. Automated seizure detection
The use of nuclear norm regularisation induces low rank structure, therefore, it allows to incorporate spatial information from the multichannel EEG. As a result, seizure detection performance improves even if limited amount of training seizure examples are available.

2. Seizure modelling using Block Term Decomposition
BTD decomposes a tensor in low multilinear rank terms. As such, it can extract nonstationary seizure patterns which evolve in frequency or topography even from severely contaminated EEG.

3. Localising the seizure onset zone using Independent Component Analysis
ICA can extract sources from the fMRI time series which coincide with the seizure onset zone even in cases where no epileptic activity is seen in EEG. Subsequently, a classifier should be applied to automatically select the epileptic independent component. Finally, the spatial map corresponding to the selected component provides localisation information.

Major publication
The development of quasi-Monte Carlo Methods for problems in finance

Introduction / Objective
The aim of my research was to develop new and powerful mathematical tools for computationally challenging problems in the area of finance. Many products that are routinely traded in the markets are high-dimensional in nature, and in order to quote prices institutions often resort to Monte Carlo (MC) simulations. The downside of using random points is the rather slow convergence. In order to dramatically slash time complexity these random points can be replaced by low discrepancy point sets, also called the quasi-Monte Carlo (QMC) method. The merit of QMC methods in this field has been shown time and over again for some basic financial products. However, where the MC method is robust and can be applied without much thought, one has to be much more careful when applying QMC methods.

Research Methodology
- Look at recent challenges found in the market.
- Construct tailor-made QMC routines to dramatically increase performance.
- Numerically investigate the new methods.

Results & Conclusions
Two major contributions were made. The first was a breakthrough in reducing the variance of the estimated value of basket options with barrier features. These are options on several assets that either become worthless when one or more assets hit a certain level (the barrier), or only become worth something if one or more assets hit the barrier (or a combination thereof). By using QMC and a clever algorithm that forces the assets to stay away from (or hit) the barrier a significant variance reduction was achieved.

The second achievement was made in the area of optimal asset execution. These problems deal with splitting large asset orders in smaller pieces over time in order to reduce the execution cost. This is at its core a complex stochastic optimization problem. Such problems are usually only solved for trades in one asset, as adding more assets rapidly inflates the problem dimension; a huge problem for the usual PDE solvers. A rolling horizon algorithm was created that, while sub-optimal, can deal with such high-dimensional problems in a fast and an easy-to-understand way. QMC is used to reduce the number of samples needed to obtain a decent performance.

Major publications
CMOS millimeter wave receivers

Introduction / Objective

CMOS is the preferred process for digital integrated circuits such as processors and RAM chips. Thanks to technological progress, namely gate-length scaling, these circuits have become faster over the years. But along with the digital speed, also analog speed has increased. Therefore we can now use CMOS to make analog circuits at millimeter wave frequencies (30 to 300 GHz), such as transmitter and receiver RF front-ends for telecommunication systems. Using higher frequencies, we can obtain higher bandwidths and thus higher data rates. This work investigates the use of CMOS technology to build analog receiver front-ends at millimeter wave frequencies to achieve data rates of tens of gigabits per second. These systems can be wireless or based on a new type of wired connection: plastic waveguides.

Research Methodology

High-speed data communication using millimeter waves in CMOS is investigated on three levels:

- Physical layer: both wireless and plastic waveguide connections are characterized
- Circuit level: design, layout and verification
- System level: starting from the link budget, system specifications are determined

Several CMOS processes (90 nm, 45nm, 40nm) are used to fabricate receiver chips. The research on the physical layer gives information of the loss that can be expected from the channel. The system level design uses this information to make up a link budget, which dictates the system specifications such as transmitted power, received SNR, noise figure and linearity. These specifications are used to design the circuits which are fabricated and measured in the lab. Beside measurements of receiver specs, modulated signals are also applied to test the data communication link.

Results & Conclusions

The first CMOS implementation that is demonstrated, is a 200 GHz down-converter. At the time of publication, this was the first CMOS circuit at such a high frequency with multi-GHz bandwidth.

A complete system-level model is presented of a Costas-loop based receiver. It is able to simulate the effects of noise and IQ-imbalance and produce eye-diagrams, constellation plots and compute bit error rate.

A 90 GHz receiver is fabricated for a plastic waveguide link. An on-chip bondwire antenna picks up the millimeter wave signal from the waveguide. A maximum data rate of 9 Gbps is achieved for a length of 60 cm and 2.5 Gbps is achieved for 9 m. These realizations show that CMOS is indeed a viable candidate for millimeter wave RF circuits and that by using these high frequencies, high data rates can be achieved. Plastic waveguides can serve as low-cost and low-loss channels for millimeter waves for distances up to 10 m.

Major publication

Data fusion

Tensor factorizations by complex optimization

Introduction / Objective

In our information age, the amount of data observed has increased tremendously in volume, velocity and variety. Concealed inside this new natural resource lies a wealth of information waiting to be mined. Arrays with two or more dimensions, known as matrices and tensors, respectively, serve as the computer representation of many types of data. Knowledge can be extracted, or inferred, from such arrays by capturing their underlying patterns and structure with so-called matrix and tensor factorizations that attempt to explain the observations with a small number of variables. The ever increasing volume of data demands new algorithms that can deal with the curse of dimensionality, while the growing variety of data calls for new approaches to integratively analysing several sources of data at once. The goal of this thesis is to develop data fusion as a new paradigm for the joint analysis of one or more data sets by coupled low-rank factorization of dense, sparse or incomplete matrices and tensors, leading to insights which are deeper and more accurate than those resulting from a single source of data. There are many choices to be made in a data fusion model.

Research Methodology

Tensor factorizations are one approach to integratively analysing a set of matrices of the same size. In fact, a tensor factorization can be interpreted as a joint matrix factorization in which the different factorizations are coupled with each other by sharing certain factors. Taking this idea one step further, the information in a set of data sets of different size and dimensions can be fused by factorizing each data set with a tensor decomposition and coupling these factorizations through their factors. Meeting multiple objectives and imposing structure are difficult tasks to achieve in an algebraic framework. We elect to use optimization, which is in comparison much more flexible and generic in nature, as the framework underlying data fusion.

Results & Conclusions

We developed a framework for the joint analysis of one or more data sets by coupled low-rank factorization of dense, sparse or incomplete tensors, leading to insights which are deeper and more accurate than those resulting from a single matrix factorization. The framework allows for a free choice of which decomposition to use for each data set and what kind of structure to impose on the associated factors, enabling users to rapidly iterate through the vast search space of possible data fusion models. Moreover, tensor decompositions and factor structures are a modular part of the framework so that users are able to pick from libraries of predefined components, or even add their own if desired. We have created a language with which data fusion problems can be modelled in an intuitive yet formalized way, and algorithms that are flexible enough to solve such dynamically generated problems. With Tensorlab (www.tensorlab.net) we offer a concrete implementation of an efficient set of kernels for operating on tensors, the data fusion modelling language and the accompanying algorithms built on these kernels.

Major publication

Experimental analysis of the dynamic characteristics and lubricant film of a ball bearing under combined static and dynamic load

Introduction / Objective
Rolling element bearing failure is one of the foremost causes of breakdown in rotating machinery. Bearings are cheap, but bearing failure is not. A 4000€ wind turbine bearing replacement can easily turn into a 200000€ project. Lifetime calculations of bearings are based on the ISO 281 standard. For bearings subjected to highly varying loads, recent research emphasises a strong reduction of the actual bearing lifetime w.r.t. the calculated bearing lifetime. The study of this manuscript aims to understand the effect of externally applied dynamic loads on the bearing lifetime.

Research Methodology
The effect of externally applied dynamic loads on the bearing lifetime is experimentally investigated in the following way:
- Development of a novel bearing test rig. The test rig allows multi-axial static and dynamic loading of different types and sizes of bearings.
- Analysis of the dynamic behaviour of a test bearing. The stiffness and damping properties are identified for different operational conditions.
- Analysis of the lubricant film during dynamic excitation. The behaviour of the lubricant film is measured using the bearing electrical resistance.
- Analysis of wear of the raceway surfaces during dynamic excitation. Accelerated lifetime tests under high dynamic load are performed.

Results & Conclusions
When introducing a radial or axial excitation on the bearing, the lubricant film thickness follows the imposed variations of the load. Variations of the lubricant film thickness are similar to the variations when the magnitude of the static bearing load is changed. An increase of metallic contact or breakdown of the lubricant film is not detected. Under axial excitation, sliding motion between asperities of the contacting surfaces in the bearing does occur. Accelerated lifetime tests reveal polishing of the raceway honing structure. This polishing is clearly observed on SEM images of the inner raceway after a test duration of only 0.5% of the calculated L10 life. When the bearing is further exposed to the high axial dynamic load, polishing wear of the surfaces is expected.

Major publication
Classical Electrodynamics and Plasmonics: an Engineering Point of View

Introduction
Within the framework of classical electrodynamics, we have systematically introduced a set of analysis tools based on the Volumetric Method of Moments (V-MoM) algorithm to study the interaction of a nanoantenna with incoming optical radiation. We believe that this set of tools can facilitate the analysis of the light-nanoantenna interaction and thus promise a new pathway towards the design of nanoantenna-based applications.

Research Methodology
Throughout the thesis, light-nanoantenna interaction has been solved at three levels. Under the assumption that the metals constituting the nanoantenna are linear and causal, we obtain:
I) the linear response of the nanoantenna to a given incident light at a specific frequency (See Fig. 1),
II) an excitation independent solution, i.e. the eigenmodes of a nanoantenna (See Fig. 2),
III) an excitation and frequency independent solution, i.e. the natural modes of a nanoantenna (See Fig. 3).

Results & Conclusions
To sum up, this work mainly focuses on the solution to the following three equations:

\[ Z(J_{\text{ind}}(\omega)) = E_{\text{inc}}(r, \omega) \quad \text{(See Fig. 1)} \]

\[ Z(J_{\omega}(\omega)) = \lambda_{\omega}(\omega)J_{\omega}(\omega) \quad \text{(See Fig. 2)} \]

\[ Z(J(\omega_n)) = 0 \quad \text{(See Fig. 3)} \]

Fig. 1. Illustration of the optical response of the G structure under a top excitation of X polarized light at 800 nm.

Fig. 2. Illustration of the frequency dependent eigenmodes of the V-shape structure.

Fig. 3. Illustration of the natural frequencies and natural modes of Gold (Au) and Nickel (Ni) nanopatches.

Major publication
Efficient frequency averaging techniques for noise and vibration simulations

Introduction and Objective
In the latest decades, noise and vibration characteristics of products have been growing in importance, driven by market expectations and tightening regulations. Accordingly, CAE tools have become irreplaceable in assisting acousticians and dynamics through the design process, and their accuracy and efficiency are essential to model the behavior of complex engineering systems. This dissertation aims at increasing the computational efficiency of simulation techniques for steady-state noise and vibration problems. In particular, the focus is on the efficient evaluation of the frequency averaged input power into a vibrating system.

Efficient frequency averaging
Classic approaches make use of numerical quadrature to evaluate a frequency integral. However, the response of a vibrating system is commonly a highly oscillating function of frequency, and a large number of sampling points might be required to achieve an accurate integration. As an alternative, the residue theorem is proposed to compute the weighted integrals. The band integral is computed by moving the path of integration to the complex frequency plane and applying efficient quadrature schemes. Due to the smoothness of the integrand in the complex frequency plane, the accuracy and efficiency of the integration are increased with respect to classic quadrature applied over real frequencies. This allows a significant reduction of computation time to evaluate frequency averaged input power. Moreover, it is shown that using numerical quadrature in the complex plane indirectly leads to the definition of a novel family of weighting functions over the real frequency domain.

Conclusions
The developed techniques for the evaluation of the frequency averaged input power are accurate, efficient, easy to implement and can be employed within any classic deterministic framework. The methodologies have proven to be very effective also for complex geometries, frequency dependent properties and in combination with optimization schemes. The proposed numerical strategies can also be extended to other branches of computational analysis where the evaluation of oscillatory integrals is required.

Major publication
Introduction / Objective

Acetic acid is an important organic chemical used in a wide range of applications worldwide. Since the separation of acetic acid from water using distillation is far from being the best process, any cost-efficient method to dehydrate acetic acid is in demand. Among many other alternative methods, membrane-based processes have been suggested. This study aims to explore the potential of reverse osmosis and pervaporation to separate the binary mixtures using commercial and lab-scale membranes, respectively.

Research Methodology

Separation of acetic acid and water mixture based on reverse osmosis using BW30-XLE membrane and pervaporation using self-made polyphenylsulfone (PPSU) membranes have been studied. Besides standalone pervaporation, a cascaded pervaporation process has been investigated using the CAPE-OPEN to CAPE-OPEN (COCO) simulator using Matlab custom models. Finally, the effect of silica nanoparticles on pervaporation has been evaluated. Other investigation activities include:

- Synthesis of PPSU membranes.
- Synthesis and modification of silica nanoparticles using hexamethyldisilazane
- Synthesis of silica nanoparticles incorporated PPSU membrane.

Results & Conclusions

- By using a reverse osmosis, at least 45% of acetic acid rejection was obtained.
- The transport of the permeants in a more dense top layer of the membrane are slower (PPSU-27.5 and 30), resulting in a lower flux.
- Scanning electron microscopy image of the cross-sectional area of PPSU membrane indicates finger-like pores structure.
- The replacement of –OH groups by trimethyl (CH₃)₃ groups results in a decrease in wetting of the surface of the membranes.

Major publication

**Automatic Speaker Characterization**

**Automatic Identification of Gender, Age, Language and Accent from Speech Signals**

**Introduction / Objective**

Listening to an utterance raises judgments about speaker characteristics such as gender, dialect, age and emotional state. However, the capability of making accurate judgments differs from person to person and requires expert knowledge. In this research, we try to employ the large memory capacity and fast data processing capability of computers to identify speaker characteristics from speech recordings automatically. Speaker characterization has a wide range of commercial, medical and forensic applications such as natural human-machine interaction, diagnosis and monitoring of speech-related diseases, directing the forensic investigation process in many forensic scenarios, and service customization. However, effective factors such as speech content, environmental noise, recording device and speech duration are not controlled in real-world scenarios and make the identification very challenging.

**Research Methodology and Results**

In this research, we first applied the state-of-the-art utterance modeling approach, namely the i-vector framework, to estimate the age. Evaluation results on spontaneous telephone speech recordings of the NIST 2008 and 2010 SRE corpora show that the proposed approach estimates the age of speakers with around 6 years mean absolute error.

To improve the state-of-the-art i-vector framework, we explored the availability of information in Gaussian mixture model (GMM) weights by applying them to speaker gender detection, age estimation and native language recognition problems. Our experiments show that GMM weights carry less, yet complimentary, information to i-vectors. Therefore, the non-negative factor analysis (NFA) framework for GMM weight adaptation has been developed. This modeling suggests a new low-dimensional utterance representation method, which uses a factor analysis similar to that of the i-vector framework. The obtained subspace vectors are then applied in conjunction with i-vectors to the language recognition, dialect identification and speaker age estimation problems. The evaluation results show that the proposed method yields more accurate recognition results compared to conventional weight adaptation approaches and an intermediate-level fusion of i-vectors and NFA vectors improves the performance of the state-of-the-art i-vector framework considerably.

**Conclusions**

- The i-vector framework has been applied to the speaker age estimation problem.
- GMM weights have been used for age, gender and native language identification.
  - It was shown that Gaussian weights provide a new source of complementary information to Gaussian means.
- The NFA framework has been developed for GMM weight decomposition and adaptation.
  - Evaluation results show that a fusion of i-vectors and NFA considerably improves the state-of-the-art i-vector framework in identification of speaker age, dialect and language.

**Selected Publications**

Formation and behaviour of Mn-containing oxysulphide inclusions during desulphurisation, deoxidation and alloying

Introduction / Objective
Manganese oxysulphides play a crucial role in the production of high clean steel. The effective utilization of these inclusions requires accurate control on their chemistry, microstructure, size distribution, morphology and dispersion in the steel matrix. Therefore, thorough understanding of the alloying, deoxidation and desulphurisation during the ladle refining is required for close control of the Mn-containing oxysulphide inclusions and thus proper inclusion engineering.

Research Methodology
Steel refining with lime-alumina based synthetic slag
- Sulphide capacity measurement and calculation (50 g scale)
- Proof the concept of de_[S] and cleanliness control (15 kg scale)
- Application in industrial ladle refining (120 ton scale)

Early stage of deoxidation and alloying
- Alloying dissolution and interfacial reactions (100 g scale)
- Inclusion formation and behaviour (0.5 g scale)

Results & Conclusions
Desulphurisation with the optimised lime-alumina slag compared to the current lime-silica-fluorspar slag
- Similar desulphurisation effect
- Improved steel cleanliness
- Predictable/controllable steel/inclusion composition
- Improved slag valorisation potential

Early stage of deoxidation and alloying
- Predicted alloy melting and dissolution
- Inclusion formation
- Large (or small) inclusions with Al and Mn(or Si) deoxidation
- Inclusion behaviour
- MnO/Mn(O,S) disappearance/dissolution
- Growth of Mn(O,S) during cooling

Major publication
P. Yan, M. Guo and B. Blanpain: In-situ observation of the formation and interaction behaviour of the oxide/oxysulphide inclusions on a liquid iron surface. Metall Mater Trans B, online published 10.1007/s11663-014-0024-0.
Origin of Defects in Directed Self-Assembly Using Feature Multiplication

Introduction / Objective

The continuously smaller sizes of line/space patterns required for transistor fabrication have passed the physical limit of traditional lithographic techniques. Directed self-assembly of diblock copolymers has emerged as a potential candidate to succeed the current optical lithography. However, defectivity remains as one of the main challenges for DSA of BCP to be implemented in the industry. The purpose of this project is to understand the origin of defects and their relationship to various boundary conditions and, at the same time, to determine the ultimate level of defects that can be obtained using directed self-assembly of diblock copolymers on chemically nanopatterned substrates.

Research Methodology

Approach:
- Implementation of the Liu-Nealey (LiNe) flow on 300mm wafers in order to access a controlled and automated processing and inspection.
- Assess the optimal properties of the chemical patterns that will minimize defect formation at given annealing conditions.
- Differentiation of defects originated from the assembly process from those originated by external sources.

Results & Conclusions

Investigation of multiple processing conditions on a single sample shows large window with good alignment of the BCP to the chemical patterns.

Optimization of the composition and dimensions of the chemical patterns for 3X density multiplication:
- Chemistry: P(51%S-r-49%MMA)
- Geometry: Width of the guiding stripe around 0.5L0 provides the largest process window.

Using optical inspection, it was found which specific materials and processing conditions were the main contributors to the final defect levels.

Major publication

Paulina Rincon Delgadillo, Gordon Craig, Roel Gronheid, Paul F. Nealey, Scale-up of a Chemo-Epitaxy Flow for Feature Multiplication Using Directed Self-Assembly of Block-Copolymers, *Journal of Photopolymer Science and Technology, 26*(6), 2013
Introduction / Objective

Tasks tackled using software are becoming ever larger, involving complex and fast-changing requirements. This evolution complicates software development, e.g., because in most software paradigms the domain knowledge is tightly mixed with how a task is solved. Recently, the Knowledge Base paradigm was proposed, based on the idea that knowledge is in fact not tied to a specific task. Instead, it proposes to specify knowledge in a truly declarative language; solving different tasks then comes down to applying the appropriate inference to the specified knowledge.

One objective was to put the paradigm into practice by building a knowledge base system and evaluate its applicability on practical applications. Second, the aim was to develop robust inference engines, to separate performance concerns from the modeling of knowledge.

Research Methodology

We developed IDP, a knowledge base system for the language FO(.)IDP, a rich extension of first-order logic. Inference engines were developed for optimal model expansion (closely related to combinatorial optimization) and deduction. The search algorithm MiniSat(IDP) was designed as the search backend of the system.

Experimental evaluation took the form of comparing performance against existing ASP and MiniZinc benchmarks, in combination with case studies in the domains of data mining, security and scheduling (see figure).

Results & Conclusions

The main contributions of the work are:

• The knowledge base system IDP, one of the first declarative systems natively supporting multiple inferences.

• A demonstration of the applicability of the KB paradigm, with reduced development time and easier maintenance is main results, without sacrificing performance.

• The solver MiniSatIDP, one of the best ASP and CP systems.

• Novel techniques to improve automated combinatorial search, that reduce the need for an initial grounding phase and detect some types of implicit knowledge.

Major publication

The numerical solution of large scale dynamic soil-structure interaction problems

Introduction

- Dynamic soil-structure interaction (SSI) often plays a crucial role in structural mechanics and should be accounted for in numerical models, e.g. for the following problems:
  - damage assessment of buildings subjected to earthquakes
  - design of offshore structures exposed to wind and wave loadings
  - annoyance evaluation of vibrations due to road and railway traffic
- The numerical solution of large 3D dynamic SSI problems is very challenging from a computational point of view, however, and often beyond current computer capabilities. Novel techniques are needed to cope with the challenges faced in academia and industry.

Research Methodology

- Efficient numerical techniques for large scale dynamic SSI problems have been developed:
  - fast boundary element method based on H-matrices
  - innovative algorithms for the coupling of finite elements and boundary elements
- Challenging applications related to railway induced vibrations have been tackled:
  - the influence of source-receiver interaction
  - wave propagation in an urban environment

Results & Conclusions

- The developed techniques enable the solution of much larger problems than classical methodologies.

Major publications

Introduction / Objective
Foams are encountered daily bringing flavor and texture to your espresso in the morning or your beer in the evening. They are also important in applications such as fire fighting and oil recovery. The overall goal of this thesis is to develop novel tools and concepts for studying and controlling film stability in foams and emulsions. A thin film balance set-up is developed and particle interactions are exploited to control film stability by interfacial rheology. A third objective is to study the effect of the surface free energy on the mechanical properties of clay-laden polyurethane foams.

Research Methodology
The stability of aqueous foams and emulsions is related to the interfacial properties and the stability of the liquid films. Here is focused on the controlling the interfacial rheological properties and study how these affect thin liquid film stability.
- A thin film balance set-up (see picture) is used to measure disjoining pressure-film thickness isotherms and to perform dynamic film thinning.
- Interfacial shear rheology is used to study roughness induced attractive capillary interactions between nanoparticles.
- Contact angle measurements are used to determine the surface free energy of clay powders. Resulting polyurethane foam properties are interpreted accordingly.

Results & Conclusions
1) A homemade thin film balance has been developed:
- It is validated by measuring the disjoining pressure-film thickness isotherm of simple surfactant foam film systems, of which literature data is available.
- The growth rate of black spots during stratification is measured. The data is used to evaluate literature models.
- The set-up is used to make large in vitro planar lipid bilayer with diameters up to 1 mm for the first time.

2) Rough nanoparticles at oil-water interfaces are studied:
- Lateral capillary attractions induce surface aggregation and lead to the formation of elastic monolayers.
- A mastercurve is obtained with which the effects of roughness, concentration and time can be scaled and evaluated.

3) The surface free energy of clay particles determine the properties of clay-laden PU foams:
- Clay particles with the highest compatibility with the matrix show the highest dispersion.
- The highest dispersion does not imply the best mechanical properties. On the contrary, clays, which are likely to get trapped at the cell wall during foaming, show most improvement.

Major publication
**Digitizer Architectures for Short-Range Wireless Localization in Nanoscale CMOS**

**Introduction / Objective**
This work is on the design of digitizers for short-range localization systems using chip technology (CMOS). The considered localization systems use estimations of signal arrival times to obtain the range between objects. The most famous and commercial example of such a localization system is GPS satellite navigation. The work closes the gap between high-level specifications for localization systems and design of the digitizer as part of the receiver. Covering a high bandwidth is a good method to create a high performance localization system. The way it is allocated has implications on design of the digitizer. The idea is to allocate a bandwidth as high as possible to get the best performance over the highest range at the lowest amount of power and the shortest signal durations.

**Research Methodology**
First, a theoretical basis is introduced with respect to localization based on signal arrival times. Two strategies are considered regarding the use of bandwidth. These are a single-carrier (SC) approach and a multi-carrier (MC) approach. A prototype digitizer chip for both types will be studied, designed, fabricated and tested.

Both digitizer chips exploit a different method to take advantage of high bandwidths. Both chips use the continuous-time digital domain since it fits the typical signals, used in these localization systems.

**Results & Conclusions**
- A figure-of-merit for the specific localization systems is introduced.
- Event-based digitizers have a significant added value with respect to classic digitizers. Though the effect of input depending propagation delays need to be tracked.
- The continuous-time digital domain is a useful signaling domain. For long signal durations, continuous-time digitizer architectures are beneficial if sampling clock stability and on-chip oscillator stability improves accordingly.
- The design flow of a digitizer using the continuous-time domain is dominated by long-lasting simulation times. A solution for reliable spectral analysis based on short simulation durations has been introduced.
- Discrete carrier localization is a valuable alternative to single carrier localization, achieving high-update rate, sub-cm range precisions at ranges up to 4 meters. Sub-sampling can be used to reduce power consumption in the receiver’s digitizer.

**Major publication**
Real-Time Moving Horizon Estimation for Advanced Motion Control Application to Friction State and Parameter Estimation

Introduction / Objective
Real-time moving horizon estimation (MHE) algorithms are developed to optimally estimate the states and parameters of advanced friction models in order to track online friction dynamics in mechatronics systems, and compensate for the estimated friction. Real-time MHE is implemented and experimentally validated on a high-precision positioning system.

Research Methodology
State and parameter estimation via MHE aims to solve an optimization problem over a fixed-size observation window of past data, moving in time towards more recent measurements. Despite computation complexity, MHE are gradient-based estimation techniques that can efficiently be implemented in real-time systems via code generation tools based on automatic differentiation, such as the ACADO Toolkit developed within OPTEC.

To benefit from gradient-based optimization techniques and automatic code generation; an analytic, i.e. smoothed, version of the generalized Maxwell-slip (GMS) friction model, called S-GMS, is developed. Similar to the GMS model, the S-GMS is a multi-state model that also describes all essential friction characteristics in presliding and sliding motion.

Results & Conclusions
- Improved accuracy of the newly developed S-GMS model compared to the single-state LuGre model is demonstrated in the presliding hysteresis regime (represented by the friction vs position curves).
- Real-time MHE friction observer is implemented for the S-GMS model at a sampling frequency of 1-10 kHz on a high-precision direct-drive linear motor.

Major publication
Dynamic grid support by wind farms: potential of rotating kinetic energy

Introduction / Objective
A variety of control features to support the power system is proposed and tested on conceptual and simplified grid topologies. Nevertheless, we feel there is a lot of experience to gain with case studies considering real grid topologies. To this end, the first research objective in this work aims at a better understanding of dynamic voltage and frequency support by wind farms in existing grid topologies hosting a significant share of wind power. The second research objective aims at investigating the potential of wind farms to provide frequency support by making efficiently use of the kinetic energy in the rotating masses of VSWTs. The power converters in wind turbines allow a fast and precise power control and the variable speed range allows a larger kinetic energy exchange. We aim at an exploration of this potential and the value of the necessary tools to exploit this potential.

Research Methodology
Achieving a better understanding of supporting modes by wind farms (1st objective) is tackled:
- by the analysis of dynamic simulations of critical load scenarios,
- in specific areas in the Belgian and Cypriot power system.
The value of kinetic energy in wind farms (2nd objective) is explored as follows:
- to smooth power variations or assist in the task of frequency regulation,
- by means of an optimization algorithm,
- solved on the supercomputer of the Flemish Supercomputer Centre (VSC),
- analyzed with Pareto fronts showing variability versus energy yield.

Results & Conclusions
Proposed control modes in wind turbines for grid support often emulate synchronous generators during grid events, aiming at a preserved grid stability when replacing conventional units in favor of Renewable Energy Sources for Electricity (RES-E). Evaluation of control modes that propose new strategies benefit from a thorough analysis in extended grid models. Such studies demonstrate the precise impact (e.g. on load shedding schemes), being very dependent on the grid topology, the conventional generation mix and the instantaneous output of wind farms. The kinetic energy from rotating masses in Variable Speed Wind Turbines (VSWTs) can be used to smooth power variations due to self-induced turbulence or assist in the task of frequency regulation. The potential increases by optimally coordinating individual turbines and using forecasts of the prevailing wind speed, demonstrating the value of lidar measurements and online communication among turbines to control wind farms.

Major publication
Reconfiguration, Replacement or Removal?

Introduction / Objective
This research explores whether the intrinsic spatial surplus of the post-war, detached dwellings and low-density, dispersed residential neighbourhoods in Flanders, holds potential for transformation in line with contemporary housing standards and demands. The ageing population and the decreasing average household size result in a demand for other residential typologies: smaller, more compact, and in central locations. Furthermore, high emission levels, traffic congestion and loss of open space as a result of the low density housing model urge for strategies of transformation.

Research Methodology
This work adopted an architectural approach in order to investigate the feasibility of transformative strategies, revolving around reconfiguration, replacement, and removal of houses. As main source for data gathering throughout the entire project, 10 municipalities across Flanders, with a significant share of detached dwellings, were selected as case studies. Design, qualitative research and architectural analysis contribute to a transdisciplinary research, and develop understanding of design strategies intervening on different scale levels – from interior to neighbourhood.

Results & Conclusions
The dissertation concludes that in low-density residential environments, a search for a more sustainable housing is obstructed by a strong resistance which impedes radical, but necessary transformations. Such transformations would be most feasible if developed in the form of balanced strategies on a municipal level.

The professional designer should play an important role in outlining alternative futures, and in deconstructing resilient ideas of what is ‘the ideal dwelling’, like, in the words of David Harvey, a true insurgent architect, in search of site-specific solutions for diversification and densification of existing residential neighbourhoods.

Major publication
Raising the level of Abstraction in Behavioral Modeling, Programming Patterns and Transformations

Introduction / Objective

Evolution in software development is driven by the demand for higher productivity, better quality and ability to build larger and more complex software systems.

In No Silver Bullet, Brooks differentiates between essential complexity and accidental complexity.

Accidental complexity is caused by the way software is developed. These problems are in some sense created by the software developers, but can be solved by advancing and improving technology. Better software development processes and better software building techniques reduce this complexity.

Essential complexity is caused by the problem to be solved by the software system. If the problem has a high complexity, solving it will also be complex. No matter how good our tools or techniques are, the inherent complexity of a problem will not go away.

Goal: contribute to the reduction of accidental complexity of building software systems.

Results & Conclusions

Behavioral Modeling

Conceptual models introduce accidental complexity when they contain technical aspects in order to describe real-world facts. UML and OCL lack expressive constructs to reason about event occurrences. This work presents a new operator, the #-operator, that allows analysts to treat events as first-class citizens. Another new operator, the @-operator, enables modeling historical event information.

Programming Patterns

Properties and associations are typically accompanied with requirements. Three different types of requirements are identified: Value Requirements, State Requirements and Transition Requirements. Separation of Concerns: the description of the requirements are encapsulated in their own inspectors. A family of patterns describes how all methods describing the state and behavior collaborate.

Transformations

Different metamodels mostly have common structural constructs and associated functionality: a framework offering constructs to build hierarchical composition structures is developed. The framework also offers a metamodel-independent transformation approach. Transforming concrete metamodel elements is decoupled from the managing algorithm.

Major publication

Multiscale modelling of angiogenesis during normal and impaired bone regeneration

Introduction and Objective

Unlike other adult biological tissues, the majority of bone fractures can heal without the production of scar tissue, eventually recovering the original bone shape, size and strength. Despite bone’s remarkable healing capacity and the continuing research efforts, the impaired healing of complex orthopaedic cases is still not fully understood. The objective of this PhD work is to develop novel computational models of bone regeneration in order to unravel the mechanisms underlying impaired bone healing as well as to design and optimise experimental strategies in silico.

Research Methodology

<table>
<thead>
<tr>
<th>IMPLEMENTATION</th>
<th>Results and Conclusions</th>
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<tr>
<td>TISSUE SCALE</td>
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<td>accurate description of influence of oxygen; qualitative and quantitative correspondence with observed tissue fractions</td>
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MULTISCALE BONE HEALING MODEL

- PDE model
- Lattice-free model
- Agent-based model

CELLULAR SCALE
first step towards a full implementation of blood flow

INTRACELLULAR SCALE
DHA-Notch1 signalling; salt and pepper pattern; qualitative correspondence with observed vascular density

APPLICATION

- LARGE SEGMENTAL DEFECT
  effectiveness of a therapy depends on timing and host environment

- BONE GRAFT HEALING
  Q-dependent switch in cell fate

- BONE HEALING IN NF1 PATIENTS
  the degree of severity can be captured by various parameter combinations

Major publication

Accounting for Complex Structure in Diffusion Weighted Imaging Data using Volume Fraction Representations

Introduction
The practice of diffusion weighted imaging (DWI) involves the acquisition of images that are sensitive to the process of self-diffusion of water, using magnetic resonance imaging (MRI). Since each acquired image is only affected by diffusion with a component along a specific direction, a collection of such images for a (dense) set of homogeneously distributed directions provides information on the possibly anisotropic behavior of diffusion in each voxel of a 3D volume. Over the years, this technique has provided us with invaluable information on the axonal structures in the (human) brain.

Contributions
Novel representations of (information extracted from) DWI data were designed, that take into account the variety of complex geometrical configurations of axon populations in the brain. These representations offer a greater flexibility and render existing difficult problems trivial; yet make little assumptions on the nature of the data or underlying structures:

- The novel multi-shell multi-tissue (MSMT) representation, that allows e.g. a new preservation of principle volume fractions (PPVF) retransformation strategy for the purpose of DWI registration/deformation; and a new directionally encoded color (DEC) white matter (WM) map, solving major issues of the classical DEC fractional anisotropy (FA) map.
- A novel method, track orientation density imaging (TODI), that maps the track orientation distribution (TOD) of any tractogram. When applied to a short-tracks distribution, its amplitude is explained as a measure of track-like local support (TLS), which allows for powerful properties to be exploited by subsequent TOD-based tractography.

Major publication
Modeling and Optimization of Bidirectional Dual Active Bridge AC-DC Converter Topologies

Introduction / Objective
This work investigates the feasibility of a single-stage, soft-switching dual active bridge (DAB) converter for the realization of single-phase, isolated, and bidirectional AC-DC energy conversions. Thereby it is the principle goal to address the fundamental shortcomings in the existing analyses and circuit implementations of DAB converters. These lead to hard-switching operation and thus result in a reduced efficiency and in the worst case destruction of the switching devices. Application areas are chargers for electric vehicles, inverters for renewable energy sources (e.g. photovoltaic modules), as well as interfaces for residential DC distribution systems and energy storage systems.

Research Methodology
For the first time it is shown that the single-stage DAB AC-DC converter can be operated under soft-switching conditions within its whole operating range. The key to success can be found in combining:

► an extensive circuit analysis and the introduction of new modulation modes (exploitation of all possible degrees of freedom),
► a correct description of the soft-switching conditions, including the modeling of the semiconductor’s parasitic output capacitances,
► the application of a variable switching frequency,
► the introduction of commutation inductances as an essential circuit modification.

In order to validate the analyses, a high-efficiency, high-power-density converter prototype system is developed using state-of-the-art design methods/procedures and multi-objective optimization algorithms.

Results & Conclusions
Conversion efficiencies higher than 95 % within the major part of the output power range, with a very flat efficiency curve and thus a high partial-load efficiency, are reported. The peak efficiency is around 96 % and the efficiency at nominal power approximately 95.6 %. Moreover, a high power density of 2 kW/liter is obtained. From a comparison with several (similar) dual-stage prototype systems found in literature, it is clear that the achieved performance is state-of-the-art.

Major publication
Design and Analysis of Resonant Metamaterials for Acoustic Insulation

Introduction / Objective
In a context of noise control engineering, the mass of conventional panels and structures drives their acoustic insulation performance. Silence comes typically with heavy constructions, but conflicts with the emerging tendency towards lightweight design. Therefore, there is a very challenging quest for innovative and effective noise control measures of low mass and compact volume.

Vibro-acoustic metamaterials come to the fore as possible candidates for lightweight material systems with superior noise and vibration insulation, be it at least in some targeted and tuneable frequency ranges, referred to as stopbands. In this dissertation a novel method of metamaterial implementation is proposed, designed and analysed.

Research Methodology
The potential of resonant metamaterials with vibro-acoustic stop band behaviour is investigated through a combined numerical-experimental approach. Unit cell modelling allows characterisation of wave propagation in infinite periodic structures built by a repetition of this unit cell. The knowledge and insight gained from studying these models is used to design and analyse equivalent finite size structures and investigate the link between predicted stop band behaviour and the resulting vibro-acoustical behaviour. Through design of and measurements on a set of demonstrators, the potential of metamaterials to improve acoustic behaviour is proven and numerically predicted sensitivities for design parameters are confirmed.

Results & Conclusions
Sandwich structure based metamaterials with embedded resonant structures exhibit vibro-acoustic stopband behaviour, resulting in an improved acoustic insertion loss and paving the way for a new class of light and compact noise control solutions.

Metamaterials
- Frequency band: 700-1000Hz
- Additional noise reduction: 15 dB
- No added weight
- Demonstration: http://youtu.be/hMCIrRHSJXc

Major publication
Validation of the Taylor, ALAMEL and VPSC models for plastic anisotropy modeling of sheet metals

Introduction / Objective
Anisotropic behavior of single phase metals is mainly a result of the morphological texture and the crystallographic texture. The ALAMEL model and the VPSC model with input of them can predict the metal forming operations. It is then imperative that the two models (in comparison with the Taylor model) must make a sufficiently accurate calculation of the plastic anisotropy and the texture evolution. A problem of the ALAMEL model (giving oscillated slip rates of active slip systems) was revisited and a grain boundary driven (GBD) model was proposed to solve it.

Research Methodology
The experimental data of four industrially produced steel sheets were used for validation of the three models in prediction of:
- The flow stress anisotropy (flow stresses of tensile tests, plane strain tensile tests, simple shear tests and compression tests. Each test was repeated three times and was tested in 2 or 3 directions) of a low carbon steel (DC06).
- The initial grain shape effect on the initial q-value, the evolution of the q-value and the evolution of the deformation textures for three low carbon steels (T52, T57 and T61).

Results & Conclusions
A number of effects of the texture, the initial grain shape, the slip activities, the short/long range interaction, and so on were investigated:
- The prediction of the flow stress anisotropy by the three models combined with an isotropic hardening law is not sufficiently accurate for DC06, which has a strong texture.
- Both ALAMEL and VPSC give the same initial grain shape effect on the q-value evolutions for three low carbon steels (T52, T57 and T61).
- The newly proposed GBD model is more stable than the ALAMEL model in predicting the work hardening behavior.

Major publication

Figure 1: The q-value prediction by the VPSC model with (dashed line) or without (full line) considering the initial grain shape. The open circles indicate the experimental values.
Temperature- and Supply Voltage-independent Time References for Wireless Sensor Networks

Introduction / Objective
One of the results of the quickly emerging technological possibilities in electronics industry is the appearance of Wireless Sensor Networks in which hundreds of autonomously operating nodes are wirelessly connected in a network. Since a cost decrease of these sensor nodes is necessary to become economically feasible, a growing need for fully-integrated wireless solutions is observed. This integration often goes at the cost of accuracy under influence of temperature and changing supply voltages. This work investigates the possible techniques to overcome the temperature- and supply voltage-sensitivity of low-power fully-integrated time references for ultra-wideband transmitters.

Research Methodology
In a first step, the basic needs to build a frequency reference are studied. Furthermore, a closer look is taken to the causes of short-term as well as long-term frequency instability in an oscillator. This results in a design strategy, which is applied to six design cases: 3 free-running oscillators, 2 injection-locked solutions and a sensor interface. During the design process, 2 major steps are alternately taken:
- Theoretical study of the circuit topology combined with numerical calculations and/or finite-element simulations.
- Circuit design and simulations to obtain more accurate results on previously estimated parameters.
This eventually results in a circuit implementation which is processed and measured. At measurement time, simulations are used to fully understand the underlying mechanisms.

Results & Conclusions
Different circuit techniques are demonstrated to obtain several highly stable analog building blocks. The main highlights are:

- A novel highly temperature- and supply voltage-independent pulsed oscillator topology is developed. The frequency only depends on a bondwire LC tank.
- A novel injection-locked receiver topology is demonstrated. This receiver, which is combined with the clock generator, allows network coordination.
- A sensor interface is developed employing relative timing accuracy between oscillator stages to obtain an absolute accurate and stable sensor readout.

By combining these blocks into a wireless sensor node the feasibility of fully-integrated timing solutions is demonstrated. The presented designs surpass the state of the art when looking at power and frequency stability.

Major publication
Non-modal acceleration methods for broadband acoustic simulation

Introduction / Objective

Frequency sweeps over a wide frequency range and for a large number of frequencies are required in many applications in acoustics. When dealing with large systems, like those arising when tackling mid-frequency applications, this becomes computationally expensive, if not prohibitive. This thesis proposes the development of computational algorithms that lead to Fast Frequency Sweep approaches for the Finite Element Method (FEM) and Indirect Boundary Element Method (IBEM).

Research Methodology

The two approaches developed in this thesis are based on reduced-order models built via Padé approximations. The Well-Conditioned Asymptotic Waveform Evaluation (WCAWE) is selected as Model Order Reduction (MOR) method of choice.

- The fast frequency sweep for FEM (FFSFEM) is able to treat systems of more complicated wavenumber dependency, likely to be encountered when applying frequency-dependent boundary conditions and/or loadings.
- The fast frequency sweep for IBEM (FFSIBEM) consists in a more involved process. The matrices are fully populated and inherently frequency dependent. Therefore, the approach accelerates the assembling of the system matrices and solving the associated linear system.

Results & Conclusions

Many numerical examples are used for the validation of the proposed approaches. In the FFSFEM, exterior acoustics problems involving PML, such as a sphere with vibrating cap, provided overall speed-up above 30. Interior acoustics problems, such as a car cavity with realistic acoustic treatment provided speed-up factors from 14 up to 21. For all test cases, frequency responses obtained by the FFSFEM are in good agreement with the ones obtained by the direct approach.

In the FFSIBEM, exterior and interior/exterior problems are tackled. In particular, a car engine compartment is evaluated, on which a sensitivity analysis on many MOR parameters is performed in order to verify the robustness of the approximations.

Numerical examples have shown approximate sound pressure levels (at the chosen field points) with good accuracy when comparing to the direct solver.

Major publication

Introduction
The field of natural language processing has made great advances in the last decades. Most of us have used Google translate, and have heard of Watson, the computer that won Jeopardy! Luckily, there are still many open problems in natural language processing, specifically with the machine learning algorithms behind it.

In this thesis we apply methods from operations research to natural language processing (NLP), and more specifically integer linear programming. Linear programming is an optimization method developed during WWII, to plan production in an optimal way. The goal is to maximize a linear objective function, subject to constraints.

Research Methodology
We apply these optimization methods to 4 different problems in NLP:
- Sentence compression: summarizing individual sentences
- Rhetorical structure classification: dividing a document into segments that convey the same type of information (e.g. definitions, procedures, ..)
- Coreference resolution: determining which expressions in a text refer to the same person, location, company, ..
- Text simplification: reducing the difficulty of a text to a quantifiable level

Results & Conclusions
Solving NLP problems with integer linear programming achieves excellent results
- By combining multiple local decisions into a globally optimal solution
- By reducing the NLP problems to well-known and intensively studied problems in operations research

Major publication
Introduction / Objective
Most urban centers in Ethiopia do not have wastewater treatment facility. Few onsite systems that exist in institutions and industries do not work properly because of inappropriate technology selection. Constructed wetlands and waste stabilization ponds are reported to be the best options for developing countries. However, the functionality and applicability of these systems in low income countries is not well studied. This PhD focused on evaluating low cost wastewater treatment systems from the perspective of functionality, sustainability and cost effectiveness.

Research Methodology
First a laboratory based water quality assessment was done followed by wastewater management survey in the country (emphasis on Universities). The lab analysis led to technology choice and the constructed wetland was identified using selection criteria. Before moving to the study on constructed wetlands a bench scale (pot) experiment with 8 indigenous macrophytes was performed. Two of the best performing macrophytes were used in the pilot scale horizontal subsurface flow constructed wetland which was studied for performance, nutrient uptake, and root zone microbial respiration under irregular flow conditions.

Results & Conclusions
*Cyperus papyrus* and *Scirpus validus* were found to be the macrophytes of choice for use in constructed wetlands. Plant harvesting seems to be of little importance in terms of P removal but significant for N removal. The performance of the horizontal subsurface flow constructed wetland was good, highly tolerant to irregular flow conditions and load fluctuations.

The conventional rule of thumb design criteria (5m²/PE) can not be applied for a tropical low income country like Ethiopia which needs only 3.6m²/PE. It is highly recommended that wastewater treatment designs should consider local conditions. Universities, institutions and small communities are encouraged to use constructed wetlands as a secondary wastewater treatment option.

**Major publication**
Introduction / Objective
The "Spindus" research project, which is the abbreviation of "Spatial Innovation, Planning, Design and User involvement" was a four-year research project intending to broaden the concept of spatial quality. It's aim was to develop practical and pedagogical planning and design methodologies to assess, evaluate and implement spatial quality by adopting an interdisciplinary (involving different research disciplines in a shared methodology) and transdisciplinary (involving different types of users) approach. In the area of urban design, Spindus researchers searched for and analyzed methodologies that would allow projects to be participatory and inclusive. The PhD research, framed within the Spindus project, aspired to achieve insights into the capacity of designerly research within participatory urban design practices.

Research Methodology
The research methodology of the overall PhD was action research as a "learning by doing" process was initiated through organizing a series of urban design workshops. The outcomes of a workshop would be verified and based on these results changes were proposed to eventually launch a new workshop. As a result, four 8-day workshops took place in Marke, Hoog Kortrijk, Luchtbal and Roeselare-Hooglede (see pictures). The urban design workshops made us of designerly research, and in-depth interviews and questionnaires were conducted with key actors, designers, residents and users of the case study sites.

Results & Conclusions
Design may not only serve to bring about a shared vision for the future – and to merely have a product as an outcome – but can be versatile and inclusive as it may integrate different aspirations and opinions in space. The manuscript presents an altered workshop methodology working towards making the designerly research process more participatory and inclusive. The adapted method suggests how urban design and social innovation can be better integrated and go beyond their usual scope, namely by shortening feedback loops, introducing an iterative design process and stimulating social innovation while using design as a tool for facilitating dialogue and communication. As the city and the territory are always in development, the mutual enforcement of design and research is needed to envision – in an inclusive manner by the involvement of different types of users – how we want to live in the future.

Major publication
Optimal operation of hybrid AC/DC meshed grids

Introduction / Objective

The contribution of this work is the extension of the optimal power flow formulation of electrical systems with an integrated DC grid using HVDC Voltage Source Converters. Not only the base case calculations, but also curative and preventive security constrained cases and a wide range of optimisation objectives have been integrated in the developed algorithms.

This research is particularly important to Transmission System Operators for grid planning and operation of point-to-point DC connections (e.g. the Belgian NEMO and ALEGrO projects), multi-terminal schemes and even complexly meshed DC supergrids with multiple infeeds from offshore wind power plants.

Research Methodology

The methodology used for this research is the algorithmic creation of a set of specific state variables, equality and inequality constraints which are integrated into an existing optimisation case:

- the AC/DC converters are modelled by expressing their loss function as equality constraints;
- two independent methods are developed to model the DC grid topology: the first is analogous to the classic AC grid approach, the second creates the equations for the DC branches and grid topology separately;
- for the preventive security constrained OPF, the base case and the distinct systems taking into account the requested outages are assembled into one global optimisation case.

Results & Conclusions

The research resulted in the creation algorithms and methodologies which integrate

- the necessary constraint equations for the DC grid and AC/DC converters, in a generic way, so even the most complex topologies can be modeled,
- the creation of a solvable OPF formulation integrating all contingency states of the hybrid AC/DC system,
- an extended set of objective and user-customisable objective functions allowing also multi-objective OPF,
- the development of an open-source calculation tool

The algorithms have been tested on a range of small and large networks and are successfully benchmarked with other calculation tools.

Major publication

Introduction / Objective

The mechanical properties of severely cold-drawn steel wires are largely determined by the microstructure development (including both the plastically induced cementite dissolution and the residual stresses evolution) during drawing. Basically, the presence of the residual stresses may influence dimensional stability and static strength, onset of micro cracks and delamination and finally work-hardening and strengthening mechanisms in pearlitic steel. The aim of the present research was to explore the evolution of internal and residual stresses and their possible coupling to the microstructure development during the production process with an integral characterization technique.

Research Methodology

Synchrotron, neutron and laboratory X-ray diffraction were used in the present work to study the stresses on different - macro, micro and nano - scale levels. The experimental measurements were performed on thin high strength steel pearlitic wires and filaments over a broad range of accumulated strains ($\varepsilon_t = 0.000 - 4.007$).

Results & Conclusions

The total (surface) stress development during cold drawing can be described in terms of two distinct regimes - low and high deformation regime of the residual stress evolution during cold drawing separated by a “sharp transition” (Fig. 1). While the stress development at low strains matches with the traditional theory for (macro) residual stress evolution in drawn wires, the origin for the remarkable “oscillatory” behavior at large strains was still unclear. Synchrotron/neutron diffraction pointed to a strong orientation dependence of the micro stress evolution beyond a true strain of $\varepsilon_t > 1.190$. Nevertheless, increasing intergranular stresses (Fig. 2) alone would not give rapid fluctuations in micro phase and total stresses. Therefore, a possible physical reason for the observed divergence can consist in a distinct (bulk) microstructure development (involving thermodynamic destabilization of the cementite phase) at true strain level around $\varepsilon_t \approx 1.766 - 2.292$.

Major publication


Silicon epitaxial layers grown on buried porous silicon templates for solar cells: detailed electrical and chemical understanding

Introduction / Objective

In silicon photovoltaics, the cost of the silicon material itself forms a major fraction of the final solar module cost. In order to reduce the amount of expensive high quality silicon to fabricate solar cells, two silicon solar cell concepts have been envisaged, namely the wafer-equivalent epitaxial silicon solar cell (WE-epicell) and the layer-transferred epitaxial silicon solar cell (LT-epicell), which are only 30-50 µm thick, compared to today’s solar cell, which is ~170 µm thick. For both cell concepts, porous silicon (PSi) is crucial. In WE-epicells, PSi is used as a Bragg reflector and a gettering layer. In LT-epicells, PSi enables the silicon layer transfer process itself. In both cell concepts, PSi also acts as the epitaxial template. The importance and role of PSi as a gettering layer in WE-epicells and as an epitaxial template in both cell concepts are studied in detail and improvements are also demonstrated in this thesis.

Research Methodology

Porous silicon as a gettering layer: Firstly, the gettering mechanism and gettering efficiency of PSi is studied theoretically and correlated experimentally. Secondly, an increase in PSi gettering efficiency is demonstrated by reducing the void size. Main techniques used in this work include: ab initio simulations using density functional theory (DFT), total reflection X-ray fluorescence (TXRF), secondary ion mass spectroscopy (SIMS) and microwave-detected photoconductance decay (µ-PCD).

Porous silicon as an epitaxial template: Firstly, methodologies for quantifying the quality of an epitaxial layer grown on PSi templates using minority carrier lifetime measurements are devised, both theoretically and experimentally. Secondly, methods to improve the porous silicon template to allow the growth of higher quality epitaxial layers is demonstrated. Main techniques used in this work include numerical simulations using PC-1D, photoluminescence (PL), microwave-detected photoconductance (µ-PCD) and quasi-steady state photoconductance (QSSPC).

Results & Conclusions

Left: An example map of Fe concentration in the epitaxial layer in an Fe-contaminated sample obtained using µ-PCD. In the area where there is embedded PSi, no Fe is detected in the epitaxial layer, while high Fe concentrations can be detected outside this area, proving the high gettering efficiency of PSi.

A novel PSi stack which results in a surface zone of void-free Si (left) is shown to increase the quality of the epitaxial layer, as evidenced by the improved minority carrier lifetime (right).

Major publications

Reducing the error motion of an aerostatic rotary table to the nanometre level

Introduction / Objective

Advances in the semiconductor industry, material science and ultra-precision machining sector have heightened the need for more accurate axis-of-rotation systems. Since the requirements go beyond the capabilities of conventional bearing technologies, gas lubricated bearings are typically used. Although the bearing surfaces do not make contact in a gas bearing, the machining accuracy of the bearing surfaces, imbalance and environmental fluctuations limit their further evolution toward attaining nanometre accuracy for novel ultra-precision applications. The main objective of this dissertation is to reduce the error motion of an aerostatic rotary table to the nanometre level (i.e. < 10 nm) and to develop a spindle error motion separation technique to measure the error motion with sub-nanometre accuracy.

Research Methodology

A numerical gas film model is developed to study the influence of several manufacturing errors, bearing parameters and feeding geometries on the running accuracy of an air-bearing system. A steady-state model and orbit model is developed and compared for both an orifice-compensated bearing and porous bearing. From this study, a set of dimensionless design guidelines are formulated. The selected morphology for increasing the running accuracy is tested by measuring the error motion of a porous aerostatic rotary table. For this purpose, a sub-nanometre spindle error motion separation technique is developed. Various known reversal and multiprobe techniques are compared and assessed by means of a new error analysis method. From this, an improved implementation of the multiprobe method is proposed.

Results & Conclusions

It is found that the error motion of an aerostatic bearing is mainly influenced by the form error of the rotor, while the form error of the stator and variations in orifice diameter are of secondary importance. Moreover, it is seen that the error motion increases drastically if the feed number is greater than that corresponding to the maximal direct stiffness of the gas film. The most interesting finding, however, is that the error motion of an aerostatic bearing can be most effectively reduced by increasing the number of feedholes as it results in a uniform pressure distribution. A synchronous radial error motion of 3-4 nm and a synchronous axial error motion of 1-2 nm is obtained. The asynchronous error of the porous aerostatic rotary table is around 1 nm.

Major publication

Implementation Aspects of Security and Privacy in Embedded Design

Introduction / Objective

Electronic devices are becoming ubiquitous, mobile and integrated with their environment. This shift is however not without risks. On the one hand, the security of the devices can be compromised by malicious adversaries performing physical attacks. On the other hand, the privacy of the users can be threatened by the monitoring nature of new services and applications. It is in this context that this research is situated. It addresses aspects related to the security of embedded devices and the privacy of the humans interacting with them.

Research Methodology

Integration of (physical) security and privacy into an embedded system implies to follow a systematic approach considering all abstraction layers of the design space:

- **System**: security and privacy requirements
- **Algorithm**: cryptographic blocks
- **Architecture**: hardware, software
- **Circuit**: transistors and logic gates

Results & Conclusions

Embedded design for embedded security:

- In-depth study and characterization of the effects of setup time violations in embedded microcontrollers with a two-stage pipeline.
- Security evaluation of a widely used commercial family of secure memories.
- Development of a masking-based countermeasure against side channel attacks implementable at any order and based on inner product constructions.

Embedded design for privacy:

- Design, implementation and evaluation of a privacy-preserving solution for Electronic Toll Pricing

Major publication

Multi-view Architecture Description for Distributed Systems

Introduction / Objective
Designing the software architecture is an essential part of the development of distributed systems. Yet, to be useful to developers, the architecture needs to be documented. Architects document software architecture using Architecture Description Languages, amongst several other ways. However, there is no ADL that supports the concepts specific to distributed system, like element instantiation and allocation to networked hosts. We developed an ADL that solves these and other problems that we uncovered in the state of the art of architecture description.

Research Methodology
First, this research was driven by an industry-grade case study on e-Media. An e-Media platform supports news in different media formats and sizes, to be delivered through different communication channels, onto multiple end-user devices. The case study was essential in the creation of an environment that was complex enough to reveal the problems that we set out to solve.

Second, we have created and maintained a set of tools for architects and developers to validate our research results and put them into practice.

Results & Conclusions
Our work consists of three contributions:

- MViewADL, an ADL for distributed systems that supports the description of components and connectors, the specification of their runtime instances, and the allocation of instances onto distributed hosts.
- ReVew, a concept and technique for the modularization of the contributions of architects to the architecture description. The concept introduces the generic idea of stepwise refinement of architecture description. The technique implements the concept in a generic way, to allow its use in various ADLs.
- Tool support for the production of MViewADL descriptions, and subsequent code generation to multiple middleware platforms, such as JBoss and Spring.

Major publication
Steven Op de beeck, Marko van Dooren, Bert Lagaisse, Wouter Joosen, Modularity and variability of distributed software architectures through multi-view refinement of AO-connectors, LNCS Transactions on Aspect-Oriented Software Development, volume 7800, 2013.
Analysis of the business potential of product-service systems for investment goods

Introduction / Objective
Over the last decade, insight has grown that between a pure product manufacturer and a pure service provider, various business model options exist, in which products and services are combined to varying degrees. This concept is described by the term Product–Service Systems (PSSs), which is the subject of a considerable amount of recent research attention. The overarching goal of the presented work is to analyze the business potential of a PSS from the point of view of a manufacturer of investment goods.

Research Methodology
The main research method applied is case study research. Five in-depth case studies were performed with Belgian manufacturers who currently have a product-centric business model, but who would like to gain insight into the potential benefits of a PSS. The business potential of a PSS is investigated for a manufacturer of elevators, a provider of lighting control systems, a provider of fire detection systems, a developer of diamond polishing systems and a manufacturer of wind turbine gearboxes.

Results & Conclusions
In this thesis a theoretical foundation for PSS research is proposed, including a new PSS definition, representation scheme and typology. Moreover, Functional Hierarchy Modeling is presented, a theoretical framework that allows to represent the functions of an investment good on different levels of abstraction. Three complementary approaches for PSS ideation, that support manufacturers in identifying a broad set of PSS options, are proposed and illustrated. The second part of this dissertation presents a generic methodology to evaluate the business potential of a PSS. This methodology focuses on the innovation potential of a PSS in cost and value and allows to analyze the impact of risks and uncertainties. It is validated through its application on five in-depth case studies.

Major publication
Device Architecture and Materials for Organic Ferroelectric Memory Arrays

Introduction / Objective

Thin-film electronics are technologies to fabricate transistors and circuits, different than silicon technology. In the latter, transistors are fabricated by creating structures on the surface of a mono-crystalline silicon wafer. In contrast, thin-film transistors (TFTs) are fabricated by depositing and patterning material layers on a variety of possible substrates such as glass or even flexible plastic sheets.

Organic electronics is an emerging thin-film technology which offers a route to ubiquitous, low-cost and flexible electronics. Due to the material properties of organic (as in organic chemistry) materials, organic thin-film technology could enable printing and roll-to-roll mass-fabrication methods on flexible substrates. The low-cost and flexibility would make new applications possible, e.g. low-cost radio frequency identification (RFID) tags for item-level smart labeling.

This doctoral research focuses on organic ferroelectric field-effect transistors (FeFET) to realize a non-volatile memory component in such RFID tags.

Research Methodology

Experimental, using a systematic approach:

- Fabricate and evaluate device architectures of FeFETs
- Provide insights in device operation
- Integrate with transistor circuitry on a flexible substrate
- Realize a memory array

Results & Conclusions

- Data can be stored for at least one year in FeFETs. ON current decays in two phases. However, this memory performance differs for different device architectures.
- A model is proposed for the device operation of FeFETs, which clarifies peculiarities found in literature.
- FeFETs are integrated in a NAND-like memory array on a flexible substrate. A disturb-free read- and write operation is demonstrated.

Major publication

Micro-CT based morphological and mechanical characterisation of open porous metallic materials

Introduction / Objective
The request for porous structures with highly controlled properties, coming from different application areas within the industrial and scientific market, forced researchers to find ways to optimise additive manufacturing (AM) production techniques in order to control the morphological and mechanical properties of the manufactured porous structures on both meso- and microscale. This PhD study focused on the surface modification and the subsequent characterisation of the porous structures having customized morphological properties. Micro- and nano-CT in-situ loading tests were to be carried out to unravel of the mechanical behaviour and failure of those porous structures.

Research Methodology
Topology changes of the Ti6Al4V porous scaffolds produced by selective laser melting (SLM) were introduced by several surface treatments consisting of chemical etching followed by electrochemical polishing. High resolution micro-CT images have been used for roughness measurements of the complex porous structures subjected to the surface treatments. Finally, an automated non-rigid image registration of images acquired prior-to and after compressive loading was applied to assess the strains within the mechanically loaded Ti6Al4V open porous structures.

Results & Conclusions
This work resulted in a novel protocol for a controlled post-production surface treatment of the open porous structures that allows to eliminate the surface irregularities in a robust manner (Fig. 1), but also to produce customized structures with desired global morphological properties.

In this study for the first time, micro-CT has been applied to quantify the materials’ surface texture and a novel tool for 3D surface roughness measurements has been developed (Fig. 2).

The local strain analysis, performed using the non-rigid registration of the micro-CT images, revealed larger strain concentrations at the beam geometry imperfections of the compressed Ti6Al4V open porous structures produced by SLM (Fig. 3).

Figure 1. SEM micrographs of a typical strut of a Ti6Al4V open porous structure a) as-produced, b) after chemical etching and c) after additional electrochemical polishing.

Figure 2. a) A typical high resolution 2D µCT cross-sectional image of a single beam of a porous Ti6Al4V structure and b) a binarized section of a) with the corresponding profile lines. Scale bars = 200 µm.

Figure 3. a) 3D images of a single beam of Ti6Al4V porous structure generated before compression and at the 50% of ultimate compressive strain, at the UCS and at the sample failure and b) 2D maps of the volumetric strain generated at the 50% of ultimate compressive strain and at the UCS.

Major publication
Introduction / Objective

Today’s generation of wireless sensor networks are now moving out of the lab and into the real world. While early applications were single-purpose and primarily of a prototypical nature, contemporary deployments are increasingly evolving towards dynamic, multi-stakeholder, multi-purpose scenarios, such as smart cities or intelligent logistics. Developing applications for these scenarios requires: (i) expertise along the entire value chain, (ii) appropriate software development paradigms, and (iii) middleware support to mitigate the complexities of distribution and dynamism. Research in this dissertation has developed a programming model and supporting run-time environment that advances state-of-the-art solutions and tackles these and other problems.

Research Methodology

- **Abstractions for heterogeneous stakeholders**: improving development efficiency for all sensor network stakeholders through appropriate software development abstractions. An integrated programming model (CaPI) has been designed that incorporates these abstractions.

- **Managing the dynamic software life cycle**: efficiently addressing long-term evolution and management requirements of contemporary sensing scenarios. A reconfigurable middleware platform has been designed that provides support for software reconfiguration and operationally integrates all software technologies presented.

- **Validation in collaboration with industry and academic peers**: all solutions were prototyped on state-of-the-art embedded sensing hardware and validated in several real-world proof-of-concept scenarios with different partners.

Results & Conclusions

The Component and Policy Infrastructure (CaPI) model and runtime environment consists of the following elements:

- **LooCI**: the Loosely-coupled Component Infrastructure, a lightweight component model specially designed for dynamic sensor networks.

- **PMA**: the Policy Management Architecture, a policy-based abstraction, supporting specification and dynamic adaptation of management objectives of network administrators.

Evaluation results confirm that CaPI respects resource constraints of embedded platforms, improves development efficiency, and provides an energy-efficient means to evolve and manage sensing applications throughout their entire life cycle.

Major publication

Uncertainty quantification and reduction for river flood forecasting

Introduction / Objective
Floods are among the most destructive natural hazards. They affect thousands of people worldwide and cause damage for millions of euros. It is important that local authorities and the people at risk can be warned timely. Flood forecasting systems are being developed for that purpose. However, these systems are subject to significant uncertainties. The three objectives of this doctoral research were: (1) quantification of these uncertainties; (2) identification and testing of most efficient uncertainty reduction options; (3) communication and visualization of the uncertainties.

Research Methodology
- Statistical analysis of flood forecast errors
- Identification of most important uncertainty sources by resimulation of historical flood forecasts
- Development of improvement actions
  - Calibration hydrological models
  - Data assimilation

Results & Conclusions
- A non-parametric statistical methodology has been developed and applied to the historical forecasts of the operational river flood forecasting system of Flanders Hydraulics Research, to quantify the total uncertainty in flood forecast results for river water levels and discharges.
- This total flood forecast uncertainty was decomposed into the contributions from the main sources of uncertainty. This provided insight and guidance on priorities for model improvement actions.
- Given that improved rainfall-runoff model calibration was identified as a model improvement action with high priority, but the number of historical observations to evaluate the model under extreme flow or flood conditions is limited, a novel technique was developed to evaluate the rainfall-runoff model performance to extrapolate peak flows. The technique is based on the evaluation of peak flow changes under increasing rain storm volumes.
- A practical tool was developed for enhancing flood preparedness, based on indirect soil moisture indicators and rainfall forecasts.
- A technique was developed for probabilistic flood mapping.

Major publication
### Reconfigurable All-Digital Time-to-Digital Converter for Digital PLL

**Introduction / Objective**

A sub-gate delay resolution Time-to-Digital Converter (TDC) with power-performance re-configurability for use in Digital PLL.

**Research Methodology**

The work begins with a study of Digital PLL architecture and identified the key performance metrics of the frequency synthesizer based on a Digital PLL. An simulation platform is then developed to accurately model the functional behavior and to predict the impact of TDC quantization on the output spectral quality. Sub-gate delay effective resolution is identified as the main requirement. A qualitative comparison of the existing techniques is provided, highlighting the analog-intensive nature of existent techniques. In this work, the concept of **Spatially Oversampled TDC System** is presented, where the resolution enhancement over a gate delay is obtained by low-complexity digital post-processing of several parallel TDC outputs. These parallel TDCs have slightly different resolutions and measure the same input. Knowing the individual TDC resolutions, multiple coarse time-interval estimates can be derived. These estimates are then arithmetically processed to result in a final estimate with much better precision and accuracy than any individual TDC used in the parallel system. This system emulates a fine resolution TDC using only digital-domain techniques. The achieved resolution enhancement depends on the number of channels (TDCs) used and hence resolution re-configurability is readily incorporated.

**Results & Conclusions**

Two test prototypes are realized on silicon using 90-nm CMOS technology. In the first prototype, a system with 8 parallel current starved ring oscillator based TDCs is designed. The resolution of TDCs is changed by setting the current drive through a programmable word. Measurements show a 3X improvement over a buffer delay [52-62]ps validating the system principle. In the second prototype, a fully synthesizable architecture with 8 channels, described in Verilog is developed. This incorporates an online background calibration scheme to track the individual TDC resolutions and is a fully integrated implementation with all the post-processing done on-chip. The measured effective resolution is [14-40]ps. These two prototypes demonstrate the viability of the fully digital alternative for resolution enhancement in TDCs.

**Major publication**


Optimal Plasma Edge Configurations for Next-Step Fusion Reactors

Introduction / Objective
Divertors play a key role in the development of next-step nuclear fusion reactors. Responsible for power and particle exhaust, they have to be designed such that they can safely handle the large power loads. Specifically, their design needs to prevent from exceeding limits imposed by the materials in order to avoid excessive material erosion and melting. At the same time, sufficient particle throughput — in particular Helium pumping capacity — has to be ensured. The design of present-day divertors is heavily assisted by numerical simulations of the plasma edge. However, due to the large number of design variables and complex edge plasma flows, this is computationally extremely demanding. Therefore, this work aims at developing an automated approach based on shape optimization.

Research Methodology
In this thesis, an efficient adjoint approach to divertor target shape optimization is developed. The divertor design problem is formulated as a mathematical optimization problem, in which the divertor target shape is the control variable, while the edge plasma model appears as a constraint. Using the velocity method, shape sensitivities are obtained which depend on boundary data only. Therefore, they can be evaluated at almost negligible cost. Furthermore, with a one-shot algorithm — which solves state, adjoint and design equations as one coupled system — solutions to the entire design problem are found at an equivalent computational cost of only 4 to 10 edge plasma simulations.

Results & Conclusions
The developed algorithms are applied to divertor target design for optimal power load spreading. A number of test problems is considered in which the edge plasma is described with models of increasing complexity, ranging from fluid descriptions to coupled fluid-kinetic models including radiation transport. An almost perfectly uniform target load is achieved for the test cases, significantly reducing the peak loads, and optimally making use of the high-heat-flux plasma-facing components.

Fig. 1: Velocity method for shape sensitivities

Fig. 2: Optimized divertor target geometry (left), with perfectly uniform load to the divertor targets (right: outer target).

Major publication
Interfacial adhesion in natural and synthetic fibre composites: a physical-chemical-mechanical approach

Introduction / Objective
Understanding the fibre-matrix interface in order to improve the mechanical performance is not an easy task. Although it is widely recognized that the properties of the interface are governed by physical and chemical compatibility between the fibre and the matrix, the interaction forces responsible for the work of adhesion and the strength of the interface are difficult to estimate.

The main objective of this dissertation is to study the surface and the wetting behaviour of natural fibres, in order to establish the feasibility of performing meaningful wetting measurements on them. The current methodology for measuring contact angles on natural fibres is revised, in order to take into account equilibrium conditions during the measurement of wetting. The work of adhesion (obtained by wetting analysis) is correlated with the practical adhesion (obtained by micromechanical tests).

Research Methodology
Atomic force microscopy (AFM), X-ray Photoelectron Spectroscopy (XPS), Time-of-Flight Secondary Ion Mass Spectrometry (ToF-SIMS), and optical profilometry techniques were used to study the fibres topography and chemistry. A new approach, based on an autoclavetreatment, to reduce the noise in performing contact angle measurements on rough natural fibre surfaces is presented.

The wetting dynamics of various test liquids on natural fibres is analysed by applying the molecular-kinetic theory of wetting. Additionally, a novel way to measure equilibrium contact angles by using sound excitation is proposed, and The mechanical strength of the interfaces was assessed by single fibre pull-out tests.

Results & Conclusions
The typical large fluctuation during wetting of natural fibres is mainly a consequence of surface topography irregularities (roughness and waviness).

A methodology for calculating the surface energy components of natural fibres and thermoplastic matrices, and an acoustic vibration method to measure equilibrium contact angles on synthetic and natural fibres were developed.

The influence of physical adhesion and roughness on the interface strength was characterized by the local interface shear strength and friction stress, and the normal interface stress at the moment of crack initiation. Both interfacial parameters show a poor performance for natural fibre composites.

Major publication
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White-Box Cryptography: Analysis of White-Box AES Implementations

Introduction / Objective
Cryptographic algorithms protect data or communication in the presence of an attacker. If such algorithms use a secret key, then the primary objective of an attacker typically is to extract this key. Due to the increasing demand to deploy cryptographic algorithms within software applications executed on untrusted open platform (e.g., a smartphone, ...), a new more realistic white-box environment is introduced in which an attacker has complete access to the software implementation of a cryptographic algorithm and has full control over its execution environment (e.g., digital content protection systems such as Digital Rights Management or Pay-TV systems). White-box cryptography aims to protect the confidentiality of the secret key of a cryptographic algorithm in such a white-box environment. In 2002, Chow et al. proposed the first published white-box implementation of the Advanced Encryption Standard (AES), one of the most prominent block ciphers at this time. However, two years later, Billet et al. presented an efficient attack on this implementation, which motivated the design of three new white-box AES implementations offering more resistance against key extraction: the ones by Bringer et al. in 2006, by Xiao and Lai in 2009 and by Karroumi in 2010. This doctoral thesis covers the design and analysis of white-box implementations of block ciphers, where the main contributions address the analysis of white-box AES implementations.

Results & Conclusions
Starting from the initial improvement of Billet et al.’s attack proposed by Tolhuizen in 2012, we present several additional improvements considerably reducing the overall work factor. Our improved version leads to some useful observations with respect to the design choices made in Chow et al.’s white-box AES implementation. Further, this doctoral thesis describes the analysis of the three newly proposed white-box AES implementations mentioned above. First, we show how to efficiently extract equivalent keys out of Bringer et al.’s white-box AES implementation; these equivalent keys yield functionally equivalent implementations. Second, we present a practical cryptanalysis of the white-box AES implementation proposed by Xiao and Lai. The cryptanalysis uses a modified variant of the linear equivalence algorithm presented by Biryukov et al. as a building block. Additionally, we consider design generalizations of the Xiao-Lai white-box AES implementation and their impact on our cryptanalytic result. Third, we show that Karroumi’s white-box AES implementation belongs to the class of white-box AES implementations specified by Chow et al. Consequently, Karroumi’s implementation remains vulnerable to the attack it was designed to resist, i.e., Billet et al.’s attack and our improved version of this attack.

Based on the cryptanalytic results presented in this doctoral thesis and outlined above, it is shown that in early 2014 there does not exist a practical and secure white-box AES implementation published in the academic literature, even though AES is still considered to be a secure black-box block cipher. However, at the end of this thesis we discuss a new design principle proposed by Michiels and Gorissen that may lead to the construction of secure white-box AES implementations. All white-box AES implementations appeared in the academic literature so far are fixed-key; we present a new dynamic-key white-box technique that allows to update the cryptographic key in a more secure way than the known techniques.

Major publication
Distributed optimization methods for large scale optimal control

Introduction / Objective
We aim to develop and implement both nonlinear and linear distributed optimization methods that are applicable, but not restricted to the optimal control of distributed systems. Such systems are typically large scale, thus the well-established centralized solution strategies may be computationally overly expensive or impossible and the application of alternative control algorithms becomes necessary. Moreover, it is often desired that the information on the coupled subsystems inner dynamics is kept local, making the deployment of a centralized optimal control scheme impossible in practice. In such a case, optimization approaches based on some limited exchange of information remain the only possible option.

Research Methodology
- We consider nonlinear optimal control problems with distributed structure, for which we design an efficient distributed shooting method.
- We investigate linear optimal control problems with quadratic cost functions, i.e. quadratic programs (QP). An overview of dual decomposition based approaches is carried out, followed by the development of a novel dual decomposition scheme. The proposed method employs second-order derivatives.

Results & Conclusions
- Distributed Multiple Shooting: Results in up to 19 times faster integration time when compared to the conventional approaches.
- Dual Newton-CG method for Quadratic Programming: Experimental results suggest that it requires up to 152 times less local optimization steps than classical first-order schemes.

Major publication
Microstructure and texture of metal parts produced by Selective Laser Melting

Introduction / Objective
Selective laser melting (SLM) is an additive manufacturing technique by which structural geometrical complex parts can be created directly by selectively melting consecutive layers of metal powder (see typical setup in Figure 1). The high energy density applied by the laser beam results in high and directional thermal gradients. In combination with the additive character of the process, this results in the formation of a unique microstructure in SLM parts which can be altered by varying the process parameters or the constitution of the alloy. In order to control the properties of the produced parts, it is essential to have a good understanding of the relation between process variables and the resulting microstructure as illustrated in the Figure 2.

Research Methodology
In this work, the microstructure and texture of pure Ta, Ti-6Al-4V, AlSi10Mg and maraging steel 18Ni(300) SLM parts are characterised by microstructural analysis (LOM, SEM and EBSD) and X-ray diffraction. The influence of the unique microstructure on the mechanical properties are analysed as well. The experimental work is supported by using a pragmatic model for SLM to calculate the temperature distribution and by using a model to estimate the plastic deformation behaviour based on the measured texture.

Results & Conclusions
For most alloys, the high thermal gradients result in very fine submicron-sized cellular-dendrites growing toward the centre of the melt pool along the easy growth direction (see for example in Figure 3). Due to the partial remelting or previously consolidated layers, most grains solidify epitaxially and grow across the layers. For pure metals (Ta) and Ti-6Al-4V, the solidification front remains stable, resulting in large elongated grains more or less along the building direction. The competition between the epitaxial solidification and the orientation of the easy-growth of the parent grain with respect to the local heat flow direction is found to be the main determining factor to determine the morphological as well as crystallographic texture during SLM.

Major publication
Introduction and Objectives
Current numerical strategies do not allow to efficiently capture the local behavior of mechanical systems with variable topology (e.g., bearings and gears). The main goal of this thesis can be summarized as follows: Modify existing component-level model order reduction (MOR) techniques to develop novel MOR strategies allowing to solve flexible multibody systems in which small moving interfaces are present.

Results & Conclusions
Two methods named **Static Modes Switching (SMS)** and **Static Modes Sliding (SMS\(^2\))** have been developed and tested on different test cases ranging from academic to industrially relevant:
- The SMS method proved to be efficient and reliable for simulation of flexible multibody systems with variable topology.
- Numerical strategies have been developed to deal with the discontinuous character of the method.
- In order to improve the usability of the SMS technique, the novel parametric MOR method name SMS\(^2\) is introduced.
- The method shows similar benefits as compared to the SMS approach with improved usability and removing the discontinuities introduced by SMS.
- Future work will focus on extensions of SMS\(^2\) to non-linear contact problems.

Major publication
Nickel/Copper Plated Contacts as an Alternative to Silver Screen Printing for the Front Side Metallization of Industrial high efficiency Silicon Solar Cells

Introduction / Objective
As most of a photovoltaic (PV) system cost is area related, the highest impact on cost can be achieved by increasing the efficiency of the solar cells in the PV modules while reducing manufacturing costs. This is followed in this thesis by replacing conventional silver (Ag) screen printed front side contacts by nickel/copper (Ni/Cu) plated contacts since they present several advantageous properties (reduced optical shading, high conductivity, reduced contact resistance to optimum emitters) including being much cheaper than Ag.

Research Methodology
Despite the potential advantages of Ni/Cu plated contacts their commercialization has so far been limited due to a number of challenges (increased process complexity, lack of suitable low-cost production techniques/tools, doubts over cost-advantage and long-term reliability) as well as recent progress made with screen printing of Ag. Thus, the approach followed in this thesis is to reduce process complexity by introducing suitable low-cost production techniques/tools in an incremental manner since many processes are inter-linked and need to be co-optimized. Reliability and cost-of-ownership issues are addressed in parallel.

Results & Conclusions
Efficiency ~20.5% using inline plating/sintering tools:
⇒ high-efficiency process that is robust and repeatable
Ni/Cu/Ag contacts ~4.4€/cell cheaper than Ag contacts:
⇒ return-on-investment <3years
First evaluation of environmental module testing and thermal ageing:
⇒ long-term (>25 years) reliability appears feasible

Major publication
L. Tous, M. Aleman, R. Russell, E. Comagliotti, P. Choulat, A. Uruena, S. Singh, J. John, F. Duerinckx, J. Poortmans, and R. Mertens. Evaluation of advanced p-PERL and n-PERT large area silicon solar cells with 20.5% energy conversion efficiencies, accepted in Progress in Photovoltaics: Research and Applications
Quantification of the mechanical environment for tissue engineering in load-bearing bone

Introduction / Objective

The treatment of large segmental defects in long bones remains a clinical challenge. Bone tissue engineering (TE) is a multidisciplinary research field that has the potential to revolutionise the treatment of non-healing bone defects. However, TE products for large defects do not exist yet in the clinic. One of the reasons for this lack of successful TE products is an insufficient understanding of the role of the mechanical environment to which TE products are exposed. Finite element (FE) modelling is a powerful tool to quantify the mechanical environment inside porous scaffolds used for bone reconstruction. Therefore, the general goal of this study is to develop realistic finite element models that can be used to quantify the mechanical environment inside porous scaffolds.

Research Methodology

A 3D FE model of an external fixator is developed and validated by comparing the calculated results to the experimental testing results. Several aspects of the model are studied, in particular, the contact settings between fixator parts and between the fixator and the bone. Then, the validated FE model is used to quantify mechanical stimuli inside the scaffold under in vivo loading conditions. Finally, predicted values of mechanoregulation stimuli are compared to in vivo results on tissue ingrowth in porous scaffolds.

Results & Conclusions

By carefully adjusting the contact settings between each part of the model, a good correspondence between predicted axial stiffness and measured stiffness can be obtained. The FE model can quantify mechanical stimuli inside the scaffold under realistic in vivo loading condition. This study demonstrates the importance of in vivo loading conditions as well as mechanical properties of scaffold and fixator on mechanical stimuli inside the scaffold.

Top: Experimental set-up for axial loading of reconstructed tibia (A). A close-up view of the scaffold-bone interface is shown in a separate box. The representative finite element model shows element size for each part of the model (B). Left: histological section (a) and mechanoregulation stimuli in porous scaffold (b)

Major publication

Energy Analysis of High-Dynamic components: Model Development and Experimental Evaluation for Needle Roller Bearings and Wet Clutches

Introduction / Objective
In recent years, there has been a growing concern regarding the increasing prices and requirements of energy around the globe. One of the largest and cost effective ways to tackle this issue is by improving the energy efficiency of components/systems. This leads to a reduced total cost of ownership of machines, lower fossil fuel dependency and reduced greenhouse gas emissions. In this thesis two critical high-dynamic components, namely bearings and wet clutches are subjected to detailed energy analysis through modeling and experimental characterization. Bearings are commonly used component in machines/systems, whereas the wet clutches find application in most of the transmission devices.

Research Methodology
The approach adopted in the present thesis in order to tackle the issue of energy analysis of bearings and wet clutches that could enable the system level energy efficiency improvement is shown schematically in adjacent figure.

Results & Conclusions
The main contributions are divided into five parts as follows:
- Improvement in the state-of-the-art bearing power loss models.
- Development of an extended Reset-Integrator friction for wet clutch applications.
- Investigation of degradation and driving energy level effects on wet clutches performance and energetic behavior.
- Experimental characterization of drag torque in disengaged wet clutches
- Development of a drag torque model for disengaged wet clutches

Major publication
Performance and Characteristics of ELID-grinding

Introduction / Objective
Brittle-hard materials like ceramics and cermets are used in many challenging applications because they are characterized by very interesting properties, such as a superior specific stiffness, a high wear resistance, chemical stability... Their major drawback however lies in their poor machinability. Enabling an affordable production of smooth and accurate free-form shapes, will create a multitude of new applications. As an example, the fabrication of free-form cermet molds can lead to the mass fabrication of free-form lenses of optical quality through replication. This application requires the workpiece to be highly accurate and to have a superb surface quality. ELID-grinding is one of the most promising techniques to realize this.

Research Methodology
The electrochemical fundamentals of the passivation process have been studied profoundly and a model has been developed which explains the electrical behavior of the growth of the passivation layer. This model can be used to monitor and control the state of the passivation layer, in order to maintain stable grinding conditions. Experiments have been carried out to investigate the influences of some of the key parameters on the passivation speed of a grinding wheel. Additionally, several series of grinding experiments have been performed to analyze the ELID-grinding process efficiency, the workpiece precision and the surface quality of the part. This has been realized for three types of materials: a hardened steel, a cermet and a ceramic.

Results & Conclusions
Experimental research has shown that the state of the passivation layer, which ultimately determines the stability of the ELID-grinding process, depends on the current and voltage levels. The electrolytic system has been modeled based on the Helmholtz representation of a double layer. Simulations based on this equivalent scheme show a good correlation with the measured data. The fundamentals of the oxide growth have been explained with the help of this model.

The ELID-roughing alternative is preferable to conventional grinding with resin or metal bonded wheels. Resin bonded wheels suffer from low G-ratios and wheel loading effects and only remove material at moderate removal rates. Although cast iron bonded grinding wheels can achieve high G-ratios and removal rates, these wheels require intermediate dressing cycles to avoid glazing effects. Superb surface properties can be realized together with a high shape accuracy by applying the ELID-finishing steps on the same grinding machine. The effects of varying the process parameters during ELID-finishing have been analyzed through a DoE approach.

Major publication
Oxyanions in industrial waste and wastewater: formation, leaching and adsorption

Introduction / Objective
Oxyanion forming elements like As, Cr, Mo, Sb and Se are toxic and their distribution in the environment must therefore be prevented as much as possible. The existing literature is unable to explain increased concentrations of oxyanions in the leachate that are observed when contaminated solid residues are heated to obtain a structured product. Furthermore, oxyanions pose problems when they are present in industrial wastewaters; the literature on their removal by adsorption is limited to synthetic solutions. The aim of this thesis is to control the formation and subsequent leaching of oxyanions during high temperature processes and to improve the removal of oxyanions from industrial wastewater.

Research Methodology
- Synthetic mixtures were used to study the influence of process conditions on the formation and leaching of Cr and Mo oxyanions after heat treatment. Industrial solid residues that can be valorized by thermal treatment, were heated under the same conditions to check the plausibility of the findings for real situations.
- A novel adsorbent, perlite-supported magnetite, was developed and thoroughly characterized before it was tested for the simultaneous removal of As, Cr, Mo, Sb and Se from a synthetic solution. Specific attention was paid to elements interfering with oxyanion adsorption from industrial wastewaters. Finally, the adsorption from an industrial wastewater, the scrubber effluent of a waste incineration plant, was studied.

Results & Conclusions
The possibilities to treat and recycle contaminated industrial solid residues have improved:
- Increased Cr and Mo leaching after heat treatment is explained
- Optimal process conditions for recycling are defined
- Appropriate countermeasures to reduce leaching can be taken

A new method for treating industrial wastewater was developed:
- Perlite-supported magnetite has a good removal efficiency for Mo, Sb, (Se)
- Main interferences were identified: for real wastewater, they mainly hinder the adsorption of As and Cr

Major publication
Strategic Behaviour in Power Wholesale Electricity Markets

Introduction / Objective
To understand the evolution of the electricity market, dynamic market modelling tools can be applied. Using such models, stakeholders gain insights on the sensitivity of the market design against potential disturbances or market imperfections, and take necessary actions to pro-actively address them. How the state of an interconnected electrical system evolves after clearing the day-ahead market as organised under the European power exchange model, subject to strategic gaming behaviour has been studied.

Research Methodology
Firstly, a novel profit risk hedging offering strategy is presented. It submits the coordinated dispatch schedule of thermal, hydropower and renewable power plants to the market operator. The generator pursues a total profit-maximising objective by simultaneously exercising physical and economic withholding while explicitly taking into account underlying technical constraints, plant economics and step-wise, price-responsive demand.

Secondly, the offering strategy is integrated in a newly designed dynamic electricity market model. Using multi-agent systems, each generator updates its perception of the market environment, including competitor behaviour and the inherent complexities of the electricity market, by evaluating the performance of historic decisions on its profit.

Results & Conclusions
The model is commercially available on www.optimate-platform.eu. It is unique compared to competing models because:

- Any generation portfolio can be fully modelled
- Inherent market complexities are explicitly taken into account, (e.g. limited transmission capacity, price-responsive demand...)
- The offering strategy is proven to significantly outperform alternative ones assumed to support policy decisions
- Results are robust and easily tractable
- Important market design parameters can be altered to assess their impact on the efficient operation of the electricity market, subject to suboptimal behaviour of market participants
- The model is currently being used by Transmission System Operators, Regulators and Energy Administrations in Europe

Major publication
Application of nanofiltration and membrane crystallization for the recovery of the active pharmaceutical ingredient G-1

Introduction / Objective
The Center of Bioactive Chemicals Cuba is a research center focused on products with high biological activity. In this work, the recovery of the active pharmaceutical ingredient 1-(5-bromo-fur-2-il)-2-bromo-2- nitroethane, (referred G-1), is performed by means of the use of nanofiltration and membrane crystallization from the waste streams produced during the purification process of G1 and Vitrofural®. Thus, experimental work was to be performed for specific applications in order to evaluate the technical viability of this technology.

Research Methodology
The potential of nanofiltration(NF) for the separation of G-1 is evaluated by using a cross-flow configuration. Both commercial and self-made polyethersulfone NF membranes are studied in synthetic mixtures of G-1 in ethanol and the retention of G-1 and flux of ethanol through the membranes are determined in order to evaluate the applicability of the studied membranes at production scale.

In addition, during the manufacture of APIs, residual streams with variable content of APIs can be produced and their further recovery is as attractive as challenging due to the complex mixture of compounds that can be present. Membrane crystallization can be used in this case to crystallize selectively the target compound and recover it from the mixture as an integrated process solution.

Results & Conclusions
The application of NF for the recovery of G-1 from ethanol solutions is feasible; the best results were found with the membranes PES/NMP25%, PES/NMP27% and the commercial membrane NF 270 in terms of percent retention and permeance. The application of membrane crystallization for G-1 recovery can be considered as a novel technique with high potential to recover pharmaceutical compounds from waste streams.

The mass transfer coefficients inside the fiber($k_f$), shell side ($k_p$), the membrane ($k_{mp}$) and the total coefficient ($k_{total}$).

<table>
<thead>
<tr>
<th>$k_f$ (m/s)</th>
<th>$k_p$ (m/s)</th>
<th>$k_{mp}$ (m.Pa$^{-1}$.s$^{-1}$)</th>
<th>$k_{total}$ (m.Pa$^{-1}$.s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.21x10^{-5} (0.025%)</td>
<td>3.22x10^{-4} (96.97%)</td>
<td>4.53x10^{-4} (3%)</td>
<td>1.36x10^{-12}</td>
</tr>
</tbody>
</table>

Major publication
Functional Techniques for Representing and Specifying Software

Introduction / Objective
All software is represented as source code in a programming language. The programming language defines the meaning or semantics of the code, for example, its operational behaviour. Good representations and specifications make it possible for programmers to express and verify that their software has the intended semantics and to express inter-component semantic assumptions, which is crucial for efficiently producing software that is reliable, efficient and secure, and for preserving these qualities during the software’s evolution. Many types of software components and their desired semantic properties are challenging to represent and specify. In my thesis, I contribute novel functional techniques for the representation and specification of four types of software components: ad hoc polymorphic functions, context-free grammars, meta-programs and effect-polymorphic software. This poster focuses on the latter: effect-polymorphism.

Object capabilities
Object-capabilities are a technique for restricting the side-effects that components may perform, an important requirement for enforcing security properties, but also general architectural properties. The technique specifies that components may perform only those side-effects for which they have received a capability. Such capabilities are represented as objects and programmers can easily create new custom capabilities using standard object-oriented techniques. To guarantee that components cannot violate this restriction, certain restrictions are needed in the programming language (no static mutable state, no static side-effecting APIs) and programming languages that satisfy these restrictions are known as capability-safe.

Effect-polymorphism
In my thesis, I contribute a new characterisation of capability-safety. Intuitively, the idea is that if a component only produces side-effects through the capabilities it receives, then it can be used in any “world” for which implementations for the capabilities are available. This intuitive characterisation is made formal using concepts from programming languages research: monads and parametric polymorphism. This characterisation can be used to formulate and prove properties of effect-polymorphic components using the powerful concept of parametricity. If, for example, a component does not have access to a capability, this effect-parametricity can be exploited by instantiating the component in a world where the capability does not exist.

Major publications of PhD
Introduction / Objective

Our society is currently facing a new electronics revolution consisting of bendable and thin large-area electronics. The development of novel thin-film processes with organics and/or amorphous metal-oxides semiconductors is crucial.

This doctoral research focuses mainly on the realization of a new generation of complementary thin-film circuits on plastic foil, based on the integration of innovative solution-processed semiconducting metal-oxides (like In$_2$O$_3$) and organic semiconductors (like pentacene). This research was pushed forward by the potential applications like low-cost RFID tags, smart objects and flexible displays.

Research Methodology

Experimental, using a systematic approach:

- Understand the relation between chemical composition and process parameters (like conversion temperature) on semiconducting properties of solution-processed oxides.
- Fabricate and evaluate metal-oxide n-channel transistors.
- Integrate pentacene p-channel transistors into a hybrid complementary technology on foil.
- Fabricate and evaluate digital circuitry on foil.

Results & Conclusions

- One single measure is found (the Meyer-Neldel temperature) to judge the electrical quality of solution-processed oxides at different conversion temperatures.
- Metal-oxide transistors are realized at only 250 and 160 °C, resulting in mobilities up to 2.17 and 1.10 cm$^2$/Vs.
- A hybrid complementary technology is successfully realized on plastic foil (PI and PEN). The strengths and limitations of the hybrid complementary technology are revealed by discussing the static and dynamic behavior of inverters and ring-oscillators.
- The technology delivers the right optimum regarding its robustness, speed and power consumption, significantly better than competing technologies reported in literature.
- State-of-the-art 8-bit and 96-bit RFID tags have been realized on foil, with data rates up to 51 kbits/sec.

Major publication

Introduction
The ability to easily exchange and access data has transformed the way we work, study, inform and entertain ourselves. In particular, the Internet has had an effect on people's lives in the past two decades that is profound. Profound as this effect may be, people seem not to grow tired of it, and the broadband access market grows at a fast pace. Of the technologies currently available for broadband access, digital subscriber lines (DSL) is by far the market leader. One of the major problems with this technology is severe levels of multi-user interference, commonly known as crosstalk.

Results & Conclusions
- Proposed algorithm for optimal spectrum coordination is up to 60 times faster than the benchmark algorithm.
- Low complexity proposed algorithm for sub-optimal spectrum coordination is up to 15 times faster than the benchmark algorithm.
- Combined signal and spectrum coordination is seen to provide gains of several gigabits per second in realistic DSL scenarios (see figure on the right).
- Algorithm for combined signal and spectrum coordination is very robust and flexible, and can be used in several scenarios with different types of coordination on the transmitter and receiver sides or with per-user of per-transceiver power constraints or with asynchronous transmission.

Major publication
Robust Registration in Integrated Hyperspectral Imaging

Introduction / Objective
Hyperspectral Imaging (HSI) combines spectroscopy with imaging, enabling the identification of the chemical signature of scene materials and objects without physical contact. Hyperspectral data is collected in a 3D hyperspectral image cube/data structure with two spatial (horizontal) and one spectral (vertical) dimension (cfr. Fig. 1). The process of stacking spectral images acquired from a 2D hyperspectral camera to form a 3D hyperspectral image cube (cfr. Fig. 2 and 3), generally suffers from misalignment/misregistration, preventing the accurate reading of the scene’s chemical-spectral signatures. To achieve a perfect hyperspectral cube, images have to be aligned/registered with sub-pixel accuracy.

Research Methodology
To meet the above research objective, this thesis proposes a novel image feature-based spectral image registration algorithm (cfr. Fig. 4) to achieve immunity against the severe hyperspectral image artifacts such as blur, noise and spectral reflectance variations. The main contributions of this research work are:

- proposed two novel feature detection algorithms using the cosine modulated Gaussian and the tenth order Gaussian derivative filters.
- proposed a low complexity implementation approach with a fixed-length approximation filter, providing constant-time, low-cost image filtering implementations.
- uniquely combines the proposed advanced feature detection algorithms with RANdom SAmple Consensus’s (RANSAC) to robustly estimate the registration model parameters.

Results & Conclusions
The proposed feature detection algorithms show a two times higher immunity against the image artifacts as compared to state-of-the-art methods. The proposed registration algorithm reduces the registration error from hundreds of pixels in the raw hyperspectral image cube down to half-pixel registration inaccuracy, without the need of costly calibration, deblurring and/or denoising techniques in hardware or software. This eventually paves the way to a low-cost and reliable hardware/software co-designed hyperspectral imaging system.

Major publications
CMOS Front Ends for Millimeter Wave Wireless Communication Systems

Introduction / Objective

This work focuses on the development of circuit and system design techniques for millimeter wave wireless communication systems above 90GHz and fabricated in nanometer scale CMOS technologies. Thanks to the CMOS technology scaling, the speed of the transistors has increased towards a maximum frequency of oscillation above 300GHz for the latest technology nodes. So CMOS has become a millimeter wave technology, but with the great advantage of high integration capability. Although the speed of the CMOS transistors has increased, the target operation frequency of the circuits in this work (above 90GHz) is still close to the technology’s maximum frequency of oscillation. So coping with a low power gain is one of the major design challenges in CMOS. Also, the transistors tend to show potential unstable behavior, which makes multistage design a real challenge. Furthermore, the metal stack of CMOS technologies is not optimized for the design of high frequency passives, which results in a decreased performance of traditional matching circuits. At system level, problems like the implementation of the millimeter-wave chip interface and bandwidth and linearity requirements of the ADC’s, DAC’s and up- and downconversion circuits emerge.

Research Methodology

To solve the above mentioned problems, six different chips are designed in which circuit and system level solutions are proposed and implemented. Three different multistage differential W-band amplifiers are designed in which capacitive neutralization is extensively applied to improve the gain and stability properties of the transistors. The adoption of transformers and slow-wave transmission lines in the impedance matching networks resulted in small chip footprints, while improving the performance of the amplifiers even more. At system level, direct digital modulation schemes were applied in three different F-band and D-band transmitters which has lead to new digital modulation system topologies. These direct carrier modulator topologies have resulted in a relaxation of the requirements of the upconverter and made it possible to omit high speed DAC’s. Also the design complexity of these systems could be considerably reduced.

Results & Conclusions

The applied design techniques have resulted in state-of-the-art performance. Measurements of the amplifiers show high gains ranging from 11dB up to 18dB and high output powers up to 8dBm above 90GHz. Measurements of the fully integrated transmitters show high speed wireless data communication capabilities. The F-band ASK transmitter and the 120GHz PSK transmitter respectively support data rates up to 5Gb/s and 10Gb/s. The fully integrated 120GHz Star-QAM transmitter, which combines both modulation techniques of the previously mentioned transmitters is capable of supporting a 10Gb/s wireless data link. The integration of a frequency generator, modulator, power amplifier, baseband circuits and bondwire antenna has lead to a fully integrated solution which solves the problem of millimeter wave interfacing and hereby closes the gap between a laboratory chip solution and a real-life application.

Major publication

Vibro-acoustic modelling of anisotropic poroelastic materials – characterisation of the anisotropic properties

Introduction / Objective
Poroelectric materials for acoustic applications are often anisotropic due to the production processes involved, and anelastic due to the constituent material used. An accurate characterisation of these materials must therefore take into account the possible anisotropy and anelasticity. The objective of this thesis is to enable the characterisation of a constitutive material model which is as general as possible, and which includes the inherent material anisotropy and anelasticity. For this purpose, a set of advanced characterisation techniques needs to be engineered to characterise the anisotropic flow resistivity tensor and the anisotropic dynamic Hooke's tensor.

Research Methodology
The developed characterisation techniques are based on an inverse estimation procedure, and includes both experiments and numerical predictions. The property to characterise is isolated in a specially designed set-up such that it can be modelled by physics solely involving this property. The obtained experimental and numerical data then serve as the input to an optimisation, in which the difference between both is minimised. The obtained model parameters are then considered to give a best possible representation of the material parameters.

Results & Conclusions
The relevance of including anisotropy in the material model is demonstrated by the characterisation of the flow resistivity and the elastic material properties of a melamine foam, clearly showing that both properties are non-isotropic. Moreover, it is found that the production process has a significant influence on the material properties, and that the anelasticity of the material needs to be included for a correct representation of the material behaviour.

Major publication
Quality Maintenance in Geographical Data and Services for Spatial Networks

Introduction / Objective
The present thesis describes various applications based on concrete questions originating from GIS practice. The following three themes are treated throughout this work.

1. Quality maintenance in geographic information systems (GIS). It is pursued through the identification of patterns, describing relational regularities, and corresponding outliers indicating probable inconsistencies in the data. This approach is different from classical approaches to quality analysis in GIS, traditionally relying on techniques prospecting for statistical and positional deviation in geo-data. The quality of this type of data is of high influence on the service quality offered by navigation systems, online route planners and apps providing location-based services.

2. Efficiency enhancement of shortest path (cost) approximation components for spatial networks. Shortest path algorithms are the basic component of point-to-point route planners and navigation systems and operate on spatial networks, extracted from geographical data. An approximation component returns a path of which the length approximate the length of the shortest path between two locations in a network. This work focusses on such components in resource-constrained environments where exact approaches cannot be applied.

3. The fast and automated discovery of attractive closed paths. This process operates in spatial networks where the edges have both a length and an attractiveness score. An algorithm of low computational impact generating heuristic solutions is presented, and gives rise to a web component for tour suggestion for outdoor activities.

Research Methodology
The first theme implies the modeling and design of a tool for data engineers, tracing relation regularities and outliers in large and dynamic geographical databases. It is validated during an extensive sanity check. Theme 2 involves the design of approximation components based on auxiliary structures in spatial weighted graphs. The presented techniques are supported by large-scale experimental analyses of the approximation accuracy, the calculation time required to produce an approximation and the structures' compactness. The last theme implies the introduction of the tour suggestion problem for outdoor activities and a fast algorithm generating heuristic solutions to this problem.

Results & Conclusions
The underlying concepts and approaches introduced in the present thesis are applicable in more general domains. Four software components resulting from this research have been adopted by industry.

Major publication
Statistical Process Monitoring for fault detection & diagnosis in (bio)chemical processes

Introduction / Objective
Abnormal event management is of central importance to the process industries. Early detection and diagnosis of process faults permits timely interventions to keep the process within a safe controllable operating region and avoids production loss associated with the abnormal situation.

Research Methodology
Given the abundance of sensors in today’s chemical and biochemical plants, extensive historical databases containing frequent measurements of online sensors on hundreds of variables are readily available. Statistical Process Monitoring (SPM) exploits these historical databases for fault detection and diagnosis of the current process.

The basic concept of SPM is the statistical comparison of the current process measurements with historical data obtained under Normal Operating Conditions (NOC). Process behavior not included in the NOC data is detected by fault detection statistics. The process is monitored using control charts which depict the value of the statistic and corresponding control limits for normal operation at each time point.

Results & Conclusions
This PhD research focused on the online implementation of SPM-methods as an industrial process monitoring tool. Results have been obtained in the areas of data-alignment for batch-end quality prediction\(^1\), PCA-based fault detection for dynamic processes\(^2\), fault isolation using contribution plots\(^3\) and fault diagnosis with classification algorithms\(^4\).

Major publications
Low-Rank Representations for Sum of Squares Polynomials

Introduction / Objective

The purpose of this research is to study the Pythagoras number of polynomials, together with their corresponding low-rank representations, from theoretical and practical points of view. The results are used to solve several optimization problems that can be reformulated over non-negative polynomials, such as low-pass filter design problems.

Results & Conclusions

- Gave and proved the lower and upper bounds on the Pythagoras number of sosm-polynomials; gave a new proof for the upper bound on the Pythagoras number of sos-polynomials which is known in the literature
- Proposed algorithms for approximating the low-rank representations of sos(m)-polynomials and for computing their Pythagoras number
- Proposed an algorithm for decomposing a non-negative polynomial as a sum of squares of rational functions
- Proposed an optimization model that can be used to solve several (IIR, FIR) filter design problems

Major publication

- M. Ferranti, T. H. Le, R. Vandebril. A comparison between the complex symmetric based and classical computation of the singular value decomposition of normal matrices. (Accepted to Numer. Algor.)
**Patient-specific instrumentation in orthopaedic surgery**
A computational model for design optimization

**Introduction / Objective**
A recent trend in orthopaedic surgery is the use of preoperative plans based on 3D imaging data of the patient. One method to transfer this plan to the actual surgery is the use of patient-specific instrumentation. To allow an accurate transfer of the plan, three important criteria are identified: stability of the fit of the guide on the anatomy, uniqueness of the fit position and correct use of the guide by the surgeon. This work focuses on the requirement of stability.

**Research Methodology**
A mathematical model is introduced to predict the fit stability during the virtual design process, by providing the designer with a stability score. This model originates from robotics theory and analyses the resistance of the contact surface towards a potential translational or rotational movement. Validation experiments have been performed by using both fit experiments and quantitative measurements relating applied forces and resulting displacements. The validation experiments confirmed that the stability score resulting from the model provides a reliable indication of the haptic feeling of stability when fitting the guide on the respective bone model. As both the preoperative plan and guide design are based on 3D models of the patient's anatomy reconstructed from medical imaging data, one chapter of this thesis discusses the accuracy of image segmentation and 3D model reconstruction.

In addition, the knowledge obtained during the development of the stability model was used to create tools to optimize the guide design process. Methods were developed to indicate how an existing guide design can be improved with respect to the predicted stability, either by extending the current guide with functional features or by enlarging the contact surface. In addition, a method to create the optimal contact surface for a specific anatomy was investigated, maximizing both stability and accuracy.

**Results & Conclusions**
The results presented in this work suggest that the currently used process of surgical guide design could benefit from the introduction of mathematical algorithms to reduce design uncertainties such as the stability of fit, thereby improving the quality of the instrumentation sent to the surgeon for patient treatment. The methods currently developed provide a good starting point for optimizing this design process, creating an opportunity for additional improvement in automatic design of the optimal guide for each patient.

**Major publication**

**Acknowledgement**
This PhD research was funded by both the Baekeland scheme of the Agency for Innovation by Science and Technology (IWT) and Materialise NV.
Identification of subject-specific parameters of a Hill-type muscle-tendon model for simulations of human motion

Introduction / Objective

Biomechanical analysis for the evaluation of human motion is a valuable tool. The potential applications are very diverse: treatments of mobility impairments in order to enhance the individual's quality of life, optimization of sports performance, and design of prosthetics. These analyses rely on musculo-skeletal models from which the muscle-tendon model is a submodel. The better these models reflect the patient, the more reliable the analyses are. However, in general generic models are used. Therefore, this thesis aimed at subject-specifically describing the force generating capacity of the muscles and tendons by identification of the muscle-tendon parameters based on experimental force data.

Research Methodology

- Sensitivity analysis: which parameters are crucial for the accuracy of the simulations?
- Design experimental set-up: enhance regular dynamometer to allow full 3D inverse dynamic analysis.
- Experimental design: find minimal set of experiments for maximum amount of information on parameters.
- Parameter identification: non-linear optimization, validation in simulation environment.
- Proof of concept: experimental data, different measurement conditions.
- Focus on knee joint.

Results & Conclusions

- Hierarchy in muscle-tendon parameters: reduction parameter space.
- 3D experimental joint moment registration and proper modelling of joint: more accurate data.
- *A priori* intelligence results in definition of feasible set and hot start for non-linear estimation algorithm.
- Estimation algorithm outperforms benchmark by more than one order of magnitude when noisy data are involved.
- Subject-specific muscle-tendon parameter estimation: added value for motion simulation. However, development of other modelling aspects might show its full potential.

Major publication