Innovate:

Issue 15 2020

DRIVING INDUSTRY 4.0

Smart transportation and cities

First-in-Africa concrete laboratory

Educating civil engineers for the future

SDG 9: Industry, Innovation and Infrastructure

Disruptive technologies in the 4IR

Society 5.0

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Engineering, Built Environment and Information Technology

Fakulteit Ingenieurswese, Bou-omgewing en Inligtingtegnologie / Lefapha la Boetšenere, Tikologo ya Kago le Theknolotši ya Tshedimošo

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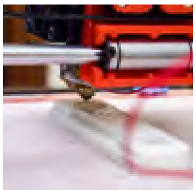

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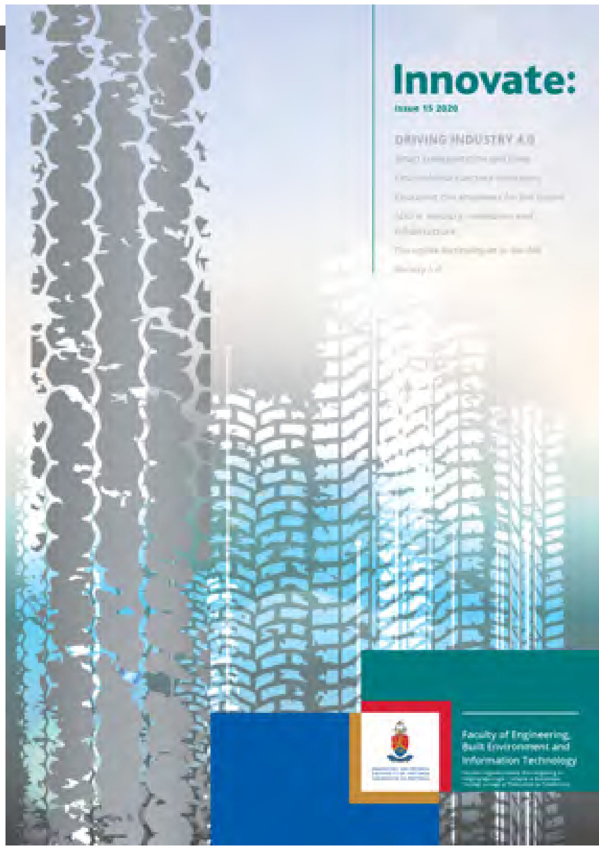
Innovate is an annual publication of the University of Pretoria's Faculty of Engineering, Built Environment and Information Technology.



ON THE COVER

DRIVING INDUSTRY 4.0

The Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria is driving innovation through its cutting-edge research focus areas and the addition of the Engineering 4.0 Complex.

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... and then came COVID-19

For almost a decade, Fourth Industrial Revolution (4IR) strategies have had an impact on industries, governments, service organisations and – ultimately – the lives of people around the globe. The agendas of politicians, business managers, project managers and researchers have been dominated by the question of how the 4IR could improve economic growth, profitability and productivity, and improve lifestyles. Many companies still struggle to identify and select the most appropriate 4IR technologies and successfully implement them in their business operations in order to realise the required economic benefits. And then came COVID-19, totally unexpectedly, and it seemed that the 4IR was forgotten, at least for the moment.

Within a few weeks, the world almost came to a standstill. Except for some "essential" services, the world economy crashed, businesses closed down and people's social lives were severely impacted. Governments around the world reacted in panic and the doomsday prophecies (reminding everybody that 50 million people had died during the 1918 flu pandemic) did not help get them out of the shock. Many governments took precautions similar to those taken in 1918, by isolating people from each other and closing businesses. The results were devastating when global supply chains collapsed, many companies permanently closed down and millions of people faced the reality of losing their jobs.

The fact is that the world in 2019 looked very different from the world in 1919. At the beginning of the COVID-19 pandemic, it seemed that many people ignored the fact that our world today is dominated by technology. Fortunately people soon started realising that technology is the major resource that could keep industry and society going. Innovative ideas resulted in technology being utilised to share valuable information regarding the pandemic, make forecasts, keep businesses running by working from home, continue with school and university education, and accelerate research to find a drug to cure the disease, among others. Personally, I think that unnecessary damage to the global economy and society was done because of the ignorance of the role of technology and the resultant bad decision making that followed. The world will probably feel the pain for a long time to come. But one thing is for sure, the world of the future will be different. Science and technology development will be driven in new directions forced by what we have learnt from our COVID-19 experiences.

Technology is the major resource that could keep industry and society going. Innovative ideas resulted in technology being utilised to share valuable information regarding the pandemic, make forecasts, keep businesses running by working from home, continue with school and university education, and accelerate research to find a drug to cure the disease.

ONE THING IS FOR SURE, THE WORLD OF THE FUTURE WILL BE DIFFERENT.

The University of Pretoria was quick to react to the consequences of COVID-19 to prevent a slowdown in our educational and research goals and activities. Our well-implemented technology systems and continuous efforts to be on the leading edge with science and technology innovation made it possible for both our staff and students to continue with their planned activities. In addition, the University engaged, through its expertise, in many initiatives to help government and industry re-establish competitiveness.

In this edition of ***Innovate*** you will again find a selection of interesting contributions on the research and educational activities of the Faculty of Engineering, Built Environment and Information Technology. Enjoy reading!

Prof Tinus Pretorius
Editor

Message from the Dean

Prof Sunil Maharaj
Dean: Engineering, Built Environment and Information Technology

Global technology is evolving on an exponential scale, and the Faculty of Engineering, Built Environment and Information Technology at the University of Pretoria is responding to this challenge by developing sustainable technologies for inclusive societies.

Within the context of the current global pandemic brought about by the rapid spread of COVID-19, the Faculty has continued to implement disruptive approaches to higher education by embracing online teaching and learning.

By encouraging students to embrace these disruptive technologies, it is preparing them for the world beyond university on an unprecedented scale.

At the same time, its researchers are rising to the challenge of ensuring that they can make a significant contribution to society at large by focusing their research on topics that are aligned to the Sustainable Development Goals (SDGs) of the United Nations. According to a recent audit to determine the extent to which research in the Faculty is making an impact, it was found that the Faculty's research has succeeded in addressing the 17 SDGs

During 2019/20, the University participated in the Times Higher Education Impact rankings, the only global performance indicator that assesses universities against the SDGs. The impact of the Faculty's research became evident in the University's participation in this ranking exercise, as the Faculty could participate in four of the SDG categories, and was tasked to champion SDG 9: Industry Innovation and Infrastructure. For this SDG, the University was ranked 94th out of 494 institutions. This is a great achievement, given that universities worldwide are expected to make an impact in their environment and collaborate closely with industry.

The highlight of the year for the Faculty was certainly the completion of the long-awaited Engineering 4.0 Complex on the University's Innovation Africa Campus. This is the result of a public-private co-funded infrastructure partnership with the South African National Roads Agency Limited (SANRAL) and the Council for Scientific and Industrial Research (CSIR). This state-of-the-art collaborative hub will not only serve research in the area of future smart cities and transportation, but will also link the Faculty's vast resources in technology and data science to other faculties via Future Africa, which fosters research networks within the University and in the global research community.

This year also saw the Faculty's School of Engineering maintain its position in the top 1% in the world for research citations, as determined by the Web of Science Clarivate Analytics Essential Science Indicators. It has also been rated as the 2020 top School of Engineering in South Africa and Africa according to the Best Global Universities for Engineering ranking of the US News and World Report. This is the outcome of ensuring that our academic programmes and research are of a high quality, as required for professional and international accreditation, and ensuring the continuous improvement of our facilities to the benefit of our students and research partners.

It has been my vision as Dean to continue to take the Faculty to a higher level in terms of student access and success, quality, relevance, diversity and sustainability.

> **THE UNIVERSITY WAS RANKED 94TH OUT OF 494 INSTITUTIONS BY THE TIMES HIGHER EDUCATION IMPACT RANKINGS FOR ITS CONTRIBUTION TO SDG 9: INDUSTRY, INNOVATION AND INFRASTRUCTURE, WHICH WAS CHAMPIONED BY THE FACULTY. IN ADDITION, THE FACULTY'S SCHOOL OF ENGINEERING HAS BEEN NAMED THE BEST IN AFRICA ACCORDING TO THE 2020 BEST GLOBAL UNIVERSITIES FOR ENGINEERING RANKING OF THE US NEWS AND WORLD REPORT.**

Best Global Universities Rankings

The Best Global Universities Rankings by the US News and World Report provide insight into how universities compare globally.

Universities were assessed using 13 indicators: global research reputation, regional research reputation, publications, books, conferences, normalised citation impact, total citations, number of publications that are among the 10% most cited, percentage of total publications that are among the 10% most cited, international collaboration (relative to country), international collaboration, number of highly cited papers that are among the top 1% most cited in their respective field and percentage of total publications that are among the top 1% most highly cited papers. Apart from being ranked top in Africa, the Faculty's School of Engineering is also highly regarded globally, having been ranked 277th in the world.

Message from the Deputy-Dean: Research and Postgraduate Education

Prof Jan Eloff

EBIT Research Strategy

The Faculty's research strategy is aligned with the University's overall vision to be a leading, research-intensive university in Africa. It also aims to make a significant contribution to society at large. As such, it focuses its research strengths on six broad research themes, which are aligned to the Sustainable Development Goals (SDGs) of the United Nations.

> **I BELIEVE THAT THE FACULTY IS WELL RESOURCED TO CONTINUE TO MAKE AN IMPACT ON SOME OF THE MOST PRESSING CHALLENGES OF THE DEVELOPING WORLD, PARTICULARLY THOSE RELATED TO THE COUNTRY'S ECONOMIC DEVELOPMENT, JOB CREATION, POVERTY, INEQUALITY, FOOD SECURITY, CLIMATE CHANGE AND QUALITY HEALTH.**

WATER AND ENVIRONMENTAL ENGINEERING

Research in the Faculty emphasises issues related to water quality, wastewater treatment, waste treatment, biotechnology and environmental engineering. Furthermore, the inquiry into engineered nanomaterials investigates how nanomaterials interact with environmental and, in particular, water systems. Environmental engineering also focuses on sustainable building methods, building and development, bio-sensors and mining engineering. Within mining engineering, ongoing research includes rock engineering, rock breaking, environmental management and leadership.

MINERALS AND MATERIALS BENEFICIATION

Research in this focus area is conducted to further the frontiers of the science and engineering impact on the South African minerals value chain. Optimised industrial processes for minerals processing and the extraction of valuable metals and materials are of particular interest. Furthermore, research projects are aimed at advanced manufacturing, and the fabrication of polymers and advanced alloys. There is an emphasis on nuclear accident-resistant fuel-cladding materials, nanofluids, bio-nanofluids, nanocellulose, carbon nanotubes, thermal-fluid behaviour and heat transfer.

THE FOURTH INDUSTRIAL REVOLUTION

Research conducted across many departments in the Faculty serves as critical components for creating a highly integrated environment for the Fourth Industrial Revolution (4IR). Studies focus on computer engineering, computer science, electronic engineering, systems engineering, bioengineering, signal processing, power electronics, control systems, optics, electromagnetism, micro-electronics, nanotechnology, additive manufacturing, condition monitoring and artificial intelligence. The Engineering 4.0 Complex entails an integrated road material reference laboratory, a training laboratory and a research laboratory, combined with a live traffic research facility and an accelerated pavement testing facility.

The Faculty's research excellence is illustrated by the fact that 92 of its researchers have been rated by the National Research Foundation (NRF), and it boasts two A-rated researchers in the area of clean energy efficiency and demand-side management. Its research excellence is furthermore recognised by industry and government through the establishment of 19 externally funded research chairs.

19 EXTERNALLY FUNDED RESEARCH CHAIRS

92 NRF-RATED RESEARCHERS

A 2 NRF A-RATED RESEARCHERS

SMART CITIES AND TRANSPORTATION

Smart cities in the 21st century should be resilient and connected. This can only be achieved by employing radical and innovative planning methods to facilitate radical spatial transformation. The research related to smart cities focuses on the co-creation of solutions with communities so as to achieve healthy urban systems. It conducts investigations into regenerative public spaces, building-integrated urban agriculture, and intelligent transportation and infrastructure. Furthermore, there are ongoing research projects in modular construction management, sustainable building, quantity surveying and real estate. Transportation development in this focus area puts the spotlight on railway engineering, road pavements, vehicle dynamics, autonomous and electric vehicles, and intelligent modelling

BIG DATA SCIENCE, ICT AND TECHNOLOGY AND INNOVATION MANAGEMENT

Research in this area investigates innovative machine and statistical learning approaches to unlock hidden knowledge in big data sets. It also explores the broader field of information and communication technologies (ICT), including cybersecurity, digital forensics, enterprise architectures, artificial intelligence, condition monitoring, software engineering, and ICT and engineering. Technology and innovation management focuses on the introduction of new products so as to secure an organisation's growth and sustainability. Technology and innovation management, and engineering management also focus on supply and value chain management, optimisation, ICT for development, human-computer interaction and data science management.

ENERGY

Energy provision for all citizens of South Africa is vital to support quality of life. This includes load and distributed generation balancing, as well as the storage and utilisation of all energy resources. Researchers in multiple disciplines, such as material science, mechanical and aeronautical engineering, electrical and electronic engineering, chemical engineering, civil engineering (hydropower) and engineering planning and management have contributed to efficient and sustainable energy systems. There is increased penetration of renewable energy generation such as wind or photovoltaic power into traditional grids and micro-grids. Clean energy that receives attention in the Faculty includes solar energy, heat exchange, nuclear accident-resistant fuel-cladding materials and nanofluids.

Message from the Deputy-Dean: Teaching and Learning

Prof Alta van der Merwe

Teaching amid disruption

Higher education institutions across the globe are facing unprecedented challenges resulting from social distancing practices in the time of the worldwide COVID-19 pandemic. The University of Pretoria, and in particular the Faculty of Engineering, Built Environment and Information Technology (EBIT), is not immune to these challenges, but sees this as an opportunity to embrace best practices associated with the Fourth Industrial Revolution (4IR).

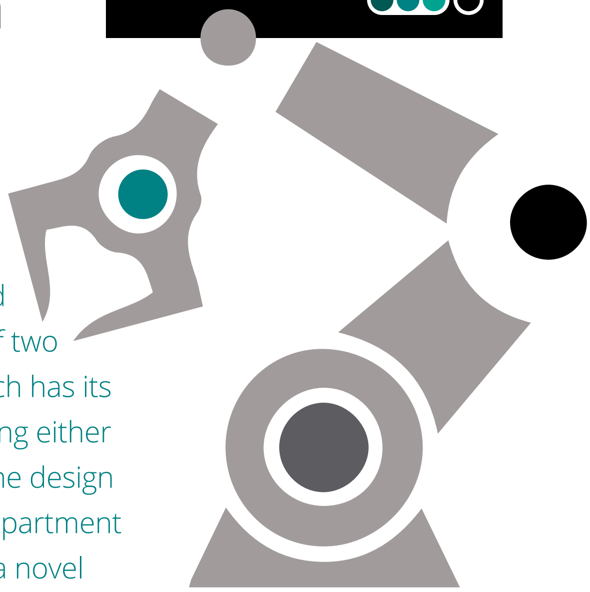
IN OUR FACULTY, WE ARE PRIVILEGED TO HAVE STAFF MEMBERS WHO THINK INNOVATIVELY AND EXPERIMENT WITH NEW TECHNOLOGIES AND WAYS TO INCORPORATE BETTER METHODS OF TEACHING AND LEARNING.

Hybrid learning in teaching and learning is used alongside traditional lecturing at the University of Pretoria (UP). We have been working for several years to implement a systemwide hybrid approach to teaching and learning. The aim is for each undergraduate module to include up to 30% online teaching and learning engagements. Almost 95% of all undergraduate modules have an active online presence. Data from the University's learning management system has also demonstrated that the most engaged students online outperformed the least engaged by 15%. This is a good argument in favour of the hybrid learning approach. Online learning also helps prepare our students for the world beyond university.

UP has always supported faculties to engage in online activities in order to ensure a blended approach to teaching and learning. We believe that, after the nationwide lockdown, we will return to contact classes, but believe that our staff will also engage in best practices learnt from the lockdown period.

Kinematic robotic arm provides 6° of freedom

Dr Sunveer Matadin



Industrial robots are commonplace on workshop floors to perform repetitive tasks where a high degree of accuracy and repeatability is required. Existing models are based on one of two architectures: serial or parallel kinematic machines. While each has its advantages, there are also disadvantages associated with using either one of the two designs. Research aimed at optimising machine design and functionality, conducted in the University of Pretoria's Department of Mechanical and Aeronautical Engineering, has resulted in a novel invention that considers the positive traits and trade-offs of both types.

As part of the research conducted to determine the benefits and drawbacks of existing models, a study was made of the two categories of robots presently in use. It was found that serial kinematic machines that consist predominantly of links interconnected with revolute joints are examples of open kinematic chains in which the actuator that activates the subsequent link is carried by the preceding link, although combinations of prismatic and revolute joints are also used for specific applications. This implies that each link carries the cumulative mass of all the links and their respective actuators that follow that link, in addition to the mass of the payload. Actuators therefore have to compensate by being higher powered in order to be put into motion and remain in motion, both in terms of the payload and the physical robot structure. The percentage of power used to actuate the physical robotic structure may be large considering that end effectors may carry low mass payloads such as spray guns.

The result is increased inertia and poorer dynamic performance at high velocities where high acceleration is required to reach the constant velocity on a typical trapezoidal velocity profile. It also has an adverse impact on the stiffness of the system and introduces unwanted vibration. This will adversely affect the accuracy of the end effector and repeatability of the system, while leading to higher power consumptions. This is especially true for higher order or degree of freedom (DOF) systems such as the 6 DOF systems that are commonly deployed due to their greater flexibility and operating workspace.

Serial kinematic machines have the advantage of offering a larger workspace and a larger degree of agility, while also having a low footprint-to-end effector reach ratio (a small footprint to large end effector reach).

Parallel kinematic machines, on the other hand, are examples of closed kinematic chains. All the actuators that provide the required degrees of freedom are located on or closest to the base, hence ensuring the lowest centre of mass. This architecture improves dynamic response and performance, especially at high velocities and accelerations.

This design also offers reduced vibration and an increase in the system stiffness, pose stability, accuracy and repeatability of the machine. Power consumption and actuator torque requirements are reduced as the actuators do not need to be as heavy and high powered as the serial kinematic design since they do not need to put heavy subsequent links and actuators in motion. Link structures are also lighter than the serial kinematic design as they do not need the increased mechanical strength to carry subsequent actuators and links. The power required from actuators is used to predominantly move the payload or end effector and payload combination. The percentage of power used to actuate the physical robotic structure is therefore low and most of the power capacity is dedicated to the movement of the payload.

The new design proposed entails a novel concept in both the control system and mechanical architecture of a high-agility 6 DOF hybrid serial-parallel kinematic robotic arm. It would address the shortcomings of traditional serial and parallel kinematic machine architectures, while preserving the benefits of each of the two designs.

AN IDEAL SYSTEM WOULD BE ONE THAT OFFERS HIGH ACCURACY, REPEATABILITY AND DYNAMIC PERFORMANCE AT HIGH SPEEDS, ALONG WITH LOW VIBRATION, HIGH SYSTEM STIFFNESS, AGILITY, A LOW FOOTPRINT-TO-END EFFECTOR REACH RATIO AND A LARGE OPERATING WORKSPACE, WHILE SUPPORTING PRISMATIC AND REVOLUTE JOINTS.

Parallel kinematic machines have the disadvantage of having a large footprint, hence the high footprint-to-end effector reach ratio (a large footprint to small end effector reach), relatively small operating workspace and reduced agility.

An ideal system would be one that offers high accuracy, repeatability and dynamic performance at high speeds, along with low vibration, high system stiffness, agility, a low footprint-to-end effector reach ratio (a small footprint to large end effector reach) and a large operating workspace, while supporting prismatic and revolute joints. In order to realise these objectives, an architecture and control system that includes the positive traits and trade-offs of both parallel and serial kinematic machines must be considered. This system must also be based on the transmission of mechanical power through the system instead of electrical power.

Earlier attempts have been made to solve this problem. These have taken on various forms and have proposed the repositioning of actuators and the use of several power transmission philosophies, including chain and belt drives, tendons and pulleys, linkages and gears. Very early attempts often only document a mechanical system with no indication or proof of a control system that ensures the accurate and repeatable operation of the system in its entirety.

The new design proposed entails a novel concept in both the control system and mechanical architecture of a high-agility 6 DOF hybrid serial-parallel kinematic robotic arm. It would address the shortcomings of traditional serial and parallel kinematic machine architectures, while preserving the benefits of each of the two designs. It would therefore need to include the following attributes:

- The robotic arm would need to take the form of a traditional serial kinematic machine that contains a series of links, where each link is attached to the link preceding it.
- Each link should offer a degree of freedom so that the entire system offers six degrees of freedom.
- All motors that power the links in the system should be housed in the base of the robotic manipulator as is the case in a traditional parallel kinematic machine.
- All motors should remain stationary at all times, and power should be transmitted mechanically from the motors to the respective link by means of a drive train.
- It should be possible to rotate each link 360 degrees in both clockwise and counter-clockwise directions. It should also be possible to control each link individually and to move each link to a desired location, regardless of the motions of other links in the system.

This research topic was proposed by Sunveer Matadin and was completed in February 2019 as a doctoral research project under the supervision of Prof NJ Theron. The invention emanating from it is in the process of being protected and applied to an industrial robotic arm.

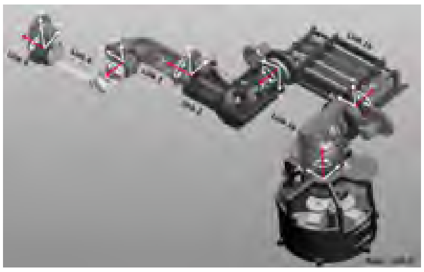
It can, however, also be implemented in robotic exoskeletons and prosthetics. Opportunities to commercialise the invention in any of the many forms that it can be applied are being investigated and any proposals to this end are welcomed.

The new invention introduces a hybrid concept for a robotic arm manipulator that aims to leverage off the benefits of serial and parallel kinematic machines, while minimising their disadvantages. The hybrid system's link architecture, which is one of two kinematic chains in the system, takes the form of a serial kinematic machine, and the motors that power these links are fixed and located at the base of the system, as with a parallel kinematic machine.

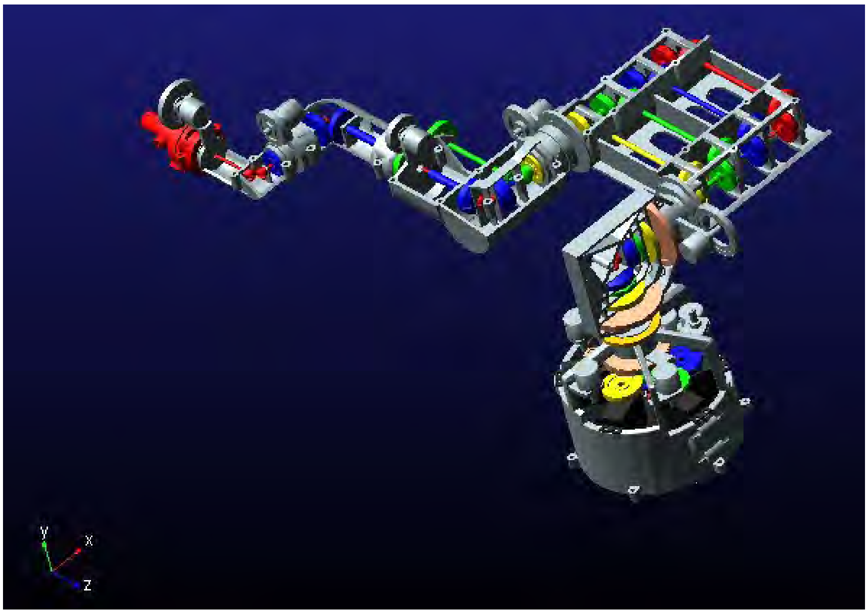
Power is transmitted from motors to their associated links via drive trains composed exclusively of gear and shaft combinations. The second kinematic chain is formed by the drive trains embedded within the links that form the body of the manipulator. The drive train configurations can take the form of purely parallel link-embedded shafts, purely concentric link-embedded shafts or a combination of the two. The concept that was initially proposed comprised a combination of parallel and concentric link-embedded drive trains.

When analysing the mechanical architecture, both the physical model and the simulation model indicated an unwanted induced component of motion for each link when the links lower down in the system are in motion. This is due to the mechanical coupling of the two kinematic chains and meant that, although the link architecture takes the form of a traditional serial kinematic machine, the system is a closed-loop system, as in the case of a traditional parallel kinematic machine. The induced component altered the intended trajectory and the end position of a link, which indicated that, other than the first link in the system, all other links could be put in motion by movements other than the actuator powering it. The intended trajectories and end position would have been realised for a given input if the induced component was not present. The input referred to has been termed the natural component of motion.

The new invention introduces a hybrid concept for a robotic arm manipulator that aims to leverage off the benefits of serial and parallel kinematic machines, while minimising their disadvantages.



Joint rotations



Simulation

A crucial element in the study was the design and implementation of control algorithms that would negate the effects of the induced component of motion, leaving only the desired motion. These control algorithms were written into a program, along with equations that determined the trajectory for each link based on the present link position, the desired next link position and the period of time allowed for the movement from one position to the next.

Subsequent tests carried out on the hybrid system indicated that the control algorithms successfully nullified the induced component of motion, hence allowing links to produce the desired motion based on the natural component of motion. This proved that the proposed mechanical link and drive train architecture, in conjunction with the derived control algorithms, produced a hybrid serial-parallel kinematic manipulator that could offer the same freedom of movement, agility, reach and working envelope as a manipulator with serial kinematic machine architecture, even though all the motors were fixed at the base of the system.

When comparing the torque requirement of the hybrid system to that of a serial kinematic system with the same link architecture and masses, it was found that the hybrid system required between 20 and 25% less torque than the serial kinematic system, depending on the pose. It was noted that, even though the total mass of the drive train in the hybrid system was equal to the total mass of the motors distributed along the system in the traditional serial kinematic machine architecture, the torque requirements in the hybrid system were still less than that of the traditional system.

These results indicate that, in hybrid robotic systems, actuators with lower torque outputs than would be required in a traditional serial kinematic system can be used. This, by extension, leads to the possibility of smaller, lighter and lower-cost actuators being used in the hybrid system, compared to those required in the traditional system. It was also observed that the serial-parallel kinematic hybrid system offers an almost spherical working envelope, thus demonstrating the agility of the system.

The concept also lends itself to active and passive reconfigurability in that links can be extended via controlled prismatic joints or manually to alter the working envelope with a minimal increase in motor torque requirements. Furthermore, the system can be altered to manipulate larger payloads by simply changing the motor and by not modifying the links. Designing the system with standardised joint gears allows for links to be changed to alter the working envelope.

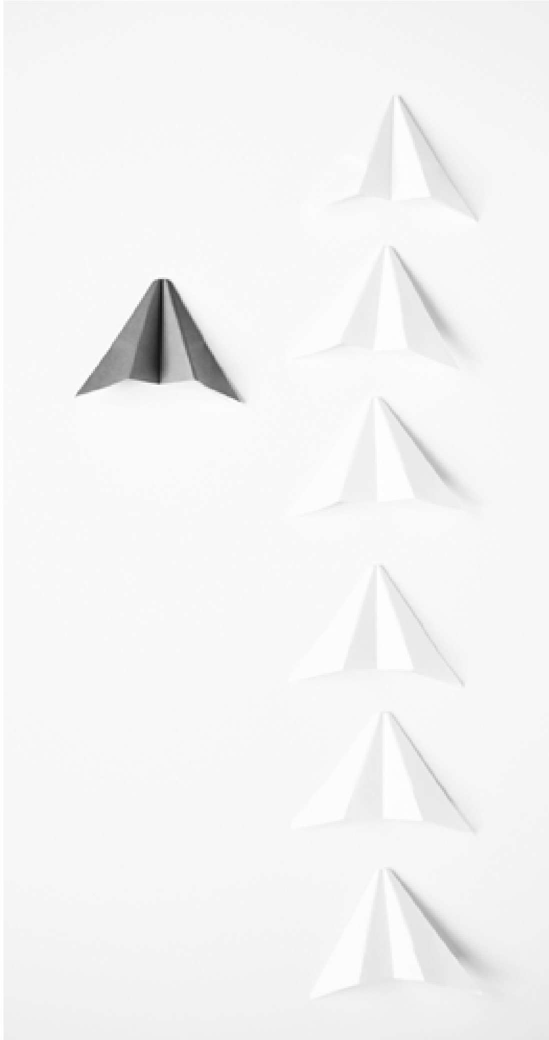
The serial-parallel kinematic hybrid system offers an almost spherical working envelope, thus demonstrating the agility of the system.

Prototype

Thoughts about innovation from the perspective of an innovator

Dr Sunveer Matadin

Not many know or understand what is meant by the term "innovation". In simple terms, it is about being clever enough to have a competitive advantage; to be set apart from the rest. However, innovation is not one single "thing" that can be bought, taught or implemented. It is not an idea and it does not come from a single person or department. Innovation is a culture.



Despite popular perception, innovation is not something new. Innovation is basically structured and supported creativity, and creativity has been around since mankind first made tools and weapons to give him the advantage over his enemies and the animals he hunted and competed against for survival. Even today, creativity is just as essential for a company's survival in the global playing field, but where most companies fall short is that creativity remains just that: ideas that never come to fruition.

Imagine a raging wildfire. Instead of associating the wildfire with destruction, take a look at its positive qualities: it is powerful, unstoppable and produces enormous light and heat energy. Now imagine your company's innovation resources as a raging resource that produces light to see the solutions to any obstacle, and with the heated passion and energy to implement these solutions. This ever-growing resource is fuelled by past successes, passion and confidence. But where would one start?

Let us start with a spark. Innovation can be sparked by anyone in the organisation. What is needed is a culture that allows the spark to turn into a flame. Once one has a spark, that creative idea needs to be supported, otherwise it will die out in an instant, never realising its full potential. Therefore, once one has this spark, one must huddle around it to prevent the winds of negativity from extinguishing it. It needs to be cultivated by being providing with fuel, which will allow it to turn into a tiny flame. This means adding something flammable like tinder, kindling or wood. This will come in the form of something that provides support in the form of funding, facilities and skilled resources.

Once the sheltered flame has been fuelled with kindling, one can provide oxygen by gently fanning the flame. The idea, already fuelled by resources, also needs to be fanned by the company with the gentle breeze of support, encouragement and the removal of the fear of failure. Just as a flame grows into a fire, so too will the idea grow into an innovation.

As the shelter that is protecting the fire is removed, so too does one remove the protection from negativity by implementing the innovation in the environment in which it is designed to thrive and become self-sufficient.

Negativity may be purely unfounded and based on the fear of trying something new, but it may also be based on quantifiable risk variables that may have a valid influence on the success of the innovation. If the idea survives the gusts of negativity, both founded and unfounded, the company can further fuel the innovation with additional resources, support and encouragement until it generates revenue or creates savings to allow it to be self-sufficient.

Both the fire and the innovation have now grown strong enough to function independently. However, just as a single fire does not a wildfire make, so a single innovation does not an innovative company make. The fire needs to spark other fires that grow and, in turn, spark even more fires. So too, the innovation must spark other ideas that grow into even more innovations. In the case of the fire, sparks of tinder are carried in the winds until they land somewhere dry where more tinder turns the sparks into a small flame fed by oxygen.

In the case of an innovative company, the wind that carries the spark of innovation, creativity and encouragement is communication. The success of the innovation and word about the support, resources and even the recognition, both financial and non-financial, must blow through the organisation. This will encourage others with ideas to come forward and share them, knowing that there has been success in the past, and knowing that the company will support them. Each of these ideas, supported by the culture of innovation, will grow into innovations and will, in turn, create opportunities for yet more innovations.

This reinforces the notion that innovation does not come from a single person or department. Everyone is capable of conceiving an idea. Some may have the personality, character and vision to constantly conceive ideas, while others may have knowledge and experience in their field of speciality to conceive a single brilliant idea. Wherever or from whoever these ideas originate, the organisation must ensure that there is a fertile environment and strong support to enable these ideas to develop into end products.

Although a department may not be responsible for the creativity and the generation of all the ideas in the organisation, the department must exist as a dedicated support structure. This department must consist of creative thinkers and visionaries, as well as executers and drivers. The department must also have skilled resources, comprising engineers, financial managers, project managers and scientists, and must have access to other departments in the organisation, such as human resources, training and change management. A funding model must also be in place to fund the growth of ideas through investigations, research and development, and prototyping.

It is this department that must drive innovation in the organisation. The creative visionaries that lead this department must be blue sky thinkers who must not only generate ideas and solutions, but must also assess ideas that originate from all corners of the organisation. An organisation does not need a dedicated department to drive innovation. As long as a leadership structure is created for innovation with a head and a few managers, this structure can manage the skilled resources that reside in other departments using a cross-functional skills management philosophy. Universities, for example, establish research groups in key focus areas that skilled resources from other departments can join. These research groups focus on innovations within the group's field of interest and will assess and develop ideas into end products.

Whether a dedicated department is created, or a management structure within the organisation is implemented using resources and research groups that already exist, ideas that are considered to be feasible must be developed into innovations under their guidance and with the support of expert resources. A key ingredient that must not be forgotten is the person who conceived the idea. As the department develops the idea into an end product, the creator of the spark must always be involved during the evolution of the idea. This will ensure that the essence of the innovation remains intact and is not diluted or contaminated by those developing it, as they may not have the same vision or passion for the end product.

The openness of leadership to new ideas and inventions, along with their commitment and support to a culture of innovation, will create a platform for innovation to thrive. The leadership of the company also needs to understand that there will be failures and lessons learnt in this environment, and that it is up to them to remove the fear of failure. As long as feasibility studies are carried out for each venture, and the risks entered into are calculated, a strong culture of innovation will ensure that new revenue streams can be created and operational optimisation can be realised via cost reductions.

Innovation and creativity require pushing the boundaries of possibility and then testing them against practicality. Doing it the other way round limits the outcome to only what one knows and what one thinks is possible; not what could be.

Sunveer is a qualified engineer with 16 years' industry experience. He is registered as a professional engineer with the Engineering Council of South Africa (ECSA) and holds a PhD in Engineering from the University of Pretoria. During his career, he has sought out projects and opportunities that involve new product development, design, innovation and inventiveness. The products and systems that he has conceptualised, designed and implemented include hardware, firmware and software for control systems, purpose-built production monitoring systems, including a national command centre, robotics systems and a novel card-based banking product that facilitates the dispensing and receipt of salaries via online payments and ATM withdrawals. Some of these products and systems have won international awards for innovation and others company awards for new product development, innovation and strategy.

Optimising the value of cochlear implants through computational modelling

Prof Tania Hanekom
Prof Johan J Hanekom

Source: South African Institute of Electrical Engineers, May 2020, wattnow.

For the past two decades, researchers from the Bioengineering Research Group in the University of Pretoria's Department of Electrical, Electronic and Computer Engineering have been working on the development of three-dimensional (3D) user-specific computational models of cochlear implants to personalise these devices so as to optimise their value for a particular user.

A COCHLEAR IMPLANT AS A NEURO-PROSTHETIC DEVICE

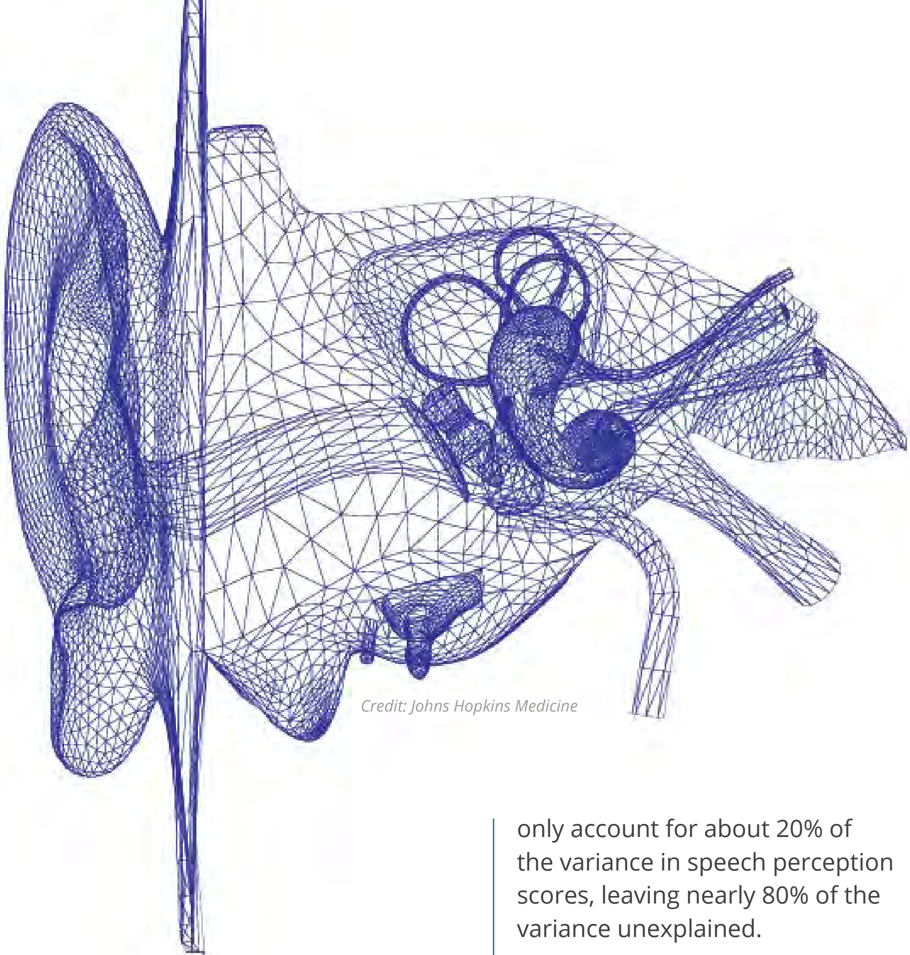
A cochlear implant is an electronic device that is surgically placed under the skin behind the ear. It provides a sense of sound to someone who is profoundly deaf or severely hard of hearing by bypassing the damaged cochlea and sending sounds electrically to the brain. A cochlear implant can give a deaf person useful hearing of environmental sounds and help them understand speech, and communicate orally.

This is arguably the most successful neuro-prosthetic device to date. It aims to cure deafness in an individual suffering from sensorineural hearing loss. It replaces the entire auditory system from the external ear up to the point that the inner hair cells (the specialised transducer cells that are responsible for conveying the incoming sound to the auditory nervous system) connect to the peripheral auditory neurons. An electrical connection to the peripheral auditory neurons of a hearing-impaired person is established through a miniature electrode array that is implanted into the inner ear (cochlea).

Current injection through the electrode array is driven through one or more current sources that are controlled by an external unit. The external unit, which is worn behind the ear, contains a microphone to capture incoming sounds and a speech processor that encodes these sounds as a stimulation protocol to target appropriate neural populations. A telemetric link between the internal and external parts of the device is used to transfer data and power.

By the end of 2015, the largest implant manufacturer had sold more than 400 000 devices since its first-generation devices became commercially available in 1981. In 2016, around 600 0000 global implants had been supplied across all manufacturers, with approximately 45 000 added to this number annually.

A COCHLEAR IMPLANT CAN GIVE A DEAF PERSON USEFUL HEARING OF ENVIRONMENTAL SOUNDS AND HELP THEM UNDERSTAND SPEECH, AND COMMUNICATE ORALLY. THIS IS ARGUABLY THE MOST SUCCESSFUL NEURO-PROSTHETIC DEVICE TO DATE, WHICH AIMS TO CURE DEAFNESS IN AN INDIVIDUAL SUFFERING FROM SENSORINEURAL HEARING LOSS.



Credit: Johns Hopkins Medicine

OPTIMISING THE DEVICE FOR INDIVIDUAL USE

Despite the widespread use of cochlear implants, hearing performance varies among individuals and may range from mere awareness of environmental sounds to almost 100% open speech understanding in a quiet space. However, while many cochlear implant users demonstrate good speech understanding in a quiet environment, the perception of speech in adverse situations (such as in an environment with competing speakers) and the appreciation of music remain inadequate.

On average, adult users' word perception ability improves from 8.2% before implantation to 53.9% afterwards, which is still far from normal hearing performance. Factors that describe the characteristics of implant users, such as age at implantation and duration of hearing impairment, only account for about 20% of the variance in speech perception scores, leaving nearly 80% of the variance unexplained.

Apart from these general characteristics, it is known that user-specific factors related to the biophysical interface between the implant and the auditory system may account for some of the variations observed in outcomes. The characteristics of the biophysical interface, such as the state of degeneration of the auditory neurons and detailed cochlear morphology, are often not accessible for investigation because of the invasive nature of the methods that would be required for their assessment.

Because of the uniqueness of each implant user's hearing impairment and biophysical interface characteristics, it is necessary to customise each device for optimal use by a particular user. This entails the programming or mapping of device parameters to a user's individual physiological responses. Although standard clinical procedures are mostly successful in producing this customisation, many users experience confounding effects at a neuro-electrophysiological level that may be difficult to untangle in a non-invasive way.

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This is where the key value of computational modelling comes into play, since it provides a virtual invasive window to observe and investigate the auditory system that is subjected to electrical stimulation. This unique window into the hearing system of a cochlear implant user may be useful in optimising the customisation of a device for a specific user and also to unravel the underlying mechanisms that complicate some cases. Furthermore, a computational model-based approach to the customisation of a device may eventually extend to the personalised design of the device even before surgery.

USER-SPECIFIC COMPUTATIONAL MODELS

The objectives of the modelling efforts of the Bioengineering Research Group are as follows:

- Contribute to the scientific knowledge base about the mechanisms that underlie the functioning of the auditory system and cochlear implants
- Apply the models to improve the hearing performance of cochlear implant users on an individual basis

The 3D models of the auditory periphery consist of a volume conduction model that describes the cochlear anatomy, the type and intracochlear location of the electrode array, and their combined effect on current distributions, resulting from intracochlear stimulation. The electric potential distribution at the location of the target neurons is predicted by volume conduction models and is used as input to a second-stage, physiologically based computational model of the target auditory nerve fibres. The output of the auditory nerve fibre model is the spatial and temporal neural excitation response that results from the simulated stimulus.

At the core of the 3D models is the reconstruction of a living cochlear implant user's cochlea and implanted electrode array from clinical images of the temporal bone. A 3D reconstruction of the cochlear anatomy is one of the primary challenges in the modelling process as the resolution of clinical computed tomography (CT) images, from which landmarks for reconstruction must be derived, is severely limited.

At the core of the 3D models is the reconstruction of a living cochlear implant user's cochlea and implanted electrode array from clinical images of the temporal bone.

A human cochlea resembles a coiling shell. It is about 6.8 mm wide at its base and 4.2 mm long. The voxel size of clinical CT scans is typically 200 µm x 200 µm x 200 µm, which means that there are only about 34 voxels over the width of an average cochlea and 21 voxels along its length with which to represent the anatomy. It is therefore generally only possible to observe the outline of the cochlea in the enveloping bone. Still, very little (if any) of the soft-tissue internal structures that affect the current distribution and, consequently, neural activation patterns, are visible. The metal electrodes also cause artefacts in the images that further compromise their quality.

PREDICTING OBSCURED ANATOMICAL FEATURES

To be able to make accurate user-specific predictions about neural excitation, a high-fidelity representation of the cochlea is essential. In a previous study, the researchers showed that the effect of variations in the anatomy of the cochlea on the prediction of nerve fibre excitation thresholds is comparable to that of the relative location of the electrode array to the surviving auditory nerve fibres. This last parameter is known to be one of the critical factors to influence neural excitation.

The implication is that errors in the reconstruction of the cochlear anatomy may also compromise the accuracy of model predictions. In a collaborative study with the University of Pretoria's Department of Anatomy, an anatomical reference framework was developed for the human cochlea that allows the prediction of obscured landmarks for a specific user. The reference framework used landmark data measured from micro-computed tomography (µCT) scans of human skulls and temporal bones that were taken at voxel sizes of between 25 µm and 50 µm. Mathematical equations were derived to describe the spiralling trajectory of landmarks on the boundaries of cochlear structures that are discernible on clinical CT images.

A set of predictor equations was subsequently derived for structures that are visible on µCT images, but obscured on clinical images, such as the bony spiral lamina from which the nerve fibres protrude. The predictor equations operate on landmark data that is visible on a specific user's CT images to approximate the location of obscured structures.

AUTOMATED MODEL GENERATION

While it is possible to construct 3D user-specific models of the electrically stimulated cochlea, the manual landmark-based approach that is required to optimise the accuracy of the models is time consuming and therefore not suitable for scaling to clinical applications. To generate user-specific models on demand for clinical use, an automated model generator is necessary. A first-generation landmark-based automated model generator was thus developed to reconstruct a user's cochlea and the implanted electrode from CT scans.

This tool can construct a user-specific model in less than 10 minutes compared to several days as is required for manual model construction. However, when tested against the anatomical reference, it was found that the current automated model generator is too fragile to be employed as a diagnostic tool. Ongoing work will therefore focus on the development of a robust second-generation automated model generator to allow the deployment of computational models in a clinical setting.

Conclusion

There is a great need for translational research in biomedical engineering that focuses on the application of advanced research methodology within a clinical setting. The work done by the Bioengineering Research Group builds on a strong scientific foundation in electronic and computer engineering, medical imaging, hearing sciences, anatomy and physiology to create specialised tools that may assist clinicians in the management and maintenance of the hearing performance of individual cochlear implant users.

Engineering 4.0 cements UP's research footprint on the global stage

The new state-of-the-art Engineering 4.0 Complex is already positioning the University of Pretoria (UP) as a centre of excellence in smart transportation. Through its focus on the development of integrated transportation systems, its research is concentrating on the reduction of energy consumption levels in transportation, maximising productivity in industry and creating a higher quality of life for the country's citizens.

To address the challenge posed by a shortage of training facilities and independent testing laboratories in South Africa, the University embarked on a collaborative partnership with the South African National Roads Agency Limited (SANRAL) and the Council for Scientific and Industrial Research (CSIR) to establish an integrated education, certification, reference and research facility, known as Engineering 4.0. This not only relates to it being the University's fourth Engineering building, but also refers to engineering of the future, which engages with the advanced technologies of Industry 4.0. Construction commenced in August 2018, and the new research and training hub for smart transport systems was completed on schedule in February 2020.

This unique world-class African facility will be a place where novel ideas, scientific research, global expertise, students, academics, entrepreneurs and industry partners can converge to generate new thought leadership, innovation and training opportunities through collaborative partnerships. It is located in Hillcrest on the Innovation Africa Campus and in close proximity to the University's Future Africa Complex, a hub for inter- and transdisciplinary research networks within UP and the global research community.

According to Prof Sunil Maharaj, Dean of the Faculty of Engineering, Built Environment and Information Technology, it will not only engage in collaborative research in the field of future smart cities and transportation, but will link the Faculty's vast resources in technology and data science to other faculties via Future Africa. It will also support the economic growth of South Africa through an improved understanding of vehicle-pavement interaction. The collaborative research to be conducted between UP, SANRAL and the CSIR will improve the quality of training and avoid the costly and unnecessary duplication of laboratory facilities.

In terms of the United Nations' 17 Sustainable Development Goals (SDGs), innovation, infrastructure, and sustainable cities and communities are critical for developing any economy. This new research hub, which will foster interdisciplinary research in the wake of the Fourth Industrial Revolution (4IR), will enable UP to make a distinct contribution to these goals through ongoing research into phenomena like data analytics, smart materials, artificial intelligence and the Internet of Things (IoT).

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Laboratories and training facilities

Engineering 4.0 houses several laboratories and training facilities, including SANRAL's National Roads Materials Reference Laboratory, the first independent transport reference testing facility in Africa.

National Roads Reference Laboratory

This is the site for the independent reference testing of materials for the road construction industry. Standard testing will mostly be conducted on road materials originating from SANRAL (for national roads projects), but also from the provinces and even neighbouring countries. It will serve as the standard for the properties of such materials, to which field data can be compared.

It will thus characterise materials for appropriate construction. The National Laboratory Proficiency Scheme for Road Materials Laboratories will be serviced from this laboratory, and it will also participate in international proficiency schemes.

Training Laboratory

This is a 20-station facility that will be used to train and certify road materials technicians employed by various testing laboratories. Once their skills are certified, laboratories can provide accurate test data to engineers. The objective is to ensure that materials testing in the field is up to standard and that the technicians who conduct the testing are capable and certified to do such tests with a high degree of accuracy. Engineering students will also be trained and certified in this facility.

Concrete Laboratory

This laboratory consists of preparation areas, curing and humidity rooms, and a large test floor where various concrete and structural testing can be conducted.

It also has a 900 mm-deep 20 x 15 m strong floor, which provides possibilities for attaching presses and test members onto the floor and a strong wall for testing.

York Wood Engineering Laboratory

This facility endeavours to cultivate, grow and expand the footprint of mass timber construction using advanced engineered wood products in South Africa and on the African continent in a collaborative effort between civil and chemical engineering, architecture, materials science, data science, genetics and other related bio-economy disciplines.

Accelerated Pavement Testing (APT) Track

The 100 x 6 m APT track allows for the construction of different pavement structures and their accelerated evaluation using a mobile APT device developed in South Africa. This enables engineers to monitor the expected behaviour of a pavement over a fraction of its full life.

Active Traffic Lane

This active traffic test track is a lane on the N4 into Pretoria that is dedicated to research. It allows for the installation of sensors inside, next to and over the lane that can be monitored from a dedicated data house situated next to the N4. The datahouse is also the location of a traffic counter and classifier that has been developed in-house and uses artificial intelligence (AI) to monitor traffic on the N4. This unique facility allows one to characterise pavement design and construction while using data obtained from the active traffic lane to model many aspects in transportation systems. Such data and models will support the planning and design of future transportation systems, and support cost-effective and innovative pavement engineering for Africa's infrastructure development.

STUDENTS WILL BE EXPOSED TO HANDS-ON RESEARCH ACTIVITIES IN THESE LABORATORIES, WHICH WILL SUPPORT THEORETICAL TEACHING. THIS WILL ENABLE A DEEPER UNDERSTANDING OF THE CIVIL ENGINEERING CURRICULUM IN PREPARATION FOR STUDENTS' WORKING LIVES AS CIVIL ENGINEERS.

Prof Wynand Steyn
Head of the Department of Civil Engineering and Chair of the School of Engineering

Other facilities on the Engineering 4.0 Complex include a state-of-the-art auditorium for training and presentations, as well as wide, open social areas, both inside the facility and in the surrounding natural forest areas. Dedicated artworks have been installed inside the main building. The Pierre van Ryneveld memorial is situated at the entrance to the main building. This memorial commemorates the first successful flight from the United Kingdom to South Africa, which landed in South Africa on 17 March 1920.

A long-range (LoRa) low-power wide-area network (LPWAN)) antenna is situated on the roof of the main building, which provides data collection coverage over the University's entire Innovation Africa Campus, enabling unparalleled wireless communication capabilities for customised Internet of Things (IoT) sensor platforms. This will be used to monitor distributed sensors in a network that evaluates a range of environmental and related parameters on this campus. Photovoltaic panels have been installed on the roofs of most of the facility for sustainable power generation, and a battery-operated car-charging station is located in the parking area.

Collaborative research

On 22 July 2020, the University signed a Memorandum of Agreement (MoA) with the **CSIR** to collaborate on smart transport, cities and environments. This cooperation means that UP can focus on creating a pipeline of potential researchers in these areas. According to Prof Wynand Steyn, Head of the Department of Civil Engineering, smart transport, cities and environments are part of an integrated system that encompasses digitised transportation systems, parking management, reduced traffic congestion and addressing environmental problems.

"In order to work towards smart cities, there is a need to develop researchers with advanced skills in robotics, AI, IoT and satellite technology. To this end, researchers will be trained through complementary skills at UP and the CSIR," said Prof Steyn. "This will further develop the skills required to design, construct, maintain and rehabilitate the extensive roads network in South Africa, a network that is vital for accessibility and the mobility of its communities, and in support of economic opportunities."

Creating critical mass for the transportation engineering sector

University of Pretoria (UP)
South African National Roads Agency Limited (SANRAL)
Council for Scientific and Industrial Research (CSIR)

South Africa's transportation engineering sector is facing many challenges, including limited training to bridge the current knowledge gap, and a shortage of training and testing facilities. It was against this backdrop that SANRAL, the University of Pretoria and the CSIR embarked on a collaborative partnership to establish the state-of-the-art Engineering 4.0 facility.

South Africa is faced with a dire lack of civil engineers compared with other countries. In its Infrastructure Report Card, the South African Institution of Civil Engineering (SAICE) indicated that Europe, North America, India and China have one engineer for every 130 to 450 inhabitants. In South Africa, this ratio is one engineer for every 3 200 inhabitants. This disadvantage applies equally to technologists, technicians and artisans, leading to a lack of quality personnel throughout the transportation sector. The result is a technical skills gap with regard to project quality control and quality assurance.

Prior to the establishment of Engineering 4.0, the South African transportation engineering sector was faced with the following additional challenges:

- Limited training facilities for the training of material testers and no national facility for the accreditation of material testers.
- The lack of a national reference materials testing laboratory for road materials for the country to participate in international proficiency schemes run by the relevant authorities in the USA and Europe. These proficiency schemes ensure the international accreditation of material testing performed in the local roads industry. Such a laboratory would also be able to provide objective evidence that the commercial laboratories utilised by road authorities are competent to perform quality control and quality assurance in transportation infrastructure construction. It would also enable the independent verification of test results on road projects.
- The need to re-establish a world-renowned research and development (R&D) competency (people and facilities) that would ensure a pipeline of new master's and PhD qualifications, innovative solutions and advice to the transportation sector.
- The need to strengthen the relationships between the CSIR and universities that conduct training and R&D in transportation engineering.

Through the establishment of Engineering 4.0, maximum cooperation could be ensured between the parties to create, develop and maintain a critical mass in laboratory facilities and human resources to address these challenges efficiently and avoid the further erosion of the country's remaining skills.

It would also enhance the quality and quantity of the outputs, and avoid the costly duplication of laboratory facilities. In the process, it would put South Africa in a better position to develop sustainable, optimised, smart and equitable transportation networks to support social and economic development in a disruptive and evolutionary society.

It is anticipated that the tripartite partnership will provide the following:

- High-quality facilities to provide a platform for quality training, reference testing and research in transportation engineering
- A unified effort to train engineers, technologists, technicians and materials testers for the transportation engineering sector, resulting in an increased number of civil engineers, technologists, technicians and material testers skilled in transportation engineering, as well as postgraduate output
- A pipeline of transportation engineers, exposed to the latest technologies and methods, who will be taken up in government, by SANRAL and by the industry

The main benefits for South Africa include the increased availability of technical skills in transportation engineering, and the improved skills of transportation engineers, technologists and technicians. The new facility will also bring about cost savings due to improvements in the design, construction, maintenance and management of transportation infrastructure, as well as better-performing transportation infrastructure due to improved quality control and an associated reduction in user operating costs. This will also result in a smaller impact on the environment from transport infrastructure construction and maintenance.

The vision of the facility is to provide an internationally renowned platform for academic and vocational training support in transportation infrastructure materials testing, a national transportation materials reference testing platform, high-quality research facilities and skilled staff.

This world-class facility for the training and education of future civil engineers intends to change the perceptions of future graduates of creative solutions in their work to the benefit of the South African transportation engineering sector.

Designing

a state-of-the-art facility

The architectural firm that was appointed to design and facilitate the construction of the new Engineering 4.0 facility – the ARC Group – is no stranger to the high demands of a state-of-the-art facility such as Engineering 4.0. With Anton de Jongh at the helm, this consultancy was responsible for the design of the University's Engineering 3 Building and Parkade for the Faculty of Engineering, Built Environment and Information Technology in 2011, as well as the award-winning Mining Industry Study Centre on the Hatfield Campus in 2013.

The design team at ARC has taken a sensitive approach to educational and commercial developments on the African continent over the years, keeping the specific needs of their clients in mind.

THE CREATIVITY OF THE DESIGN LIES IN ITS FUNCTIONALITY, WITH AN IMPRESSIVE EXTERNAL ENVELOPE AND METICULOUSLY DESIGNED FLOW PATTERNS REMINISCENT OF A MACHINE. THE DESIGN SOLUTION DEPARTS RADICALLY FROM TYPICAL CIVIL ENGINEERING LABORATORIES WITH LIMITED LIGHT AND VIEWS. INTRINSIC TO THE DESIGN ARE THE SHADED GLASS FAÇADES, PROVIDING VIEWS OF AND INTERACTION WITH THE NATURAL FOREST.

THE BRIEF

The design brief for Engineering 4.0 when the project was initiated in 2016 was to develop a facility that could operate as both a learning and a testing facility in an all-inclusive design. The building would have to accommodate a civil engineering laboratory with smaller laboratories, and should bring the outdoor characteristics of civil engineering indoors through an interactive design.

Although the facility ostensibly required a large, open warehouse-type building, the external design would circumvent being just a rectangular structure by incorporating several innovative features that could address sustainability and energy efficiency through a biophilic design approach: a concept used in architecture to increase occupants' connectivity to the natural environment through the use of direct and indirect nature, and space and place conditions.

The result was a facility that makes a significant impact, where education and training is supported by open architecture by means of glass-floored sections that display reinforcing to concrete structures. On the upper level, services and open roof structures display trusses, insulation, and open heating, ventilation and air-conditioning (HVAC) systems with unique intricacies and coordination. Also showcased is a visible ablution services corridor.

The facility makes provision for several major testing areas, including the following:

- The SANRAL National Road Materials Reference Laboratory, which will serve as a proficiency testing laboratory.
- The SANRAL Training Laboratory, which comprises 20 dedicated stations for the training of civil engineering geotechnical laboratory technicians. The layout allows for each technician to independently conduct testing and certification.
- The Civil Engineering concrete research laboratory, which makes provision for dedicated materials preparation areas, and unique curing rooms where large ranges of temperatures and humidity levels can be manipulated for treating concrete samples. It also facilitates a 300 m^2 strong floor that consists of reinforced concrete 900 mm deep with a compressive strength of 80+ MPa. This floor is used to conduct various types of large-scale tests on structural elements to determine characteristics and failure criteria.
- The York Wood Engineering Laboratory that endeavours to cultivate, grow and expand the footprint of mass timber construction using advanced engineered wood products in South Africa and on the African continent.

A second phase, to be constructed at a later stage, will add geotechnical, water and railway laboratories to the existing facilities.

All external concrete walls have a tilt-up design, which involves the casting of wall elements in stacks and lifting them into position on pad foundations. This approach made sense due to the weak soil conditions and extensive foundations that would have been required if normal brick-type walls were used. This relevance also allows for another educational opportunity for students to see the result of such tilt-up construction at close range.

Being a phased development, the foyer area is central and situated between a longitudinal spine and an intersecting main radial communication concourse. Accommodating the main reception, it serves the training, reference and concrete laboratories. Through this approach, the reference laboratory can also be operated as a sterile area where only dedicated staff and materials can enter without any influence from students. The foyer accommodates a collaborative working space and auditorium area.

The design is supported by external landscaping with several water features and garden seating options, which conform to the natural and established greenery. The main entrance of the building allows for an informal and friendly reception, as well as easy access to the outdoors through large, framed glass tilt-up doors.

A stormwater retention model was followed during the design, allowing for the management and recirculation of all rainwater captured on the premises. A primary attenuation and secondary retention pond was constructed. The lined primary pond allows for stormwater attenuation for a 1:50 year flood and serves as a sediment trap, with water plants acting to treat the water to enhance water quality. The unlined, secondary pond is mostly covered by natural grass and serves to lessen the effect of overflow from the primary pond in flood conditions, preventing erosion and enhancing the replenishment of the natural groundwater table.

An innovative mechanical design system: Developed for engineers by engineers

Deo du Plessis
Mechanical Engineer, Spoormaker & Partners

The University's iconic new Engineering 4.0 facility features a state-of-the-art heating, ventilation and air-conditioning (HVAC) installation that combines specific laboratory technical requirements, energy efficiency, comfort and aesthetics. The 6 800 m^2 facility is an expansion of the existing facilities of the Department of Civil Engineering, as well as a common multivolume foyer that will link the building to future phases as the facilities expand even further.

DESIGN CRITERIA

Engineering 4.0 comprises a variety of spaces, each requiring different and room-specific design conditions. These include enclosed specific-use laboratories, open-plan training laboratories, curing and high-humidity rooms, sample preparation rooms, workshops, patch and server rooms, offices, a foyer and an auditorium. The tests and experimental work being conducted in the various laboratories typically involve a range of concrete, bitumen, asphalt and soil sample preparation and property testing under different conditions.

The associated mechanical design criteria for the spaces therefore provided unique engineering challenges. The two humidity rooms in the concrete laboratory, where concrete samples are treated and tested for creep, for example, require indoor conditions with a relative humidity of 95% and a temperature of 25 °C, as opposed to the laboratory itself and the curing rooms, which have a normal relative humidity and a temperature in the range of 22.5 °C. Ventilation needs therefore involved adhering to regulatory fresh air and fire rational requirements, while ensuring that test-specific ventilation needs were met.

In addition to HVAC and building management systems (BMS) services, the various spaces and laboratories in the building required other building services such as a compressed air network, various laboratory gas supplies, a hydraulic network to heavy machinery, and electrical and wet services to the various laboratory equipment and services. The design challenge was therefore to ensure that the individual laboratory needs were met, while providing the most sustainable design possible, within the context of a service-intensive and aesthetically sensitive building.

HVAC SYSTEM

The HVAC system involves a central air-cooled, chilled and hot water generation plant as a cooling and heating source, located at ground level. Chilled water at 8 °C and hot water at 50 °C is circulated via a four-pipe, closed-loop piping system to a network of air handling and fan coil units. The pumping arrangement includes a decoupled primary-secondary loop with hot and cold buffer tanks and variable-volume secondary pumps to ensure that pumping power is minimised whenever possible, in line with the cubic flow-power affinity law. Using a four-pipe system reduced the baseline HVAC electrical energy usage by 68% with an estimated payback period of 3.9 years. No water-consuming heat-rejection systems were used, and all refrigerants were specified with an ozone depletion potential of zero.

The laboratories of the South African National Roads Agency Limited (SANRAL) (the National Road Materials Reference Laboratory and the Training Laboratory) are served by a series of above-ceiling chilled-water fan-coil units and various ventilation systems. A dedicated fresh air unit provides filtered, tempered and pre-conditioned fresh air to all spaces. A general central extraction system ensures neutral pressure in general laboratories. An independent bitumen extraction system ventilates from canopies and grilles located over oven areas. Seven different fume cupboards ensure that tests involving toxic gases can be carried out safely. These fume cupboards are connected to two dedicated extraction systems using centrifugal fans and above-roof-level exhausts. Each fume cupboard extraction system is also interlocked with a dedicated fresh-air make-up system to

ensure that the airflow in the rooms is correctly balanced, with or without operational cupboards. Safety features such as no-flow warnings and run statuses are indicated on purpose-made indicators in the user space. These systems are all located in a single plant room to be effectively screened. A seemingly complex, but carefully planned plant room space separates intake and exhaust air, while ensuring the required maintenance access, coordination and identification of all seven subsystems.

The concrete laboratories are served by various internal subsystems and a dedicated fresh-air unit located in an external screened plant room. The large multi-volume, open-plan heavy machinery laboratory is ventilated with tempered and pre-conditioned fresh air to minimise energy usage, with air supplied via long-throw jet nozzles to increase air velocity at ground level and improve occupant thermal comfort in a semi-industrial environment. Various enclosed laboratories are air conditioned, using exposed chilled-water fan-coil units and ventilated in accordance with the room requirements. The PVC ducting and spark-proof ventilation systems are utilised where chemical corrosivity and explosive risks are applicable. The materials handling area where raw materials are loaded and distributed is separated from the main laboratory and inversely ventilated with fresh air from a high level and extraction at a low level. This ensures that the space is always under negative pressure and properly ventilated, and also that the dust particles, which are heavier than air, are captured effectively at a low level.

A sample preparation room is used to cut and prepare concrete samples, resulting in a high dust loading of fine particles.

This space is ventilated by means of various canopies and strip curtain combinations to effectively capture concrete dust at the source, extracting it via high-velocity ducting to an external industrial baghouse filtration system. The system ensures high-efficiency filtration, capturing extracted concrete dust in a series of cartridges and baghouse hoppers that are automatically pulsed clean via a compressed air nozzle manifold before the clean air stream is sound attenuated and exhausted to the atmosphere.

The concrete laboratories include five climate rooms, where samples are cured in heated water baths. These rooms are air conditioned via dedicated chilled-water fan-coil units located outside the rooms to avoid the continuous exposure of systems and controls to high room-moisture levels. The coils are also selected with high latent cooling abilities to dehumidify the air sufficiently when needed. The fan-coil units are located above the concrete slab over the rooms, within an access floor void level, which serves as a mezzanine floor. The units remain accessible for maintenance and are visible via selected access floor tiles.

Two special humidity and creep test rooms presented interesting psychrometric design and control challenges. The rooms are used to test concrete samples at specific and continuously controlled relative humidity and temperature levels of up to 95% relative humidity and 25 °C dry-bulb temperature simultaneously. Each room was specified to be fully internally insulated with cold room panels, sealable and provided with floor drainage. A dedicated air-handling unit located externally serves each room with supply and return air recirculated via externally insulated ducting and special internally insulated air terminal plenums to avoid condensate issues inside the ducting as far as possible.

Each room is provided with two in-room steam humidifiers. Air flow, cooling coils, heating capacity and steam supply volumes were psychrometrically designed to supply a high air change rate at high supply air temperature to improve controllability and minimise diffuser face condensation. With a design condition requiring a room that is essentially always on the limit of full moisture saturation, the control requirements and variables had to be carefully planned to avoid oversaturation or over- and under-cooling.

The foyer space is a large multi-volume area served by two air-handling units to minimise energy usage in favourable ambient conditions. The auditorium is served by a dedicated air handling unit via high-volume radial diffusers and double noise attenuators. Finally, the central server room is served by a dedicated up-blow DX CRAC unit in a cold-isle configuration, and the patch rooms by DX blower coil units.

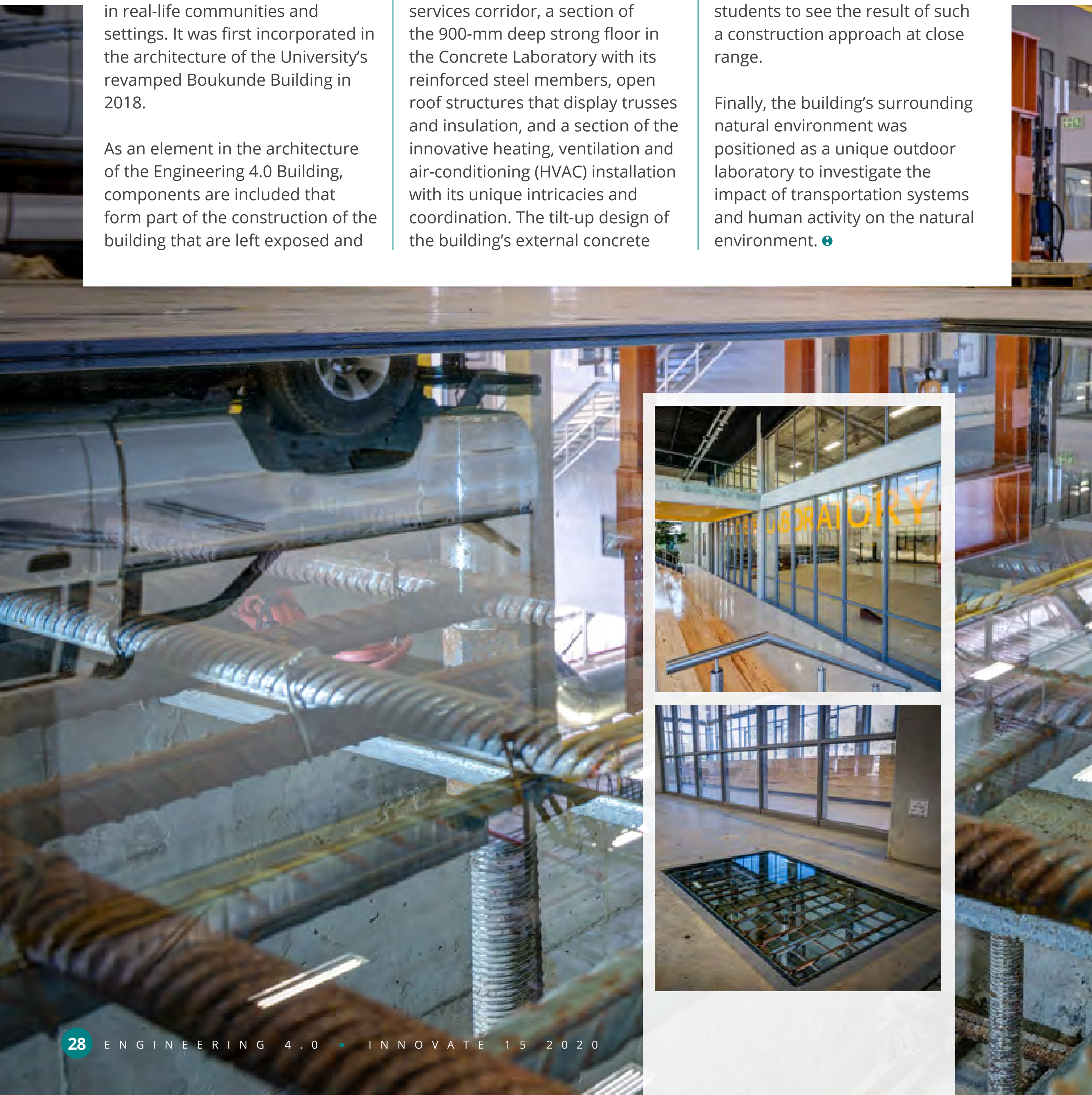
A living laboratory for Civil Engineering

An important component of the training of civil engineers entails ensuring that graduates have superior knowledge of the development and maintenance of civil engineering infrastructure. The design and construction of the new building therefore includes elements that function as a living laboratory for civil engineering.

A living laboratory is a user-centred, open innovation ecosystem that is based on a systematic user co-creation approach that integrates research and innovation processes in real-life communities and settings. It was first incorporated in the architecture of the University's revamped Boukunde Building in 2018.

As an element in the architecture of the Engineering 4.0 Building, components are included that form part of the construction of the building that are left exposed and encased in glass to enable students to experience first-hand what these structures look like and how they are used. Such components include a section of the ablution services corridor, a section of the 900-mm deep strong floor in the Concrete Laboratory with its reinforced steel members, open roof structures that display trusses and insulation, and a section of the innovative heating, ventilation and air-conditioning (HVAC) installation with its unique intricacies and coordination. The tilt-up design of the building's external concrete walls, which involved the casting of wall elements in stacks and lifting them into position on pad foundations, provided another educational opportunity for students to see the result of such a construction approach at close range.

Finally, the building's surrounding natural environment was positioned as a unique outdoor laboratory to investigate the impact of transportation systems and human activity on the natural environment.



Upgraded concrete laboratory is a first in Africa

The Department of Civil Engineering's research into innovative materials and structures is set to reach even greater heights with the establishment of the upgraded concrete laboratory, which forms part of the facilities of the new Engineering 4.0 Complex. The laboratory includes a research strong floor, which is 900 mm thick, and can be used to test the strengths of different materials. This is the largest of its kind in the country and on the continent.

This laboratory is mainly used for research into concrete materials by undergraduate and postgraduate students and staff. It comprises various areas in which a diversity of tests can be conducted on a number of components related to the development of ultra-strong concrete.

Strong floor

This unique component of the concrete laboratory encompasses a reinforced concrete floor with a compressive strength of more than 80 MPa, which can carry a weight of 50 tons. This enables researchers to perform various types of large-scale tests on structural elements to determine their characteristics and failure criteria in terms of strength. It also provides possibilities for attaching presses and test members onto the floor. Another unique element of the strong floor is that it is perfectly level to ensure that testing instruments can align exactly.

Strong wall

This component is used to perform impact tests by applying forces horizontally to determine the strength of various structural elements.

Preparation areas

Dedicated material preparation areas provide the first stage in the casting and testing of concrete specimens to investigate the effect of factors such as temperature variation.

Curing room

This area contains a range of heated curing baths, which form part of the concrete experiments that are conducted to ensure that the concrete mixture can withstand a target temperature of 25 °C.

Humidity and creep test rooms

These rooms are used to conduct a variety of tests to treat concrete samples that use humidity and temperature as variables, such as creep tests. The innovative heating, ventilation and air-conditioning (HVAC) installation simulates outdoor conditions similar to that to which concrete will be exposed.

This enables the temperature and humidity levels to be manipulated to reach a relative humidity of 95% and a temperature of 25 °C. Concrete samples can thus be tested at specific and continuously controlled relative humidity and temperature levels.

Overnight rooms

This area comprises the final stage in the casting and testing of concrete specimens, where the concrete mixture is dried overnight in furnaces.

A landing outside the glass-walled concrete laboratory, is fitted with seating so that interested students can observe the activity inside the laboratory.

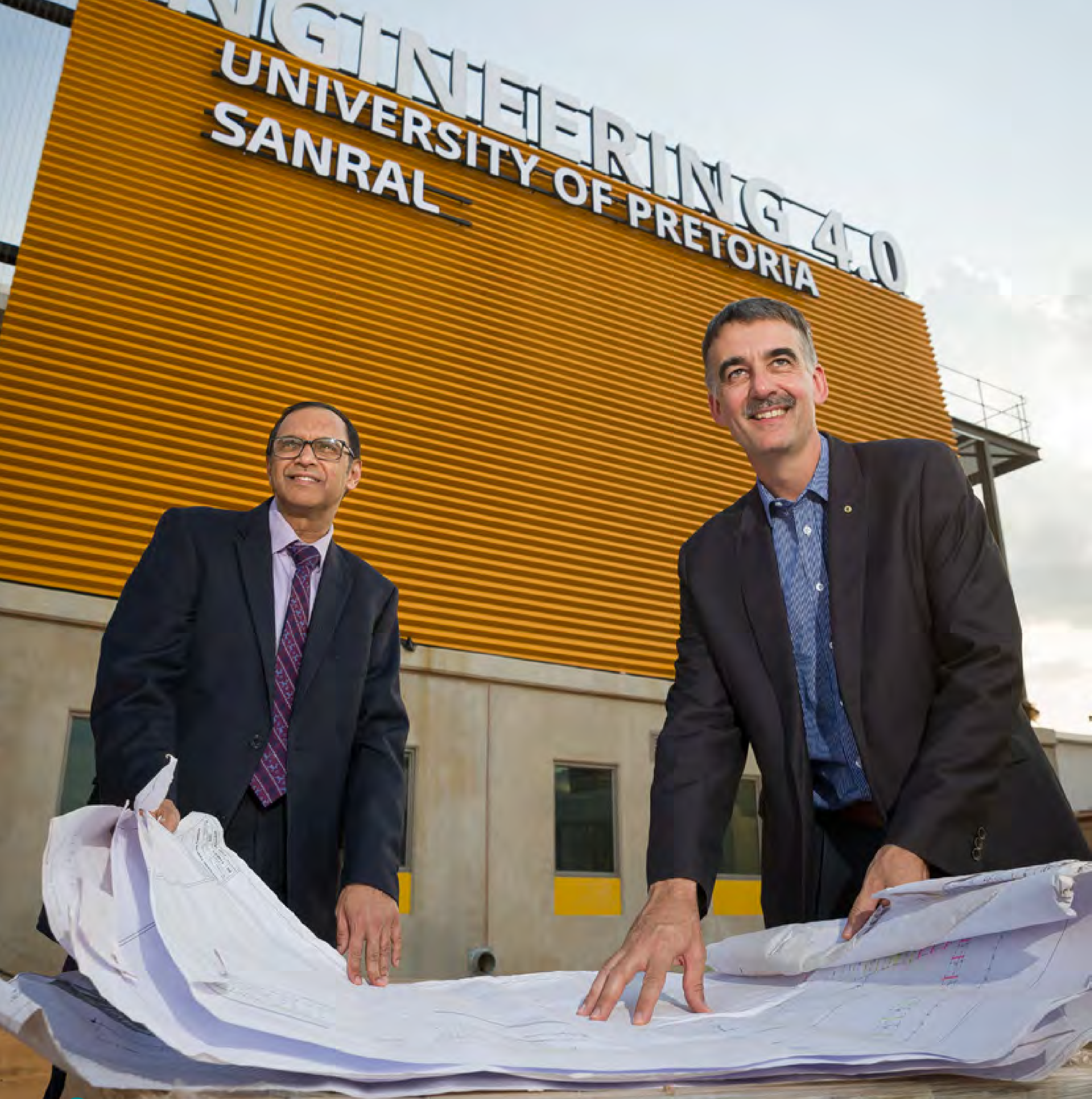
This creates an additional educational opportunity for lecturers from the Department, as well as other departments in the Faculty.

Ensuring that all the facilities in the concrete laboratory function as they should is the responsibility of Johan Scholtz, the Department's laboratory control instructor. With more than 10 years' experience in the University's Civil Engineering laboratories, he played an important role in the planning of the new laboratory. A vital aspect of his work is to keep informed about the latest technology that can be utilised to the advantage of the Department's researchers and students, and to manage the Department's laboratory technicians.

Educating civil engineers for the future

Prof Sunil Maharaj
Prof Wynand Steyn

The Department of Civil Engineering at the University of Pretoria is recognised as a leader in the training of civil engineers and the advancement of the state of knowledge via research, contributing to the development and maintenance of civil engineering infrastructure in South Africa and abroad.



The Department has produced about 40% of all civil engineers in South Africa over the past 50 years. Many of these have made major contributions to economic development and wealth creation in South Africa. According to Prof Wynand Steyn, Head of Department, "we are proud of our history and are building on these achievements with a new vision and strategic direction for the future with the establishment of the new Engineering 4.0 facility".

THE INFLUENCE OF THE FOURTH INDUSTRIAL REVOLUTION

Pavement engineering is a research focus area in the Department of Civil Engineering that plays an important role in the development of improved transportation infrastructure in South Africa. In this discipline, the influence of the Fourth Industrial Revolution (4IR), with developments such as autonomous, connected and electrical vehicles, Internet of Things (IoT) sensor networks and smart transportation and materials, is impacting on the way business is being done.

When considering the education of engineers, the focus needs to fall on the skills they will need to be adequately equipped to deal with upcoming challenges. The realities of educating civil engineering students for the future is that this training has traditionally been focused on the provision and maintenance of public infrastructure. The essence of civil engineering is to ensure that the general public has access to the required infrastructure to travel, live and work. This infrastructure is generally provided and maintained to be operational and safe for decades. Students therefore need to be equipped with tools and skills to enable them to respond proactively to the world over the next five to six decades.

The automation of various tasks is an aspect that the 4IR has introduced to the future of work. With improved intelligence incorporated into various technologies, mundane tasks that do not require complicated thinking skills can often be conducted through the application of intelligent systems, diminishing the need for engineers to conduct these tasks. This can include efforts such as predicting the non-linear layer moduli of asphalt road pavement structures, back-calculating pavement moduli using data mining and predicting the performance of the asphalt mix.

RESEARCHERS WILL BE TRAINED IN THE COMPLEMENTARY SKILLS REQUIRED TO DESIGN, CONSTRUCT, MAINTAIN AND REHABILITATE THE EXTENSIVE ROADS NETWORK IN SOUTH AFRICA, A NETWORK THAT IS VITAL FOR ACCESSIBILITY AND THE MOBILITY OF ITS COMMUNITIES, AND IN SUPPORT OF ECONOMIC OPPORTUNITIES.

Research focus areas in the Department of Civil Engineering

The Department provides research opportunities in the following focus areas:

- Smart cities and transportation
- Transportation and development
- Road pavements and materials
- Railway engineering and railway safety
- Concrete (including artificially intelligent concrete)
- Pipelines
- Hydropower
- Centrifuge and geotechnical engineering
- Structural analysis and testing
- Timber engineering
- Urban runoff

Responding to the challenges of industry

Prof Wynand Steyn

Engineers need to be educated to be resilient, with the required knowledge base to adapt their skills to a changing environment, with continuous value addition when analysing any engineering problem. Against this background, educators should resist placing too much emphasis on applied technologies at undergraduate level. The focus should be on teaching principles that will not change with evolving technologies.

It is therefore necessary for both the new engineer and the engineering educator to reflect on what a pavement engineer should be able to do in the next 50 years to ensure that they are trained and educated for continuous changes in their careers. In this way, engineers who were trained using the slide ruler in the previous millennium were able to survive and excel in a world of computers and tablets, as their fundamental training supported their abilities to use new technologies that did not even exist when they were at university.

An aspect that should never be neglected in the education of engineers is the ability to communicate effectively. Based on their confidence in their knowledge of the basic and engineering sciences, an engineer should be in a position to listen to the requirements for a specific project clearly analyse and synthesise the fundamental issue, develop a solution, and then communicate this solution to both specialists and laymen with confidence and clarity.

Some of the critical issues in transportation for the next two decades have been identified as transformational technologies and services, resilience and security, system performance and asset management, goods movement, institutional and workforce capacity, and research and innovation.

The expected effects of the 4IR on the life of the pavement engineer may include changes in pavement structures due to the wandering patterns of autonomous vehicles, changes in materials due to developments in nanotechnology, changes in traffic loading due to vehicle technology developments, the availability of traditional materials such as bitumen and the need to develop novel road pavement surfacing options. An in-depth understanding of materials science and chemistry is probably becoming increasingly important to understand the interactions between materials and the environment. The interaction between civil engineering and electronic engineering (known as Civiltronics) is another field that may become more applicable in the next few years.

In order to work towards smart cities, there is a need to develop researchers with advanced skills in robotics, artificial intelligence, the Internet of Things and satellite technology.

PAVEMENT ENGINEER 4.0

The pavement engineer of the future will therefore need to internalise the fundamentals of materials science, engineering mechanics and dynamics. This knowledge should be combined with an appreciation of the environment and its effects on materials, as well as a sound appreciation of the Internet of Things (IoT) and Big Data analysis. Another essential skill is the ability to integrate internalised knowledge with searchable information and data, combined with the development of models to describe the interaction between materials, traffic and the environment.

Globalisation allows pavement engineers to be in constant contact with colleagues overseas, assisting in solving pavement-related challenges through a much more focused approach. While each region has specific issues, based on local materials, environment and traffic conditions, the principles underlying potential solutions remain similar. Global communication is thus vital for sustainable solutions for future pavement engineering challenges.

A recent study found that economic benefits, demographic trends and safety factors are catalysts for automation, with low- and medium-skilled workers typically being exposed to high risks of automation. Novel technologies that may affect the future of work in transportation include the automation and maintenance of vehicles and infrastructure, digital user interfaces between customers and operators, and new services. An analysis of the effects of automation indicates a potential shift in the workforce, rather than labour reduction. However, in a developing country such as South Africa, with its current high unemployment rate and low educational skills in the younger workforce, such shifts to higher-technology jobs may be problematic.

The development of new transportation routes, new transportation modes and the related maintenance requirements may affect the life of Pavement Engineer 4.0 through the development of new facilities and the maintenance of these facilities under higher productivity cycles, but using novel materials, incorporating new modes and models of transportation, maintenance during use, and the development of automated and autonomous maintenance techniques. The pavement engineer of the future will therefore require a solid traditional education in the basic and engineering sciences, combined with the ability to apply such knowledge in unknown situations to develop solutions for a world that is constantly changing. This should be supported by a solid continuing education and training programme to obtain new knowledge in the design, construction and maintenance of pavements, as influenced by diverse fields such as electronics, chemistry, nanotechnology and environmental sciences. These changes are mostly driven by factors outside the area of influence of the pavement engineer.

The Pavement Engineer 4.0 is therefore a well-educated and resilient individual, with access to a toolbox of both traditional and modern solutions to the transportation demands of the future.

The faces of Engineering 4.0

Despite the fact that the University's new Engineering 4.0 Complex has not been officially launched due to the restrictions imposed by the COVID-19 pandemic, several students and staff members have already been making use of its state-of-the-art research facilities since the completion of the building in February 2020.

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PROF WYNAND STEYN

At the helm of the new facility is Prof Wynand Steyn, Head of the Department of Civil Engineering and Chairperson of the School of Engineering. He also serves as an adjunct professor at the Chang'an University in Xi'an and the Shandong Jianzhu University in Jinan, China. He obtained his undergraduate and postgraduate qualifications from the University of Pretoria, and is a professionally registered pavement engineer. His professional activities include academic and industry research in the areas of pavement engineering and pavement materials. His research interests include vehicle-pavement interaction, accelerated pavement testing, pavement engineering and materials, and civiltronics and instrumentation. He was the driving force behind the planning and construction of new Engineering 4.0 Complex.

He has completed a synthesis of international accelerated pavement testing activities for the National Academies of Science in the USA, and is involved in pavement materials and vehicle loading projects for the South African National Roads Agency Limited (SANRAL) and projects involving the vehicle-pavement interaction analysis of selected corridors for the California Department of Transportation.

Prof Steyn is a member of the South African Institution of Civil Engineers and the Academy for Pavement Science and Engineering (APSE) and served on the Board of the International Society for Asphalt Pavements (ISAP). He is also a fellow of the South African Academy of Engineering (FSAAE) and the South African Institution of Civil Engineering (SAICE), and is recognised internationally as a leading pavement engineering specialist.

He is involved in various South African and international conference committees. He was chair of the Southern African Transport Conference (SATC) from 2011 to 2015, and is co-chair of the fourth GeoChina Conference and the fifth International Accelerated Pavement Testing Conference. He is actively involved in the activities of the Transportation Research Board of the National Academies of Sciences, Engineering and Medicine as a member of several committees since 2007. He is also an Associate Editor of the *International Journal of Pavement Engineering*. He has a B3 rating from the National Research Foundation (NRF).

PROF HANNES GRÄBE

Prof Gräbe is an associate professor who holds the Transnet Freight Rail Chair in Railway Engineering and the Railway Safety Regulator Chair in Railway Safety. His research focuses on the behaviour of railway foundation material that is subjected to cyclic loading and the characterisation of track component performance and behaviour through field and laboratory experimentation. He combines his experience in track technology, soil mechanics and advanced laboratory testing to develop novel condition monitoring techniques, maintenance models and the numerical analysis of track structures. As a professional engineer, he serves on the Transnet Freight Rail Advisory Board, and is a fellow of SAICE. He is also an international research associate of the Institute of Rail Technology at Monash University, Australia, and has a B3 rating from the NRF.

What is your role in the Department of Civil Engineering?

My focus is on railway engineering in the discipline of transportation. For the last ten years I have been supervising a group of between six and eight master's and PhD students who are equally passionate about railway engineering.

What activities are you conducting at Engineering 4.0?

We are currently testing polyurethane-reinforced ballast for improving the long-term performance of track transitions, i.e. transitions from normal ballasted track to rigid structures like tunnels, viaducts, slab tracks and bridges. Preliminary results indicate that we can reduce long-term settlement significantly, thereby improving vehicle-track dynamics, ride quality and ultimately the design life of the infrastructure. We are also developing sophisticated Internet of Things (IoT) devices for railway applications.

Our flagship research project entails instrumenting an Isuzu truck that has been modified to travel on both road and rail infrastructure. This vehicle is part of the National Equipment Programme of the NRF, and researchers from various departments within the Faculty of Engineering, Built Environment and Information Technology will be using it for multidisciplinary research in the fields of railway, mechanical and industrial engineering.

We have already carried out condition monitoring on the test track, focusing on vehicle dynamics and track geometry, as well as vehicle emissions research with the aim of developing accurate vehicle emission models. A sophisticated light detection and ranging (LiDAR) system, with high-accuracy GPS and a 3D video camera, is being installed, and will complement the vehicle response measuring system and road and rail roughness measurement. This road/rail vehicle will be the ultimate condition monitoring vehicle for transportation infrastructure as it will improve maintenance interventions, decision making and optimisation to ensure the best possible utilisation and performance of our transportation infrastructure.

How are the new facilities going to enhance your work?

The development of Engineering 4.0 also makes provision for the construction of South Africa's first test track for research and development. This roughly 4-km test loop will be in the shape of the infinity symbol, enabling the continuous running of test trains, turning in both directions and traversing different types of track structures and components. With a link line to the national rail network and a special connection to the main Engineering 4.0 laboratory, we will have unparalleled capabilities and facilities in the field of railway engineering.

How do you see Engineering 4.0 contributing to transportation research in South Africa?

We foresee that the railway test track, laboratory and proposed training facilities will be unique in southern Africa and that they will be a national asset to be utilised by researchers, railway operators and infrastructure owners from across the entire country, including the private and public sectors, in collaboration with academic institutions. New products and technologies will be developed and tested here to enhance the competitiveness of the railway industry. The rail industry in South Africa faces many serious challenges, including theft, vandalism, lack of proper maintenance, poor management and under-investment. At Engineering 4.0, we aim to address these issues with the goal of getting freight back onto rail – efficiently, safely, predictably and at the right price.

Our flagship research project entails instrumenting an Isuzu truck that has been modified to travel on both road and rail infrastructure. Researchers from various departments within the Faculty will be using it for multidisciplinary research in the fields of railway, mechanical and industrial engineering.

ANDRÉ BROEKMAN

André is a doctoral student who is making use of the facilities of Engineering 4.0 for his research. He is pursuing research in the field of railway engineering under the supervision of Prof Hannes Gräbe.

What activities are you conducting in Engineering 4.0?

I am pursuing my PhD in the field of Railway Engineering. I also assist with lecturing and developing new content for the third-year Instrumentation and Measurement Techniques module. My research is focused on transportation engineering with an emphasis on integrating facets from electronics, computers and information technology. My research study aims to fuse optical instrumentation, neural network architectures, virtual reality datasets and a real-time kinematic (RTK) global positioning system (GPS) to accurately quantify railway geometry. Neural networks accelerate the three-dimensional reconstruction process of the surrounding environment using photographs recorded from multiple perspectives, installed onto a vehicle that traverses the track. This technique, compared to traditional multi-view stereopsis techniques, is significantly faster and invariant to the reflective materials that are typically encountered in the railway environment.

How are the new facilities at Engineering 4.0 going to enhance your work?

The new facilities present a unique physical space to foster and accelerate the adoption of disruptive technology and rapidly evolving research methodologies. This allows me to conduct experimental work using both the new laboratories, with the capability to deploy and test instrumentation and sensors on the existing railway test track. New hardware installations can be deployed with ease across the new campus, with the surrounding natural environment positioning itself as a unique outdoor laboratory to investigate the impact of transportation systems and human activity on the natural environment.

How do you see Engineering 4.0 contributing to transportation engineering research in South Africa in the near future?

Amid the 4IR, it is imperative that we continue to educate and train a new generation of internationally competitive researchers. Engineering 4.0 serves as the catalyst to forge new industry partnerships, build capacity in the form of research infrastructure and facilities, and encourage transdisciplinary problem solving. Creative solutions are the key to realising sustainable and equitable transportation networks for our smart cities.

The new facilities present a unique physical space to foster and accelerate the adoption of disruptive technology and rapidly evolving research methodologies

PROF ELSABÉ KEARSLEY

Prof Kearsley graduated from the University of Pretoria and obtained her PhD from the University of Leeds. After working as a structural engineer in both South Africa and the United Kingdom, she joined the Department of Civil Engineering in 1990. For the last 25 years, she has been involved with cement and concrete materials research. Her research interests include reducing the environmental impact of concrete used for infrastructure development. Projects include research related to soil structure interaction, as well as the use of lightweight concrete, fibre-reinforced concrete, ultra-high strength concrete, recycled aggregates and waste materials in cement and concrete.

What is your role in the Department of Civil Engineering?

As a professor in the Department, I conduct research on minimising the environmental impact of the cement and concrete industry.

What activities are you conducting at Engineering 4.0?

I am responsible for the experimental work of approximately 200 undergraduate students in the Reinforced Concrete Design and Civil Building Materials modules and about 16 students in Postgraduate Concrete Technology, while I supervise about 20 final-year Research Project students and eight full-time postgraduate research students who make use of the concrete laboratory every year.

How are the new facilities going to enhance your work?

My research is mostly experimental, and the large modern concrete laboratory in Engineering 4.0 will make it possible to conduct larger research projects in a controlled environment. In the past, the limited laboratory space in the old concrete laboratory on Hatfield Campus was fully occupied by undergraduate students and all research projects had to be put on hold while these students were using the laboratory. In contrast, the new upgraded facilities will make it possible for researchers to continue with their research projects uninterrupted throughout the year. The large new climate chambers will also make it possible to investigate the effect of temperature and humidity, as well as climate change, not only on the behaviour of small concrete test specimens, but on larger structural elements manufactured from reinforced concrete as well.

How do you see Engineering 4.0 contributing to engineering research in South Africa?

Currently the effect of thermal gradients in large structural elements is rarely taken into consideration by design engineers. Our research on the thermal behaviour of concrete can in future be used to limit the damage caused to concrete infrastructure as a result of the large temperature ranges to which it is exposed. As a result of the restrictions imposed by the COVID-19 restrictions, limited research was possible in 2020, but we are looking forward to attracting new funders to expand our concrete research activities in the new Engineering 4.0 concrete laboratory in the near future.

The large modern concrete laboratory in Engineering 4.0 will make it possible to conduct larger research projects in a controlled environment.

MEGAN WEYERS

Megan is a doctoral student who is making use of the concrete laboratory at Engineering 4.0 for her research. She is pursuing research in the field of new concrete materials under the supervision of Prof Elsabé Kearsley.

What activities are you conducting in Engineering 4.0?

I am a PhD student in the Division of Materials and Structures. I am also involved in teaching activities for final-year students in Student Research, third-year students in Civil Engineering Building Materials and postgraduate students in Advanced Concrete Technology. My teaching activities mainly comprise laboratory experiments, such as the casting and testing of concrete specimens. Some of the experiments performed by final-year students involve investigating the effects of different aggregates in pre-stress concrete, the use of rubber as a replacement material for aggregate, temperature variation in concrete structures and the effect of temperature on ultra-thin continuously reinforced concrete pavements. For my postgraduate research, I am investigating the performance of nuclear shielding concrete.

How are the new Engineering 4.0 facilities going to enhance your work?

As my research focuses predominantly on nuclear shielding concrete and its application while using local South African materials, the newly upgraded concrete research facility will enable me to conduct the necessary research for my PhD.

The spacious areas, overhead crane, strong floor, as well as the temperature- and humidity-controlled curing rooms, will extend the type and scale of research that can be conducted in the new laboratory, which will benefit my research, as well as similar research projects, immensely.

How do you see Engineering 4.0 contributing to transportation engineering research in South Africa in the near future?

One of the major difficulties experienced in the civil engineering community in South Africa is the gap between theoretical knowledge, or research, and the actual working practice. Besides the state-of-the-art research capabilities the new Engineering 4.0 facility has to offer, which will be making a "concrete" footprint for the University of Pretoria on the global civil engineering stage, the increased capacity at Engineering 4.0 also allows undergraduate students to be educated on true engineering practices and the behaviour of building materials. The new facility allows students to conduct research on full-scale structures in a controlled laboratory environment, which will contribute significantly to the civil engineering community in South Africa.

The spacious areas, overhead crane, strong floor, as well as the temperature- and humidity-controlled curing rooms, will extend the type and scale of research that can be conducted in the new laboratory.

Pavement engineering research makes a positive impact on livelihoods

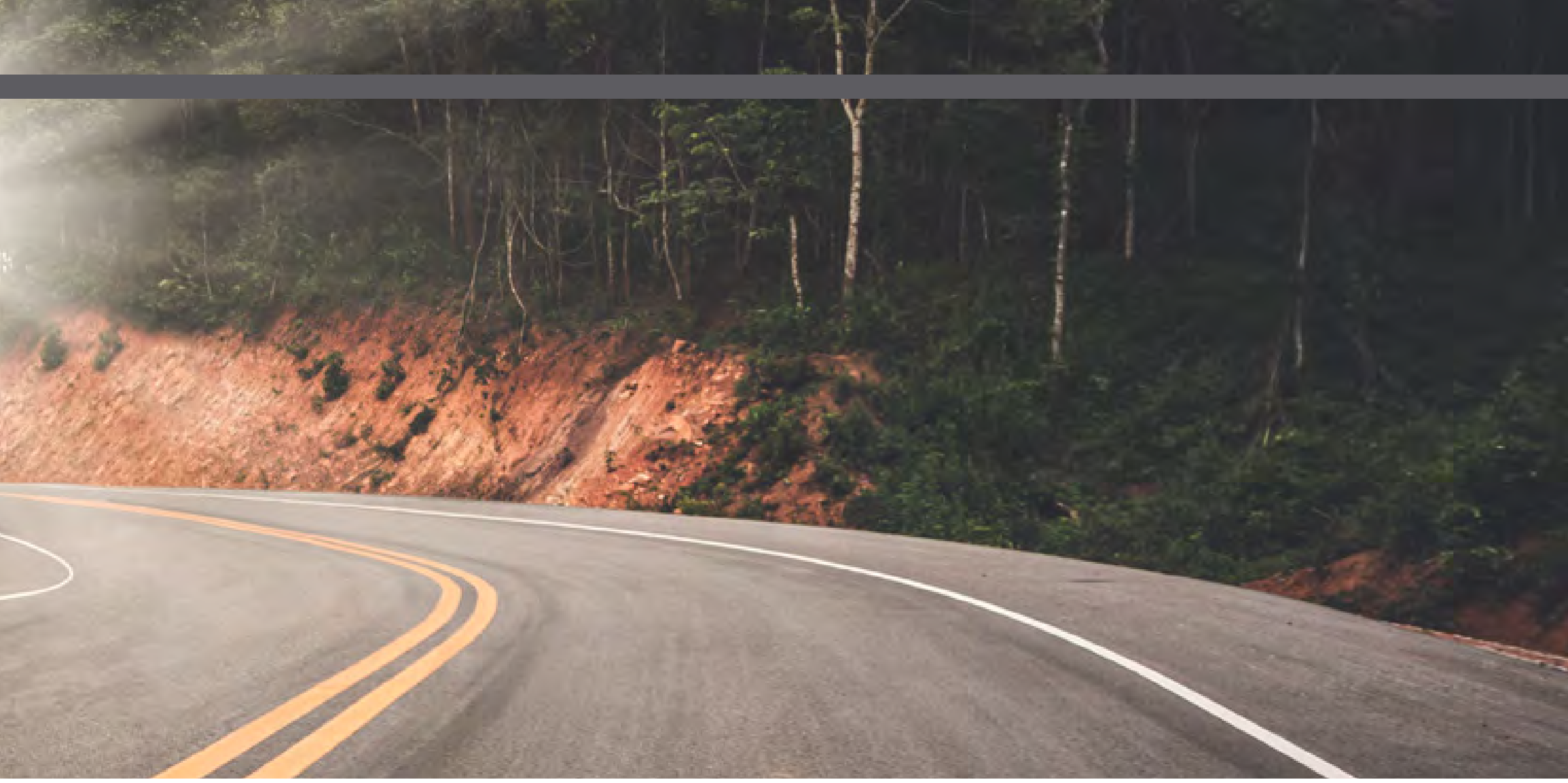
The Illinois Centre for Transportation in the USA recently invited Prof Wynand Steyn, Head of the Department of Civil Engineering at the University of Pretoria, to participate – as one of ten speakers from the international transportation community – in a webinar on transportation engineering. He delivered an insightful presentation on pavement engineering research in South Africa titled "7.8 billion customers: Who benefits from my research". This virtual presentation, held on 11 June 2020, formed part of the Centre's Kent Seminar Summer Series Around the World.

With a global population of approximately 7.8 billion, and a road network of 64 million km throughout the world, roads are the foundation to improving the livelihood and quality of life of all the earth's inhabitants, connecting them to social, economic, commercial, safety and many other opportunities that enable them to function. As such, pavement engineers and researchers need to ensure that they can keep the wheels rolling: safely, economically and cost efficiently.

Prof Steyn explained the two basic elements that form part of pavement engineering teaching and research by referring to the Janus principle. This principle is named after the Roman mythological god of beginnings and ends – Janus – who faces two directions: the past and the future. This reflects the two most important elements of road use: accessibility in order to reach the opportunities that are essential for human functioning, and mobility to ensure the efficient movement of people and goods.

Accessibility relates to the basic principles that form part of the traditional and fundamental training of engineers. It is only with an understanding of the basics of soil and mechanics that engineers can apply advanced analyses, civiltronics and disruptive technologies to resolve the mobility challenges encountered by the road user as their primary client.

Prof Steyn continued to explain the functions of accessibility and mobility by way of two examples. He illustrated accessibility with the example of the nano-silane stabilisation of *in-situ* material, and mobility with the example of agricultural produce transportation, which provides options that affect the lives of both the agricultural producer and the consumer.



NANO-SILANE TREATMENT OF *IN-SITU* MATERIALS

The importance of the nano-silane treatment of *in-situ* materials in South Africa relates to the fact that this country has 750 000 km of roads, of which 80% is unpaved. This is the 11th longest road network in the world. Unpaved roads have many problems: they are dusty when dry, with associated road safety issues; and they are impassable when wet, making it difficult to travel between different locations. As South Africa has many rural inhabitants who make use of unpaved roads, they experience challenges reaching employment opportunities, which exacerbates unemployment issues.

The South African National Roads Agency Limited (SANRAL) has identified 13 000 km of unpaved roads as being socio-economically important and in need of improvement to the level of an all-weather road. As rural areas are far from material resources, and the material that is found is often of a marginal quality and cannot be used as a base material, it is important to consider an alternative option.

A study conducted by the World Bank in 2019 determined that, as the Rural Access Index of roads declines, so poverty increases. This is related to the idea that a good transportation network supports a good economy.

In the nano-silane treatment of *in-situ* materials, the surface of the rock aggregate or soil typically changes from a hydrophilic to a hydrophobic condition, which enables a better attraction between the organic (bitumen or equivalent designed molecules) and the inorganic material, also actively repelling water molecules, on condition that the applicable combinations have been accurately identified through detailed testing to minimise the risk of failure.

Some of the selected benefits of this process is that naturally available materials that are generally regarded as being non-standard, marginal, low-cost or sub-standard can be treated with the correct nano-silane to achieve all-purpose surfaces.

This enables better adhesion between the organic bitumen and the aggregate, which is relatively water repellent, can provide a stronger bond between the material particles, and can start to solve some of the problems associated with marginal materials. If one considers the costs involved, a nano-silane pavement can be installed for a quarter to half the cost of a traditional pavement, with the added benefit of eliminating the need to import costly material great distances from the site.

There are, however, certain conditions that need to be considered in the use of nano-silane treatments. These include toxicology, health and safety aspects, as well as environmental aspects such as leaching and the effect of the material that is added to the soil on ground water. Other aspects that need to be considered are how much material is required to cover the specific surface area, as well as the stability of the carrier fluid and the compatibility of the stabilising agent with the mineralogy of the materials. There are also cases where it is more cost-effective to use a traditional pavement design.

This treatment has been used in two case studies in South Africa. The first is the application to a dolomite surface, where it was found that applying the nano-silane treatment to the raw dolomite brings about a water saving of 40 000 litres per kilometre on a two-lane road. In a water-scarce country like South Africa, this has a major impact on the lives of communities, who now not only have a road that is in a good condition, but also more water for their basic needs.

In another example, an existing road that was in need of rehabilitation was treated with the nano-silane material, which was applied to a compacted marginal quality base material. This also brought about a 50% cost-saving on the conventional pavement design. To determine the long-term effectiveness of this application, heavy vehicle simulator tests were conducted on the surface. It was found that, with the appropriate treatment of a pavement structure, even with the inclusion of marginal material, a very effective road could be established, which is still in a good condition two years after the initial treatment, providing access to users in a rural environment.

AGRICULTURAL PRODUCE TRANSPORTATION

Over the past 10 years, the University of Pretoria has been conducting research to establish the impacts of road and transportation conditions on agricultural produce. This research comprised more than seven different projects over the years related to optimising the road condition to ensure that produce such as tomatoes and avocados can arrive at the consumer in the best condition with the longest shelf-life.

The first project considered aspects like road roughness and mechanical stresses such as damage to the fruit and reduced shelf-life. Tests conducted included the measurement of road roughness, accelerations and the impact of inter-tomato stress on the shelf-life of the product. A set of relationships was developed comparing the roughness of the road with the shelf-life of the tomatoes transported on a particular stretch of road. The finding was that, when transporting tomatoes in a certain type of vehicle on a road with a high Roughness Index, the fruit will have a shorter shelf-life due to bruising. This provides guidance for gravel road maintenance to ensure that the farmer can optimise the shelf-life of his produce.

The second project considered when particular portions of gravel roads should be maintained to ensure optimal cost and condition. Road roughness was monitored using a response-type road roughness measuring system to identify sections of the road with inadequate roughness. Maintenance efforts could thus be focused on these sections alone in order to save time and money for both the road owner and the farmer.

The third project considered the contribution of Fourth Industrial Revolution (4IR) technologies to providing a solution to the impact of road and transportation conditions on agricultural produce. An intelligent vehicle with sensors and accelerometers was used to continuously monitor the condition of a particular stretch of road. The data was then submitted to a central repository, continuously analysed and summarised, and reports submitted to the maintenance unit or user. This results in an almost autonomous decision regarding

PAVEMENT ENGINEERS AND RESEARCHERS NEED TO ENSURE THAT THEY CAN KEEP THE WHEELS ROLLING: SAFELY, ECONOMICALLY AND COST-EFFICIENTLY.

Credit: Brand South Africa

maintenance needs, providing guidance in terms of which sections of the road need to be graded. The necessary sections of the road are then graded, and with GPS geo-logging, completed maintenance is monitored.

The fourth project considered how deterioration data can contribute to maintenance decisions. Regression models were developed using real response-type road roughness measurement data, together with the maintenance history and historical rainfall data. This contributed to the further development of deterioration models, where the effects of wet and dry seasons, low and high slopes, and low and high traffic volumes could be used to budget for the next year as the farmer could predict how the environment, local conditions, location, materials and traffic would affect the deterioration of the roads.

The fifth project considered how financial management objectives could support road maintenance decisions. Several objectives were considered, including minimising annual road maintenance costs (where an extended shelf-life will be forfeited by minimising grading costs when transporting red tomatoes) and maximising tomato shelf-life (where transporting pink tomatoes will maximise the shelf-life, but with higher maintenance costs). This forms part of the grading triggers of unpaved roads, where varying characteristics are governed by market factors (high or low market demand as opposed to high or low shelf-life). This ultimately results in maintenance decisions being governed by dynamic maintenance scheduling.

The sixth project considered which part of the transportation cycle causes the highest potential damage.

The researchers measured the relative cumulative kinetic energy exerted in the cycle of bringing avocados to market, which included manual handling during harvesting, transportation in crates to the loading bay, transportation of the fruit over mostly paved roads, transportation over good gravel roads, and handling in the packhouse. Critical points were identified, and it was possible to focus on improvement efforts.

The last project considered whether a decision-making model can assist in optimisation. A Bayesian decision-making model was developed to determine probabilities and the potential effects of transporting the fruit from the farm to the packhouse.

This concluded Prof Steyn's illustration of the impact of the road network on mobility as a function of road use.

Credit: Brand South Africa

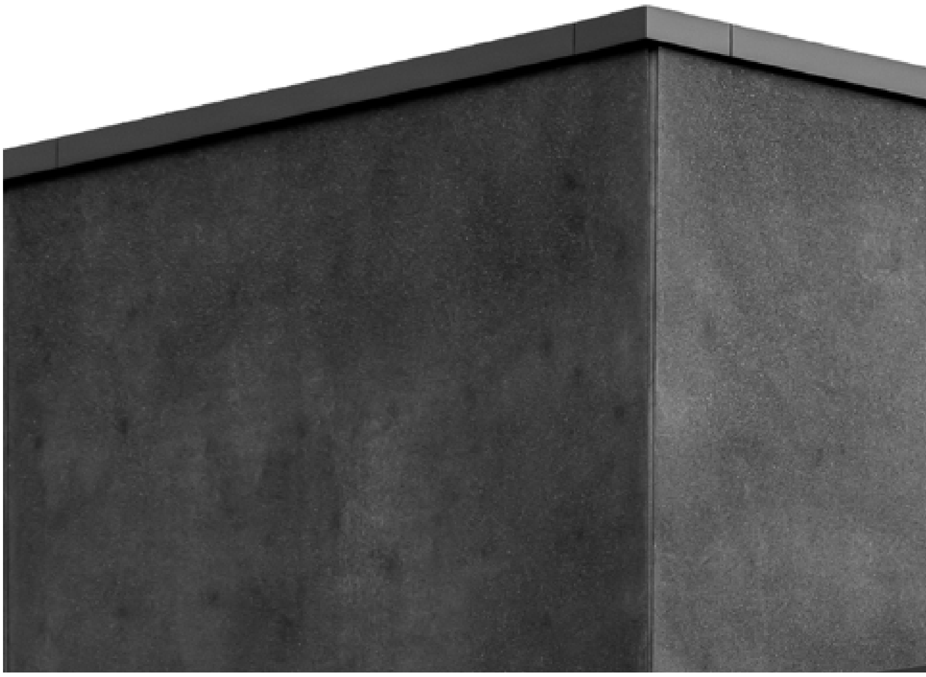
BENEFITS, IMPACTS AND KNOWLEDGE MANAGEMENT

Transportation and pavement engineering benefits all road users. Prof Steyn believes that the impact of research in this regard should be significant, and should not just be aimed at publication in peer-reviewed journals. "Knowledge becomes valuable when shared, benefits accrued and impacts made in normal people's lives," he said.

The question to be asked is thus: Does your research enable someone to have improved social, economic, security or educational opportunities? It is only if the research outcomes can be seen to improve their lives that the research can be considered significant.

View the full presentation: https://ict.illinois.edu/kent-seminars/7-8-billion-customers-who-benefits-from-my-research/

Predicting the behaviour of reinforced concrete structures



Prof George Markou
Dr Nikolaos P Bakas

A multidisciplinary project that involves machine learning algorithms in civil engineering was launched in 2018. The main objective of the project was to develop design formulae to predict the maximum capacity of reinforced concrete structural members through the use of software-generated data that would be made available free of charge to train machine learning algorithms.

This innovative approach has been extended to the structural problem that aims to predict the fundamental period of reinforced concrete structures during the seismic design and assessment of framing systems by accounting for the soil structure interaction phenomenon. Investigating the dynamic response of structures is of significant importance, particularly when it is essential to predict the fundamental period of structures in an accurate and realistic manner. This is crucial to reassure safe designs and a sustainable built environment when designing for seismic loading conditions.

ARTIFICIAL INTELLIGENCE AND MACHINE LEARNING

Artificial intelligence (AI) and machine learning algorithms are involved in a variety of scientific and industrial tasks, and contribute to the solution of corresponding problems, from data modelling and analysis to automatic literature reviews, face recognition and autonomous vehicles.

In recent years, researchers and professionals have been fetching AI algorithms in an unusually wide range of scientific, technological and business fields. Regardless of the database, their basic purpose is to develop a prediction algorithm, which will be accomplished by a mathematical model to describe the complex interactions among some input variables and a corresponding response. The relationship between independent and dependent variables is often highly non-linear, and mathematical models aim to form a generalised relationship that can objectively link them.

The final aim is to develop a numerical model that can predict new outputs for new, out-of-sample inputs, which may be within the given domain (interpolation) or even outside the domain (extrapolation). Predicting out of the limits of a given domain is a hard and highly unstable problem without interesting results. However, a numerical solution was recently published, with extended prediction horizons. This significant breakthrough provided new insights and mathematical tools for this research project.

PREDICTING THE FUNDAMENTAL PERIOD OF REINFORCED CONCRETE STRUCTURES

Designing seismic-resistant reinforced concrete structures is of significant importance when establishing a safer built environment and avoiding loss of life due to earthquake excitations. Understanding the intrinsic characteristics of structures – and specifically their expected dynamic response – is a key factor in the design process. In addition, accounting for the soil-structure-interaction effect when evaluating the dynamic response of a structure is decisive in predicting its dynamic behaviour. The computation of the fundamental period is one of the most important characteristic parameters of structures when analysing and designing in seismically active regions as it strongly affects the magnitude of the computed seismic forces. The simplicity of the current design formulae in predicting the fundamental period appears to be evident, since a detailed modal analysis requires an excessive computational effort in relation to a time-consuming mesh generation routine. Therefore, the requirement for a more precise computation of the fundamental period of reinforced concrete structures, also accounting for any soil-structure-interaction conditions, is apparent.

In order to alleviate the accuracy limitations related to simplified formulae for the prediction of the fundamental period of reinforced concrete structures, and to account for different soil-structure-interaction conditions, 3D detailed analysis tools were utilised for the generation of a database of 475 cases. The structural systems considered in this research comprised bare frames, since infill walls are not accounted for in Eurocode 8 and the South African National Standard (SANS), given that these non-structural members do not contribute to the resistance of the frame under ultimate limit-state conditions.

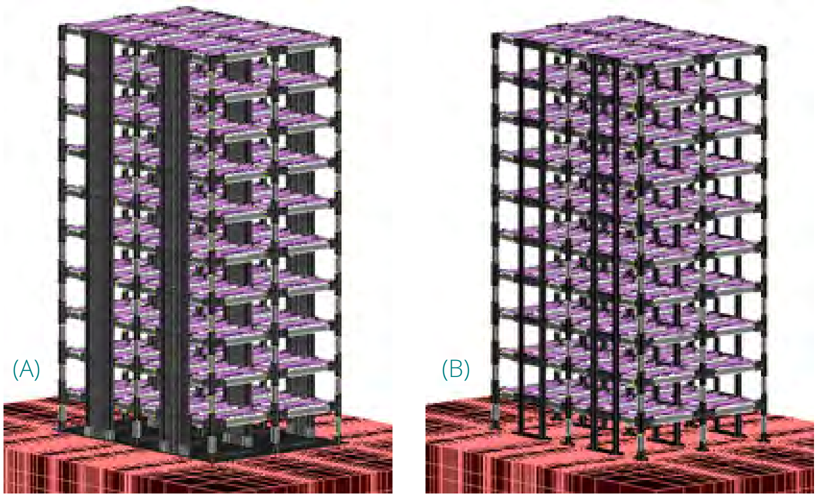
According to the numerical investigation performed through the use of different reinforced concrete frames, it was found that the geometry of the frame, the use of dual framing systems and the soil-structure-interaction effects were parameters that controlled the fundamental mode of reinforced concrete buildings. The following parameters were therefore used as variables in the newly developed expressions: fundamental period, height of the building, ratio of the

INVESTIGATING THE DYNAMIC RESPONSE OF STRUCTURES IS OF SIGNIFICANT IMPORTANCE, PARTICULARLY WHEN IT IS ESSENTIAL TO PREDICT THE FUNDAMENTAL PERIOD OF STRUCTURES IN AN ACCURATE AND A REALISTIC MANNER. THIS IS CRUCIAL TO REASSURE SAFE DESIGNS AND A SUSTAINABLE BUILT ENVIRONMENT WHEN DESIGNING FOR SEISMIC LOADING CONDITIONS.

total area of shear wall sections along the direction of the seismic action to the total area of the walls and columns at the ground floor, the Young's modulus for the soil, the length of the building along the seismic action direction, the width of the building perpendicular to the seismic action direction, and the depth of the soil.

Based on the generated dataset, a machine learning algorithm was used to develop a predictive formula (with different characteristics and intrinsic features) and predict the fundamental period of reinforced concrete structures, with and without accounting for the soil-structure-interaction effect. The developed fundamental period formula was validated with 60 out-of-sample fundamental period cases.

According to the numerical investigation, the developed fundamental formula exhibited high prediction accuracy. In addition, the proposed formula was compared to three fundamental period formulae found in the literature that claimed improved predictive capabilities compared to the design code formulae that are currently used in the seismic design of reinforced concrete buildings. Based on the research findings, the proposed fundamental period formula was found to significantly outperform all the current expressions found in the literature, including the prediction capabilities of the different design code formulae. Specifically, the proposed fundamental period formula derived a 5.68% absolute average error on the validation dataset, where Eurocode 8 – the most accurate from the investigated fundamental period design formulae – derived a 45.24% absolute average error. The significant inability of the under-investigation design code formulae was therefore further highlighted through the validation stage, where it was found that the design codes' inability to realistically predict the expected fundamental period of reinforced concrete buildings was evident.

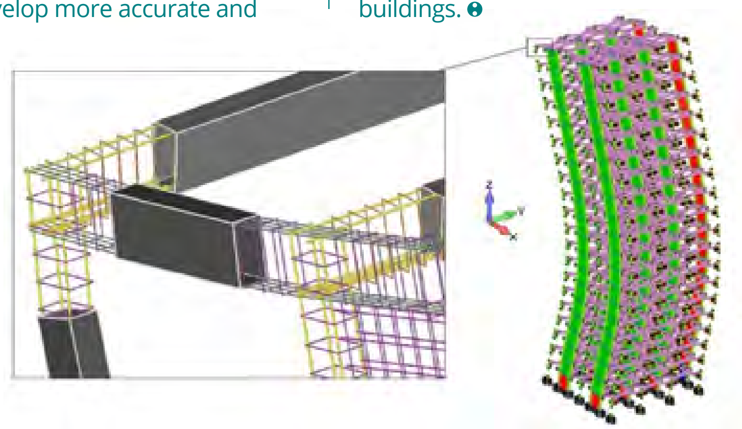


Finite element meshes of ten-storey reinforced concrete models with (A) and without (B) shear walls.

Conclusion

Based on the research presented in this project, a free-distribution application was developed, which is currently being tested by the research team in the Department of Civil Engineering's Structures Division. The software application is integrated with the predictive model developed from this research project and will be made available free of charge to anyone who wishes to use it to predict the fundamental period of structures through the use of an AI-generated model. It must be noted that this is the first predictive model of its kind currently found in the international literature.

Future research will extend the variety of building geometries, thus increasing the range of structural geometries to which this formula can be applied. Larger models will be used to further investigate the dynamic behaviour of reinforced concrete structures to enhance the training dataset. The investigation of infill walls and masonry structures will be the subject of future research to develop more accurate and objective fundamental period formulae that will enable civil engineers to obtain realistic predictions for both the design of new structures and the assessment of the dynamic response of existing buildings.


Modal shape of a fixed-base 20-storey reinforced concrete building with shear walls, together with the deformed shape of the 368 773 embedded rebar elements.

Design and implementation of conduit hydropower plants in the City of Tshwane

Marco van Dijk
Chantel Niebuhr
Anja Bekker

The Hydropower Research Group in the University's Department of Civil Engineering has been involved in the development of conduit hydropower plants for the past 10 years.

As a water-scarce country, it is often presumed that South Africa does not have the most prevalent hydropower conditions, as may be found elsewhere in Africa and the rest of the world. However, large quantities of raw and potable water are conveyed daily over large distances and elevations under either pressurised or gravity conditions. Within these systems exists the opportunity for conduit hydropower generation.

In water distribution systems, excess pressure, which can be exploited for conduit hydropower, is generally dissipated by employing equipment such as orifice plates and pressure-reducing valves. Conduit hydropower differs from more conventional hydropower development in that it is not located on natural rivers or waterways, and does not involve the potential negative types of environmental impacts that are usually associated with hydropower projects. The water supply and distribution systems consist of a complex network of interconnected pipes, service reservoirs and pumps that deliver water from the treatment plant to the consumer.

The Hydropower Research Group has been actively involved in the following activities:

- South African policy and legislation
- Feasibility studies
- Site evaluations
- Small-scale hydropower plant development
- Turbine development and design
- Numerical computational fluid dynamics modelling
- Guideline and software tool development

A Memorandum of Agreement, cementing the collaboration between the University of Pretoria and the City of Tshwane, endorsed the research group's opportunities to evaluate, plan, design, experiment and develop conduit hydropower plants on the water infrastructure of the City of Tshwane.

In 2011, the **Pierre van Ryneveld** conduit hydropower plant was launched, showcasing a 15 kW cross-flow turbine installed on the reservoir roof.

The research group also assisted in the development of the **Annlin Reservoir** conduit hydropower plant, which consisted of three 50 kW pump-as-turbine installations, with two grid-connected units and one unit supplying the reservoir complex. Unfortunately, this site was vandalised (a reality for most municipalities) and requires refurbishment.

Three pump-as-turbine installations at the Annlin Reservoir

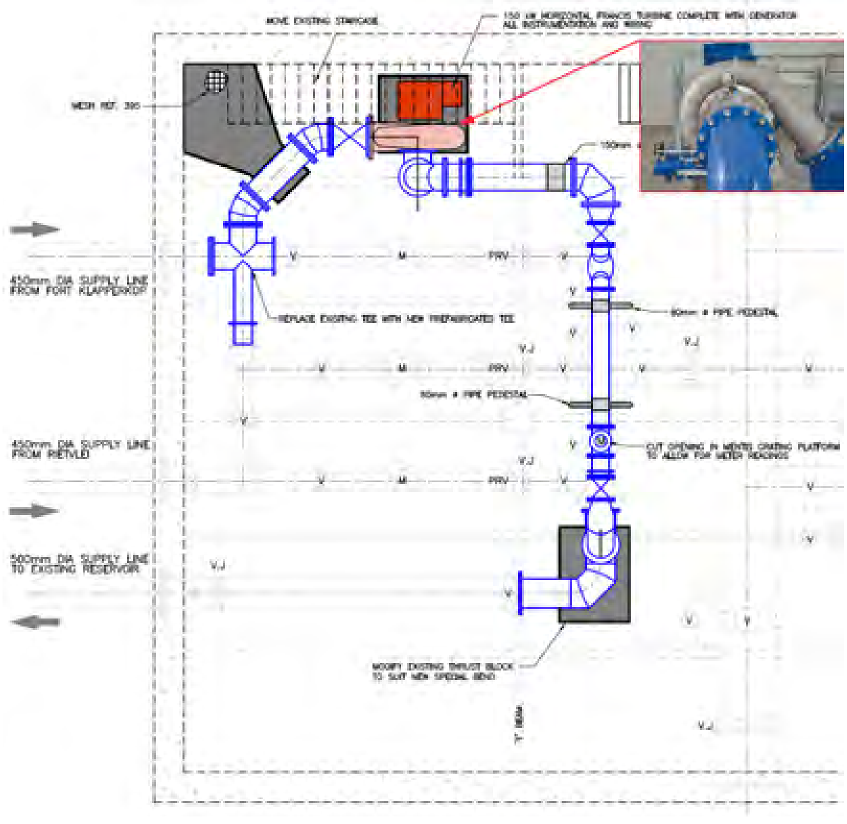
The Otter turbine installed on a bypass in parallel to pressure-reducing valves

A new reservoir was recently completed in **Doornkloof**. An 8 kW prototype "Otter turbine" was installed as part of this construction. This conduit hydropower plant was recently commissioned and supplies the site with power for lighting, telemetry, cathodic protection and an alarm system. A student completing his master's degree in the Department of Civil Engineering is now optimising the design and monitoring the functioning.

INTERNATIONAL COLLABORATION

A collaboration objective between the City of Tshwane and the City of Aarhus in Denmark incorporates evaluating the Salvokop Reservoir site for its conduit hydropower generation potential. The Salvokop Reservoir complex is located south of the Pretoria Central Business District, and a new 30 Mℓ reservoir is being planned adjacent to the existing 27 Mℓ reservoir.

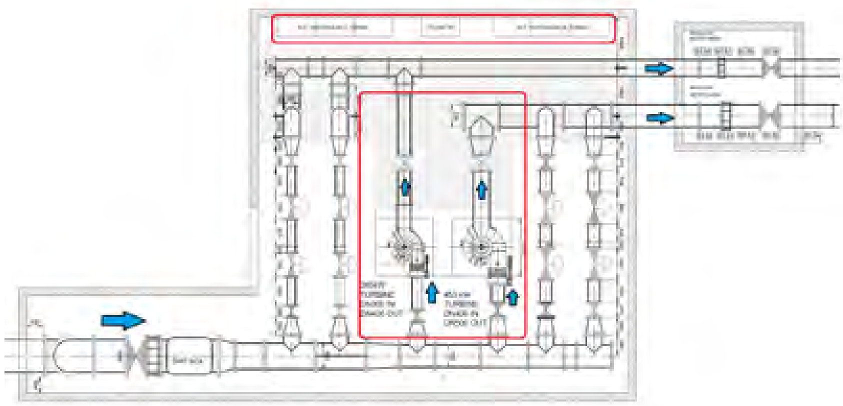
The Embassy of Denmark facilitated the cooperation, and the Hydropower Research Group conducted the feasibility study and eventually the design of this 152 kW conduit hydropower plant to be installed in the existing pressure-reducing valve chamber. Approximately 245 ℓ/s flows from the Fort Klapperkop reservoirs under gravity to the Salvokop Reservoir, where an excess pressure of ±78 m requires dissipation. The City of Tshwane has approved the allocation of funds in the 2021/22 budget for this installation to be implemented.



The design layout of the 152 kW conduit hydropower plant at Salvokop Reservoir

LARGE-SCALE FEASIBILITY STUDY FOR THE CITY OF TSHWANE

The Hydropower Research Group conducted a feasibility study for the City of Tshwane, which found that more than 2.4 MW of hydropower potential exists in five of the larger reservoir complexes in the City of Tshwane. Two of these sites are the two Heights reservoirs located close to the Voortrekker Monument. Initially, two conduit hydropower plants were planned at the Heights High Level and Heights Low Level reservoirs, respectively, but these two sites were sensibly combined into one installation. Currently, a hybrid pressure-control station and conduit hydropower plant is being constructed, which will ultimately house two Francis-type turbines of 265 kW and 455 kW, which will be connected to the City of Tshwane's electrical grid.



The Heights hybrid pressure-reducing station and conduit hydropower plant

The need for power in remote locations remains a reality for a large metropolitan municipality like the City of Tshwane. As part of a master's degree study, an inline pressure wheel was developed to allow for power generation anywhere along a pipeline. At the Klipgat Reservoir in Mabopane, a 300 W inline pressure wheel was installed that will supply power to the site. This is a very simple design with an inline wheel installed on top of the pipe, enclosed and connected to an axle and a pulley system with an alternator.

> **THE NEED FOR POWER IN REMOTE LOCATIONS REMAINS A REALITY FOR A LARGE METROPOLITAN MUNICIPALITY LIKE THE CITY OF TSHWANE. THE DEPARTMENT OF CIVIL ENGINEERING'S HYDROPOWER PROJECTS IN THE CITY OF TSHWANE ILLUSTRATE HOW EXISTING MUNICIPAL INFRASTRUCTURE CAN BE UTILISED TO MEET SOUTH AFRICA'S SUSTAINABLE ENERGY GOALS WHILE PROVIDING ESSENTIAL SERVICES TO CONSUMERS.**

Following the promising pilot projects undertaken around South Africa, and a presentation by the Hydropower Research Group to the City of Tshwane in 2013, a Mayoral Resolution was taken that all new reservoirs in the city would consider the inclusion of hydropower. With this decision, the City of Tshwane aims to meet a goal that was set for the sustainable management of water, energy, waste and ecological environmental management.

The City of Tshwane's hydropower plants illustrate how existing municipal infrastructure can be utilised to meet South Africa's sustainable energy goals while providing essential services to consumers. The City of Tshwane should be used as an example to other municipalities to realise the potential that is available within their existing water infrastructure. Additionally, projects such as these showcase the possibility for innovation within the hydropower sector. Conduit hydropower development through pilot studies and installations allow for a broader range of applications of retrofitted traditional hydropower systems, as well as new innovative designs. As South Africa struggles through the current electricity supply crisis, reliable, localised and sustainable energy production is an invaluable alternative and asset for the water industry.

A pico inline pressure wheel hydropower turbine installation at Klipgat Reservoir

Providing leadership for the sustainable development of industry, innovation and infrastructure

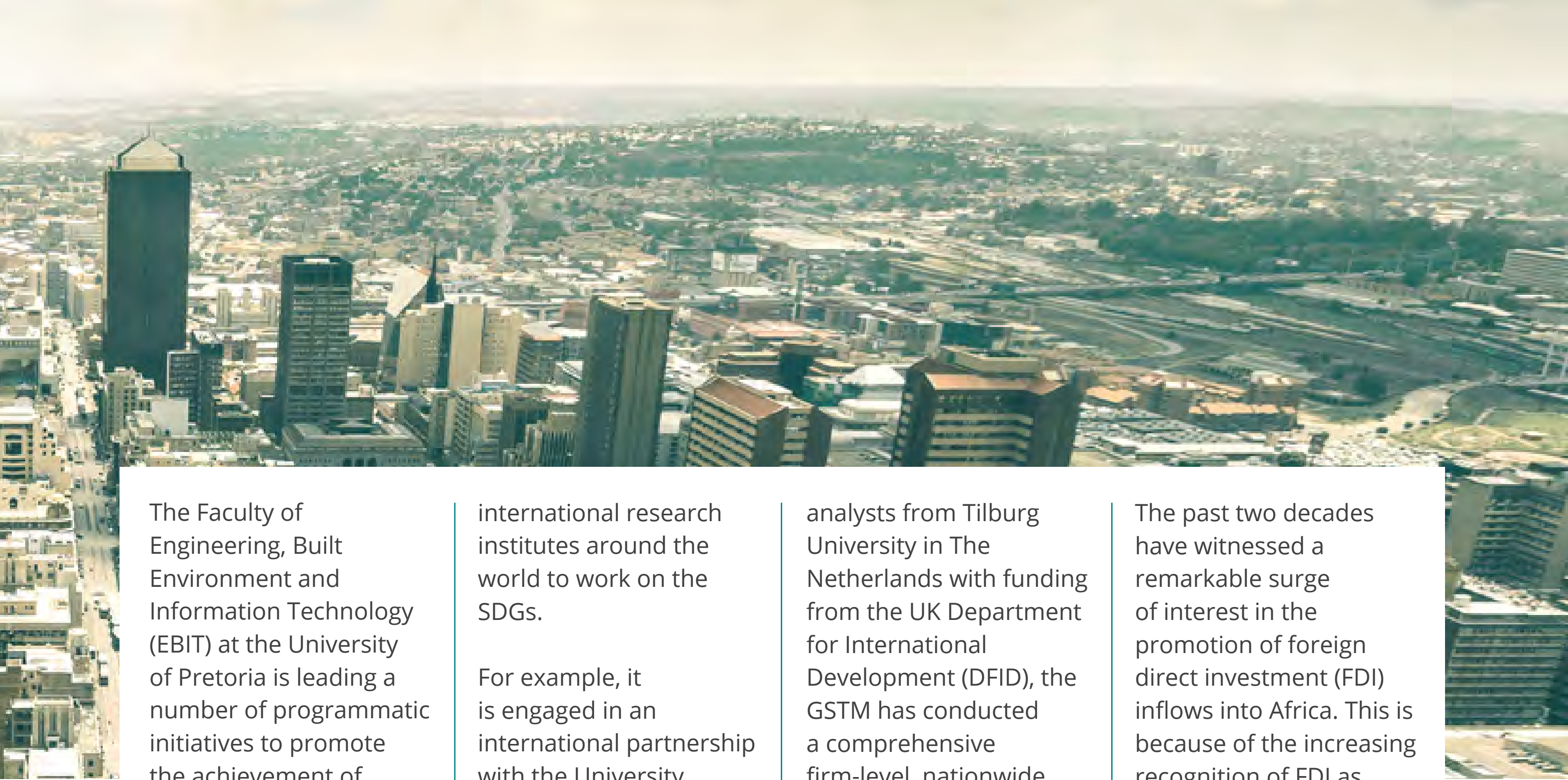
Prof John Ouma-Mugabe

In September 2020, the world's leaders met at the United Nations (UN) General Assembly to review progress on the implementation of the UN Agenda 2030 and its Sustainable Development Goals (SDGs) adopted five years ago. The UN General Assembly meeting took place in the midst of the COVID-19 pandemic that shattered global geopolitical and economic systems in unprecedented ways.

This pandemic has vividly exposed the structural and governance weaknesses of national health systems. To address the health crisis and related weaknesses in health infrastructure, declining economic growth, loss of employment and other challenges, governments around the world are increasingly investing in various forms of innovation, infrastructure and industrialisation or manufacturing activities, including the manufacture of personal protective equipment (PPE), ventilators for hospitals, masks and other health products.

The interconnected nature of the SDGs, particularly between SDG 3 (Good Health and Wellbeing) and SDG 9 (Industry, Innovation and Infrastructure), is demonstrated in the interventions that some countries are currently taking to handle the pandemic. Many African countries are directing their economic stimulus packages to small- and medium-scale enterprises to manufacture PPEs, masks and other products to be used for COVID-19 testing, tracing and treatment.

Engineering faculties at universities throughout the world can play a critical role to support small and medium enterprises (SMEs) and governments to spur manufacturing, and advance the achievement of SDG 9 as a pathway to SDG 3, including banishing COVID-19, and developing pathways out of poverty (SDG 1). They are key sources of knowledge, information and skills that public organisations and private enterprises require to implement programmes for the implementation of the SDGs.



The Faculty of Engineering, Built Environment and Information Technology (EBIT) at the University of Pretoria is leading a number of programmatic initiatives to promote the achievement of SDG 9 – promoting industry, innovation and infrastructure. The Faculty's strategic work across its schools and departments focuses on building world-class skills and knowledge assets, and providing policy advice to governments and private companies in key areas such as building sustainable cities with green transport and energy systems, and industrialising African economies through the development and deployment of modern technologies, including those related to the Fourth Industrial Revolution (4IR).

The Graduate School of Technology Management (GSTM) is one of the Faculty's schools that is at the forefront in supporting governments and private enterprises in Africa attain SDG 9 and related SDGs on poverty reduction, economic growth and job creation, and good health and wellbeing. The GSTM has partnered with universities and international research institutes around the world to work on the SDGs.

For example, it is engaged in an international partnership with the University of Sussex and the University College London in the United Kingdom, the United Nations Development Programme (UNDP), UK Research and Innovation (UKRI) and other organisations around the world to help governments in low- and middle-income countries harness and steer science, technology and innovation to achieve the SDGs.

Focusing on SDG 9, the GSTM is coordinating research and policy engagement in sub-Saharan Africa on how technology and innovation can best help reduce an overdependence on capture fisheries, reduce conflicts and spur local manufacturing.

Another related initiative on SDG 9 in the Faculty is a project on unlocking systemic barriers to innovation by manufacturing SMEs in South Africa. Conducted in collaboration with economists and policy analysts from Tilburg University in The Netherlands with funding from the UK Department for International Development (DFID), the GSTM has conducted a comprehensive firm-level, nationwide survey of the innovation activities and capabilities of SMEs.

The project identified specific policy instruments and institutional arrangements for unlocking barriers to innovation in manufacturing SMEs in the industrial sectors occupied by pharmaceuticals, automobiles, agro-processing, textiles and defense.

Research emanating from the project recommends specific policy measures that the government of South Africa and other African countries should institute to fast-track manufacturing and industrialisation, particularly through SMEs.

In addition to the focus on supporting manufacturing SMEs, African countries need to harness and direct foreign capital inflows to sectors with high potential for achieving SDG 9.

The past two decades have witnessed a remarkable surge of interest in the promotion of foreign direct investment (FDI) inflows into Africa. This is because of the increasing recognition of FDI as an important source of capital and foreign technologies that are critical to the continent's efforts to achieve economic growth and industrialisation, helping to attain SDG 9. If well configured, FDI can spur the technological change and structural transformation of African economies, creating employment and reducing poverty, while at the same time maintaining the integrity of the natural environment.

Other ongoing research by the GSTM is about the nature of policies and institutions that would ensure that FDI inflows contribute to the achievement of the inclusive and sustainable industrialisation of Africa. This shows that African countries need investment, as well as industrial and innovation policy mixes, that directs FDI inflows to sectors and activities that spread the economic, social and environmental benefits of industrialisation across society.

Enhancing universities' contribution to the SDGs

Prof Jan Eloff

The University of Pretoria has been ranked among the top universities in the world for its contribution to the Sustainable Development Goals (SDGs) of the United Nations (UN). The Times Higher Education Impact Ranking assesses the performance of universities across the globe against the UN's SDGs in terms of their social and economic impact.

In terms of this ranking, the University achieved an overall placement in the 101–200 band of institutions, and was placed second in South Africa. The ranking includes 766 universities from 85 countries, and compares the broad areas of research, outreach and stewardship. It featured among the top 100 universities in three of the categories: Quality Education (SDG 4), Industry, Innovation and Infrastructure (SDG 9) and Peace, Justice and Strong Institutions (SDG 16). It was also placed in the 101–200 band of institutions for Good Health and Wellbeing (SDG 3) and Partnerships for the Goals (SDG 17).

INDUSTRY, INNOVATION AND INFRASTRUCTURE

For the Times Higher Education's global ranking submission, the Faculty of Engineering, Built Environment and Information Technology was tasked to champion SDG 9. It also participated in SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production) and SDG 17 (Partnerships).

In preparation for the University's submission, an extensive audit was conducted in 2019 to gain insight into how well the research conducted in the Faculty supports the SDGs. This would also ensure that the research conducted in the Faculty is making an impact on society as a whole, particularly with regard to the most pressing challenges of the developing world. These include topics related to the economic development of South Africa and job creation, poverty, inequality, food security, climate change and quality health.

This audit revealed that the Faculty is addressing all but two of the 17 SDGs (SDG 5: Gender Equality and SDG 14: Life below Water).

The Faculty's research is focused on six broad research themes:

- Water and Environmental Engineering
- Minerals and Materials Beneficiation
- The Fourth Industrial Revolution
- Smart Cities and Transportation
- Big Data Science, ICT and Technology and Innovation Management
- Energy

The audit of the Faculty's research according to these research themes revealed that the following SDGs are addressed within the Faculty:

- *SDG 1 – No Poverty:* Research in water and environmental engineering, and smart cities and transportation
- *SDG 2 – Zero Hunger*: Research in energy
- *SDG 3 – Good Health and Wellbeing:* Research in water and environmental engineering, the Fourth Industrial Revolution, smart cities and transportation, and big data science, information and communication technology (ICT), and technology and innovation management
- *SDG 4 – Quality Education:* Research in smart cities and transportation, and big data science, ICT, and technology and innovation management
- *SDG 6 – Clean Water and Sanitation*: Research in water and environmental engineering, the Fourth Industrial Revolution, smart cities and transportation, and energy
- *SDG 7 – Affordable and Clean Energy:* Research in water and environmental engineering, minerals and materials beneficiation, the Fourth Industrial Revolution and energy
- *SDG 8 – Decent Work and Economic Growth:* Research in minerals and materials beneficiation, the Fourth Industrial Revolution and energy
- *SDG 9 – Industry Innovation and Infrastructure:* Research in water and environmental engineering, minerals and materials beneficiation, the Fourth Industrial Revolution, smart cities and transportation, big data science, ICT, technology and innovation management, and energy
- *SDG 10 – Reduced Inequalities:* Research in water and environmental engineering, and smart cities and transportation
- *SDG 11 – Sustainable Cities and Communities*: Research in water and environmental engineering, the Fourth Industrial Revolution, smart cities and transportation, big data science, ICT, technology and innovation management, and energy
- *SDG 12 – Responsible Consumption and Production*: Research in water and environmental engineering, minerals and materials beneficiation, smart cities and transportation, big data science, ICT, and technology and innovation management
- *SDG 13: –Climate Action:* Research in water and environmental engineering, the Fourth Industrial Revolution, smart cities and transportation, big data science, ICT, and technology and innovation management
- *SDG 15 – Life on Land*: Research in water and environmental engineering, minerals and materials beneficiation, the Fourth Industrial Revolution, smart cities and transportation, big data science, ICT, technology and innovation management, and energy
- *SDG 16 – Peace, Justice and Strong Institutions*: Research in the Fourth Industrial Revolution, and smart cities and transportation
- *SDG 17– Partnerships for the Goals:* Research in water and environmental engineering, minerals and materials beneficiation, the Fourth Industrial Revolution, smart cities and transportation, big data science, ICT, technology and innovation management, and energy

The following research projects demonstrate the Faculty's research impact on the SDGs:

ADDITIVE MANUFACTURING OF ELECTRONIC SYSTEMS

This research project, conducted in the Carl and Emily Fuchs Institute for Microelectronics (CEFIM) in the Department of Electrical, Electronic and Computer Engineering, will establish new electronic system design techniques and reliable packaging strategies that best exploit modern additive manufacturing technologies. These methodologies will be harnessed in the domains of health, water, wireless communication and climate sciences. The project aligns well with SDG 9 through consideration of low-cost and low-volume production technologies that will enhance scientific research and support domestic manufacturing infrastructure. Waste reduction is possible when opting for additive manufacturing processes and selecting environmentally friendly materials. Both approaches will also contribute considerably to the achievement of SDG 12.

DESIGN AND OPERATION OPTIMISATION OF COMMUNITY MICROGRIDS WITH PEER-TO-PEER ENERGY SHARING

This research project, conducted in the Energy Research Group in the Department of Electrical, Electronic and Computer Engineering, will develop modern power systems by building networked microgrids with peer-to-peer (P2P) energy-sharing networks. As future power systems are expected to be affordable, reliable and smart for the development of sustainable cities and communities, the P2P energy-sharing network will offer opportunities to further optimise the design and operation of existing microgrids for enhanced reliability, improved self-consumption, and reduced reliance on the main grid. The project primarily aims to support SDG 11, while it will also support SDG 9.

WATER SECURITY AND SUSTAINABLE SANITATION

This research project, conducted in the Water Utilisation and Environmental Engineering Division in the Department of Chemical Engineering, aims to develop energy independent future water reclamation and desalination systems using forward osmosis membrane systems, the improved treatment of emerging pollutants through advanced oxidation, and water-free sanitation systems for sustainable future communities. The project primarily supports SDG 11 and SDG 9.

Society 5.0:

Humans in a digital world

Prof Alta van der Merwe

The concept of Society 5.0 was first introduced in Japan. It formed part of the 5th Science and Technology Basic Plan, and follows the hunting society (Society 1.0), agricultural society (Society 2.0), industrial society (Society 3.0) and information society (Society 4.0). The Cabinet Office of Japan defines Society 5.0 as "a human-centered society that balances economic advancement with the resolution of social problems by a system that highly integrates cyberspace and physical space".

Bruno Salgues, in his book titled *Society 5.0: Industry of the future, technologies, methods and tools* (published in 2018), urges that more research needs to be conducted to understand the situation of humans in a digital world. He argues that humans are defined by different needs, and that digital technology allows one to respond to the need for knowledge if one knows how to make use of the tools of the digital world.

STRENGTHS OF HUMANS IN A DIGITAL WORLD

According to Salgues, the first and foremost strength in the digital world is access to information. Humans now have access to information as and when needed, with the only limitation being the applicability of the information provided by search engines. Researchers are constantly improving context-relevant searches using techniques such as frequency for relevance where search engines provide information according to popularity.

Access to information also links to opportunities for skills training where humans now not only have access to unlimited online courses, but institutions are constantly renewing curricula to be more relevant in a changing world.

WEAKNESSES OF HUMANS IN A DIGITAL WORLD

A key weakness experienced in the digital world is information overload. We often find ourselves asking what we should do next, what we should look at next, what information is the most important and how to distinguish what to spend time on. Information overload – also known as infobesity – is where one struggles to make decisions since there is too much information pertaining to an issue. As a result of access to information across national boundaries, the influence of the nation states is also disappearing and being reduced. A final concern is the time humans spend on media, particularly as new phenomena such as gamefication and social media addiction emerge.

THREATS OF HUMANS IN A DIGITAL WORLD

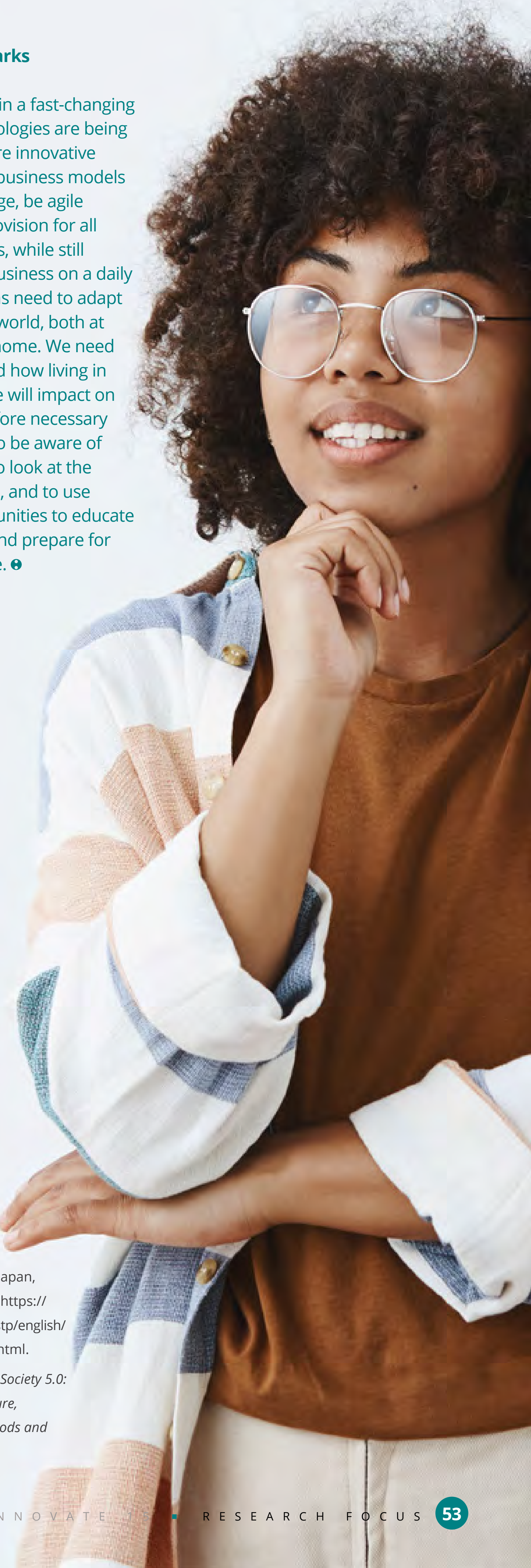
One of the biggest concerns in a changing world is the threat of the manipulation of information for propaganda purposes. Fake news is a reality and one cannot always believe what one reads on many of the forums on the internet. A lot of attention is given to the fact that some of the larger platforms do not respect the use of personal information for personal use. Mail platforms use special software to protect our mailboxes from overflowing with offers based on searches done within our browsers. There is a blur between the real world and the virtual world. We often find ourselves engaged for hours in activities in the virtual world. The gaming world, in particular, has explored this phenomenon to create software that engages one in real-world activities, but focuses on participation through activities in the virtual world. Information overload may cause a threat as we are so focused on what is out there, that we do not distinguish between information and knowledge. Knowledge has a greater focus on understanding, while information is just data. Obtaining information does not necessarily mean that there is a level of understanding of the meaning of the information. Lastly, in the digital world, reproduction is very easy, posing a threat to existing businesses in terms of the production of books, for example, where new business models need to be considered to still be economically feasible.

OPPORTUNITIES FOR HUMANS IN A DIGITAL WORLD

The digital world has created many opportunities, both in the business and in our personal worlds. In many sectors, such as the health sector, the digitisation and use of technology have given us access to a mass of information not previously available. We are also now able to use this information more effectively and educate ourselves in a more effective and efficient way. Access to information is no longer a big obstacle. The challenge rather lies in making sense of information and presenting it in such a way that it is accessible.

Closing remarks

We are living in a fast-changing world. Technologies are being used in a more innovative manner and business models need to change, be agile and make provision for all the disruptors, while still conducting business on a daily basis. Humans need to adapt to the digital world, both at work and at home. We need to understand how living in the digital age will impact on us. It is therefore necessary for humans to be aware of the change, to look at the opportunities, and to use these opportunities to educate themselves and prepare for digital change.



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Convergence of cybersecurity and big data science

Prof Jan Eloff
Johan Smit

The successful convergence of cybersecurity and big data science necessitates a clear understanding of big data, data science and cybersecurity. A global survey by the international Ponemon Institute, in conjunction with IBM, found that companies that leveraged the convergence of cybersecurity and big data science dramatically improved their overall cyber and information security posture.

Research conducted by the Cybersecurity and Big Data Science Research Group at the University of Pretoria examined the Cybersecurity Framework of the National Institute of Standards and Technology (NIST) to obtain an understanding of the convergence benefits of cybersecurity and big data science. This provided the foundation for several projects aimed at improving detection mechanisms by leveraging these convergence benefits.

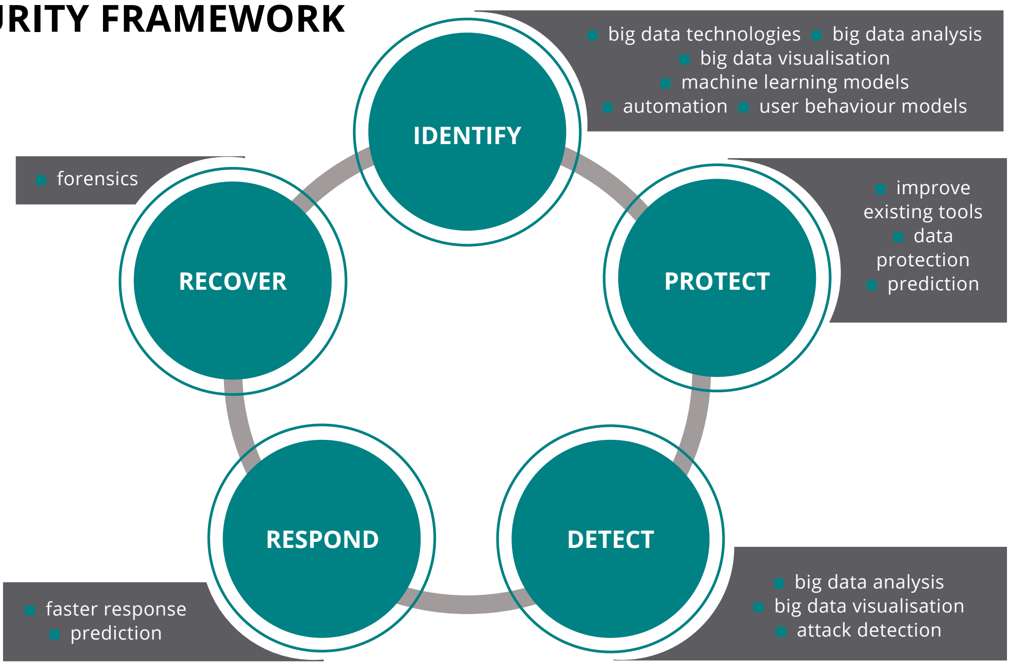
DESCRIBING BIG DATA

The volume of data is one way to describe big data – and there is much more data today than ever before. On Twitter alone, over 500 million tweets are sent per day and mobile traffic is expected to grow from 11.5 exabytes per month in 2017 to 77 exabytes by 2022. However, big data is defined by more than just the volume of data. It is also described in terms of variety (whether the data is structured or unstructured) and velocity (the speed of data flow and how fast the data is created and moved).

One of the most important components of data science is machine learning. This is a field that spans disciplines such as computer science, statistics, mathematics, psychology and brain sciences. Combining machine learning with big data is a powerful development and forms the basis for the convergence of cybersecurity and big data science.

THE CYBERSECURITY FRAMEWORK

The Cybersecurity Framework of the NIST was developed in the USA with the aim of assisting companies to understand the scope of cybersecurity and to minimise risk exposure. It consists of five functions that explain the convergence benefits of cybersecurity and big data science: Identify, Protect, Detect, Respond and Recover.



Identify

As the first function of the Cybersecurity Framework, Identify focuses on identifying risks and the security areas in the organisation that require priority focus. This is done by building an understanding and a baseline of the organisation and then working through the combined data. In the Identify function, the convergence of cybersecurity and big data science mainly focuses on big data techniques, including the benefit to be gained from using big data analysis and big data visualisation. Big data analysis can assist with creating correlations between various data sources, which can assist in digital forensic investigations. Data visualisation, on the other hand, can enable a better grasp on and a faster grasp of the data. Machine learning models can create a baseline for the organisation, and create user behaviour baselines as this has the potential to improve the discovery and detection of cybersecurity attacks and compromises. User behaviour baselines are valuable from a cybersecurity perspective since humans are often the weakest link in the cyber defence chain. Machine learning can also help define the characteristics of an existing system to identify or predict where a future attack can occur.

Protect

The Protect function refers to the safeguarding of computer networks and the information they contain. The focus is to limit cyber attacks and their impact, should an attack occur. Basic forms of protection include anti-virus programs and firewalls. However, these are reactive protection strategies, more proactive strategies are required against newer, more advanced attacks. The convergence between cybersecurity and big data science can be leveraged to develop smarter firewalls that implement near real-time internet protocol (IP) updates to block or terminate malicious connections. State-of the-art security and information event management technologies that employ big data and machine learning enable a user to view combined datasets, discover advanced attacks and predict where an attacker could try to infiltrate the cyber environment.

Detect

The Detect function focuses on detecting a cybersecurity event by monitoring and detecting anomalies, and detecting specific events. This is the function of the Cybersecurity Framework that creates the best opportunities to leverage advances in cybersecurity and big data science. One of the reasons for this is that detection is usually based on a quick understanding and interpretation of a huge amount of data, and quickly finding patterns and outliers in the data to assist with detecting anomalies. The convergence of cybersecurity and big data science can help improve the quality of cyber attack discovery. One way of implementing intrusion detection is through the use of an intrusion detection system that is enhanced with machine learning and a variety of machine learning algorithms. Regression algorithms can be used to predict what the next system call should be and to compare that result with what system call is really happening. In this way, anomalies can be detected, which could mean the detection of an attempted hack.

Respond

The Respond function refers to what needs to happen after a cybersecurity incident has been detected. In addition to defining the activities and actions that are required, this function is also concerned with limiting the impact of the potential incident. The Ponemon Institute found that having a tried-and-tested response plan enables better attack prevention and reduces the cost of a breach. Adding intelligent automated responses through the convergence between cybersecurity and big data science can help manage constantly evolving attacks. Close to real-time decision making can be achieved with big data analysis. This can provide a fast response that will protect the organisation. Other decision-making options are to create streamlined processes to quarantine malware or to revoke IP access from attackers. Classifying an attack can also assist in improving response since this provides a guide to what could potentially be the next logical steps of the attack. Unsupervised learning in the form of self-organising maps have also been used to identify the attack class.

Recover

The Recover function refers to the plans, efforts and resources required to restore capabilities and services to a working state after being affected in a cyber attack. The intent is to have everything up and running as soon as possible through the proper planning and use of resources. One benefit is to employ unsupervised models to support forensic investigators when they determine what is normal and what is anomalous behaviour. These models allow the investigator to obtain a faster overview of what happened. A more formal approach was proposed by a research team supervised by Prof Hein Venter of the Department of Computer Science at the University of Pretoria (Karie, Kebande and Venter, 2019), who created a Deep Learning Cyber Forensics Framework to assist cyber investigators. This framework makes use of deep learning techniques to create a cyber forensic investigation engine, which assists in collecting, preserving, analysing and interpreting potential evidence.

RESEARCH TO IMPROVE DETECTION MECHANISMS

The Cybersecurity and Big Data Science Research Group has conducted several projects to improve detection mechanisms by leveraging the benefits of the convergence between cybersecurity and big data science.

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The detection of insider threats

Insider threats exploit system vulnerabilities from inside an organisation, such as employees who abuse their authorised access rights to cause harm to an organisation. The number and complexity of insider threats outpace currently available cybersecurity safeguards. In order to discover insider threats, a deep understanding of the application domain within the organisation, as well as processing big and fast-changing volumes of data, is required. In an attempt to minimise cybersecurity insider threats, rule-based approaches are used. The discovery of insider threats is an imprecise and complex problem, and these rule-based approaches only focus on known abuse scenarios. The sheer volume, velocity and variety of the big data generated by highly integrated systems today also make it impossible to discover abuse committed by insiders without using specialised tools. The advances made in big data and data science, such as anomaly detection algorithms, can be leveraged to develop specialised tools for the intelligent discovery of insider threats.

One project conducted to detect insider threats focused on disgruntled employees. These individuals utilise IT infrastructures such as email to execute malicious activities. The events leading up to the attack, triggered by the insider, are often found to be behavioural, rather than technical. One way of observing the behaviour of employees is to investigate their email communications. The problem is that, due to the high volume, velocity and complexity of emails, the risk of insider threats cannot be diminished with the rule-based approaches that are currently available to detect the harmful behaviour of employees. This project aimed to proactively detect fraudulent activities by leveraging the advantages of cybersecurity and big data science.

Another project focused on the use of anomaly detection algorithms to detect insider threats. Data was obtained from a motor vehicle tracking company with approximately 700 000 vehicle tracking devices that report to the company's server infrastructure in near real-time. The data contained information such as location, and accelerometer and engine values. This resulted in large volumes of vehicle tracking data being obtained at a rate of between 1 000 and 4 000 data blocks per second. These volume and velocity characteristics of the real-life vehicle tracking big data were considered to be important aspects of the experimental work reported on in this project. Through machine learning models, the experimental results revealed that anomaly detection is a valid approach to detect insider threats.

The detection of fake identities

Identity deception is a major problem on social media platforms today. Think about cyber threats such as cyber bullying, cyber masquerading and the way sexual predators operate on the internet. In most threats of this kind, users are not honest about their identities. A project to investigate this phenomenon seeks to develop solutions for the detection of fake identities created on social media platforms. Machine learning models developed for this project use attributes and features based on user account details. These attributes and features were extended with concepts borrowed from the field of psychology, such as the fact that humans lie about their age. Newly engineered features, such as gender derived from the profile image, are evaluated to grasp whether these features detect deception with greater accuracy. These machine learning results are applied to a model for the intelligent detection and interpretation of identity deception on social media platforms. This project shows that the cybersecurity threat of identity deception can potentially be minimised if the vulnerability in the current way of setting up user accounts on social media platforms can be re-engineered.

The detection of sexual predators on the internet

Social media chat logs can be used to analyse harmful behaviour as they can be used to detect harmful behaviour, such as paedophilia. This can make an important contribution to the cyber safety of children, preventing them from being exploited by online predators. The challenge is that digital forensic investigators are expected to collect evidence from chat logs, which is a daunting task because of the sheer volume and variety of data. A project to investigate this phenomenon suggests employing a Digital Forensic Process Model that is supported by machine learning methods to facilitate the automatic discovery of harmful conversations in chat logs. It also indicates how the tasks in a digital forensic investigation process can be organised to obtain usable machine learning results when investigating online predators.

Conclusion

There is a clear convergence between cybersecurity, big data and machine learning, and great value can be achieved from this convergence. Cybersecurity is the greatest beneficiary. Big data analysis and big data visualisation are used in various functions of cybersecurity to enable better use of and value extraction from the new big data datasets. These new datasets are a treasure for attackers, and cybersecurity principles can help to protect them. Machine learning is used in various of the listed functions of the Cybersecurity Framework, but the biggest benefit is achieved by improving the different types of detection mechanisms, which can range from insider threat detection to detecting sexual predators on the internet. However, these same techniques and tools are also available to the cyber attackers, who are improving their attacks to make use of new advancements.

Insight into the Millennial mindset: The impact of Industry 4.0 and Society 5.0

Laetitia Lorna Cook

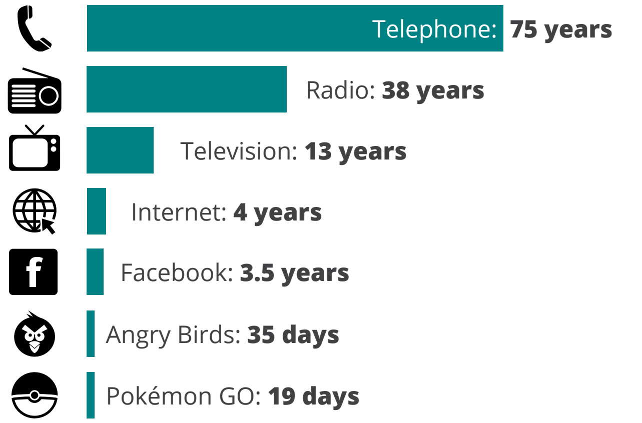
Currently, workplaces in industries across the board are made up of four (or more) unique generations, each comprising people with a unique way of thinking. One such a generation is the Millennials. Industries such as real estate and construction, which are faced with burning issues brought about by the Fourth Industrial Revolution (4IR), could benefit from an understanding of the Millennial mindset.

There is a Millennial saying that goes: "If you've got a wicked problem, you've got to hack it". In the online space, a hacker's intent is not malicious, but rather aimed at resolving complex (or wicked) problems by thinking out of the proverbial box. As a generation, Millennials are more comfortable with this notion than their Baby Boomer or Generation X predecessors. While their predecessors would typically hold strategic planning sessions in boardrooms with committees when faced with urgent and serious challenges, Millennials have hackathons in collaborative working spaces like WeWork. These events comprise a diverse group brought together on an ad-hoc basis to prototype solutions, which are usually technologically based, in order to resolve complex social conditions.

The focus is on implementation rather than over-analysis and prolonged planning. Interacting with disruptive technologies such as artificial intelligence and robotics, blockchain technologies and devices that share data via the Internet of Things (IoT) through seamlessly integrated connectivity (5G) are generally complex to members of the previous generations, and are often perceived as being threatening.

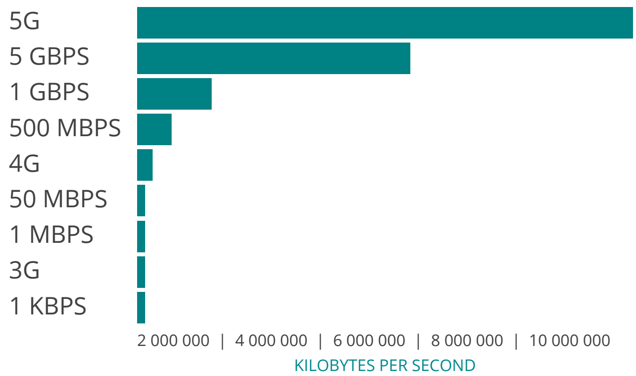
The captains of industry in the real estate environment who hail from these previous generations are also faced with what is known as Society 5.0, in which people's lives are made more comfortable and sustainable by continuously adding value and creating new services in age-old industries.

Carl Benedikt Frey and Michael Osborne of the Oxford Martin School at the University of Oxford, with contributions from Citi Research, examined the future of innovation and employment (Frey and Osborne, 2015). This research, which aimed to explore some of the most pressing global challenges of the 21st century, illustrates the exponential rate at which new technology is adopted by society.



Technology's time to reach 50 million users

One such innovation, the mobile augmented reality game, Pokémon GO, which was released in 2016, took only 19 days to reach 50 million users, compared to Facebook (also a relatively new technology), which took three and a half years to reach as many users. Since then, 5G has materialised, which has made an even greater exponential impact on the speed at which new technologies reach industries.



Exponential increase in speed of connectivity

This affects many professions in the real estate sector, including property developers, property managers, financial and investment managers, customers, tenants, landlords, retailers, project managers, valuers, conveyancers, land surveyors, quantity surveyors, engineers, architects and fund managers.

The rate of change is disruptive as it rapidly alters industries, challenges the status quo and leaves behind old methods and those still attached to them. Once the paradigm shifts, past success is no indication of future success (as illustrated by the nationwide lockdown brought about by COVID-19). Young tech-savvy Millennials from fringe industries are encroaching on the traditional domain of our industries. Mobile is the new norm, and even by 2018, consumers had downloaded no less than 194 billion mobile applications (apps) to their connected devices. This amounts to more than 25 apps per person, had everyone on earth participated.

A recent report, published by Bersin, Deloitte Consulting LLP, considered the future of talent in the world of work that applies to real estate professionals as much as to any other industry. The report presented a list of key disruptors that bring about "unprecedented change", but also huge opportunity (Bersin Insight Team, 2018). Among others, they included the following:

- Technology is everywhere with more than 2.6 billion smartphones in the world.
- A "tsunami of data" is the major enabler of machine learning.
- In the UK, 35% of jobs were vulnerable to automation, while this figure was 47% in the USA and 77% in China.
- Millennials comprise 50% of the world's population. By 2050, 2 5% of the global population will live in Africa. Millennials thus have a "longevity dividend" with a 50-year career span ahead.

WORKING WITH MILLENNIALS

Millennials are indeed the largest generation yet on earth, but also the most educated. They differ significantly from previous generations. Referred to as the "Me Me Me Generation", they are often considered to be entitled, self-centred and even lazy. They spend too much time online and appear narcissistic. But why do older generations perceive Millennials in this manner, and what contributed to these generalised perceptions?

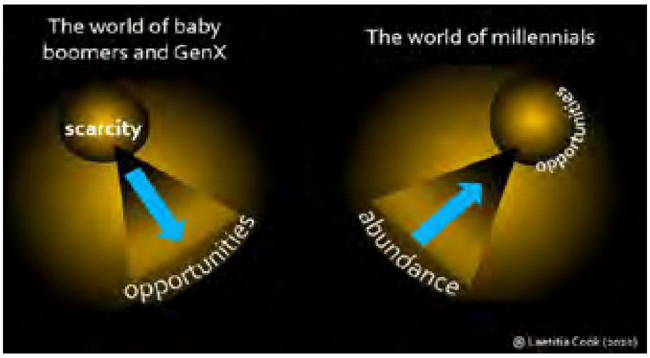
After many years of working with Millennials in several industries, most notably real estate, and experiencing the privilege of lecturing psychology and real estate to this generation, several insights led to the development of a model that might benefit other academics and practitioners. There are two aspects of Millennials and the previous generations that differ fundamentally: the first is their point of departure, and the second is these generations' future perception. The parents of the Baby Boomers and Generation X were born into a world of scarcity, often struggling to make ends meet. A single-car per household was not uncommon. Siblings had to share a room, there were limited choices of accommodation type, retail and consumables, and a set of encyclopaedias was a desired luxury. Yet, a huge world of opportunity awaited them and a good career was almost guaranteed until retirement if they studied hard, saved and postponed gratification by sacrificing what they loved.

To what extent did this benefit them, the Millennial might ask. The effects of this way of life included the heart attack that came before retirement, early retrenchment due to economic, technological or political changes, and spending one's golden years far away from loved ones on other continents. The real world was a rude awakening to many. But for Millennials as well: mollycoddled into believing that anything is possible, and that they will be successful and obtain rewards by simply participating. The dopamine addiction to likes on Facebook, role models like the Kardashians, virtual relationships and a fear of missing out (FOMO) stems, in part, from being born into the exact opposite circumstances to their parents. Theirs is a world of abundance with unlimited access to information, vast arrays of consumables and Google in their pockets. Yet, a future of scarcity awaits them as well.

Harry Kretchmer, writing for the World Economic Forum's COVID Action Platform, states that huge unemployment rates are reported for the second quarter of 2020 as COVID-19 may cost the equivalent of 305 million full-time jobs (Kretchmer, 2020). Disillusioned by leaders and politicians, an inheritance of economic and social problems, environmental disasters, a global recession and refugee crises bear testimony to the legacy of Millennials' well-meaning, hardworking and self-sacrificing parents.

It is therefore not surprising that Millennials, generally speaking, focus on being happy, creating ideas, solving problems (even wicked ones), living (not only working and studying) and doing what they love. The United Nations' World Happiness Report of 2020 agrees, and ranks a sense of community and how people interact with each other above gross domestic product (GDP) per capita. Yet, when it comes to investment, millennials are surprisingly more similar to the depression generation than they are to their parents.

Beth Kobliner, an American personal finance commentator and journalist who acted on the US President's Advisory Council, was interviewed by Forbes Magazine in 2017. She has faith in Millennials when it comes to our future. She explains that the generations who experienced the Great Depression and the Great Recession lived 87 years apart.



Generational opposite points of departure and future vision.

Generationally paradoxical mindsets.

They both endured major economic upheavals that were not of their own making, yet they survived. She remarked that many Millennials have seen what happened to their parents; they have seen what can happen with adjustable mortgages when one cannot make the spiralling monthly payments, and yet she calls them the "Greatest Generation" (Hembree, 2017). Perhaps, in so doing, she provides us with much-needed hope for our longer-term future, as it is largely in their hands.

Millennials are optimistic, confident, and pragmatic, even in the challenging times in which we live. These are not bad qualities at all, given that "... a generation's greatness is determined by how they react to the challenges that befall them. And, just as important, by how we react to them." (Time, 2013). Let us attempt to learn from these brave young minds and start hacking the wicked problems our industry faces, rather than expecting them to simply follow, or learn from us.

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Low-resourced communities benefit from

3D-printed electronic systems

Suzanne Smith
Trudi Joubert

Imagine that a smart and interconnected sensor system can be formed digitally in an economical and environmentally friendly way. Now imagine that it can be done in South Africa, near low-resourced communities who need these products the most. One need not only imagine – the local design and manufacture of smart sensors and wireless sensor networks are precisely the overarching vision of the Integrated Microelectronic Sensor System Research Programme of the Carl and Emily Fuchs Institute for Microelectronics (CEFIM) in the Department of Electrical, Electronic and Computer Engineering.

In the midst of the COVID-19 pandemic, with many people working from home during the nationwide lockdown, there is much discussion about the efficiency of combining two important mitigation measures to curb the uncontrolled spread of the disease. These measures are extensive testing and case tracking, which includes contact tracing.

The work of the CEFIM research group envisages appreciable contributions in this context, including the following:

- The availability of a low-cost platform for smart rapid diagnostic devices that can be produced locally
- The interconnection of tests to provide data that initiates case tracking and may simplify contact tracing

The multiplexed microsensor platform that is under development integrates into low-cost printed microsensor systems using printed electronics and integrated sensor micromanufacturing, pushing the boundaries of current solutions.

Such a platform can impact not only on point-of-care health diagnostic tools, but also environmental point-of-need monitoring devices. Environmental monitoring, including water quality, is critical to the scientific understanding of global change, and such devices and technologies can assist with responding to these changes.

This multidisciplinary research programme aims to position CEFIM towards innovation relevant to the sustainable development of local communities, while maintaining global relevance and excellence. Historically, CEFIM has specialised in the design of novel integrated microelectronic circuits. Its consistent "more than Moore"[1] approach means that it is focused on improving the functionality of microelectronics through the design of innovative and novel devices and structures, rather than merely the brute force implementation of technology.

The recent inclusion of additive manufacturing in CEFIM's work aims to be less wasteful of material resources than traditional subtractive manufacturing, while research is ongoing to use manufacturing materials that have a reduced environmental footprint, contributing to a number of the United Nations' Sustainable Development Goals (SDGs).

Process modelling, analytics and design are important to facilitate technology transfer in this context, in alignment with the global trends of the Fourth Industrial Revolution, machine learning and big data. These design methodologies and modern micromanufacturing technologies are currently being harnessed to realise novel solutions in optical, physical, gas and electrochemical sensor systems.

Important engineering aspects for the platform that is currently being developed are sensor signal transduction and readout, analogue and digital signal processing, algorithmic result extraction, visual or audible results display, data communication and networking, as well as energy harvesting and storage.

[1] Moore's Law refers to the observation that the number of transistors in a dense integrated circuit doubles every two years.

Device integration strategies that best exploit modern additive manufacturing technologies are used. Printed functionality enables different functional components to be printed directly onto a variety of substrates, including low-cost options such as adhesive labels, paper and cardboard. By printing onto flexible substrates, system integration into customisable form factors is a possibility. Key processes include planar printed electronics (inkjet, screen and aerosol jet printing) and 3D printing (filament extrusion and stereolithography). CEFIM's work considers novel materials for custom-printed sensors. The envisaged solution is illustrated below, showing a flexible, thin device with different building blocks that would be required for an automated, intelligent device to be realised.

Envisaged printed functionality solution and various on-board components for point-of-need applications in health, water, wireless communication and climate sciences. Reproduced with permission from The Royal Society of Chemistry.

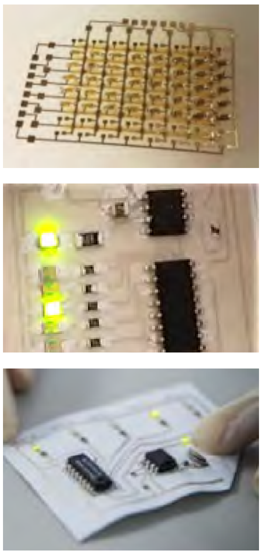
Functional blocks such as sensing, electronics, data processing, connectivity, and readout and display are all components that are currently being explored. These building blocks are important in the development of point-of-need solutions, where ideally low-cost, automated and disposable devices would be needed. This is particularly crucial in resource-limited settings, including clinics and rural villages, where infrastructure is limited. In recent years, there has been a drive to develop low-cost and innovative point-of-need diagnostics to reach resource-limited populations, where the burden of disease is greatest and resources are the least. South African research affords the opportunity to understand first-hand the challenges faced in these settings, and the potential to make a difference where it matters most.

CEFIM's work focuses on novel electronic components and circuits, with the goal of developing custom-integrated circuits and printed electronic devices. Various printed electronic components can be produced by printing single or multiple layers of conductive, resistive, insulating and semi-conductive layers. These include resistors, capacitors, inductors, and even light-emitting structures and transistors. Hybrid printed electronics currently provide feasible implementations, utilising off-the-shelf components and custom-designed integrated circuits. These are then integrated with printed tracks and other printed circuit components to realise flexible solutions on various substrates. Several printed electronic components, circuits, and subsystems have been developed utilising different materials with inkjet and screen-printing processes.

THE MULTIPLEXED MICROSENSOR PLATFORM INTEGRATES INTO LOW-COST PRINTED MICROSENSOR SYSTEMS USING PRINTED ELECTRONICS AND INTEGRATED SENSOR MICRO-MANUFACTURING, PUSHING THE BOUNDARIES OF CURRENT SOLUTIONS.

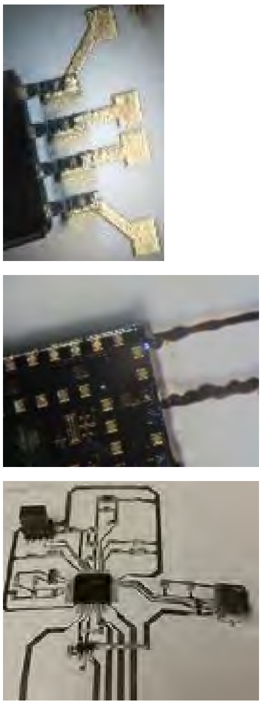
Examples of additively manufactured electronic components and circuits:

READOUT

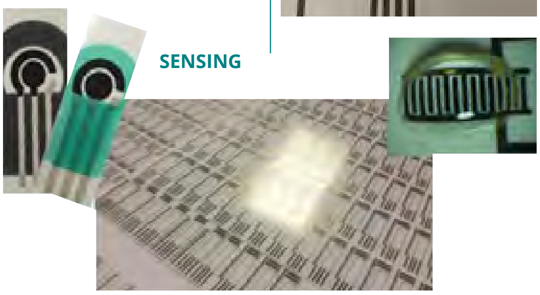


Credit: Trudi Joubert, Suzanne Smith and Petroné Bezuidenhout

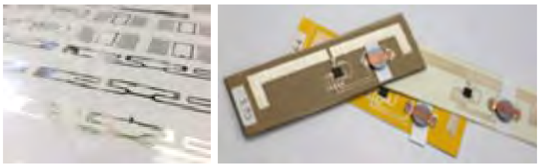
PRINTED HYBRID CIRCUITS



SENSING



WIRELESS COMMUNICATION



EXAMPLE OF APPLICATION

An example of a solution for health applications involves a low-cost, automated wireless reader device, using cardboard packaging to house printed functionality components. This provides a maintenance-free device that can be deployed in clinics, used several times, and then disposed of. The device provides automated result readouts from diagnostic tests, and communicates the results wirelessly to a central database. The device is low in cost, with the long-term goal of being environmentally friendly and able to be mass produced, using existing and modified industry processes for printing and packaging.

Credit: The Royal Society of Chemistry

The specific applications that are currently being explored through various research collaborations include the following:

- Medical diagnostic sensor devices
- Environmental and climate monitoring, for example of water and quality
- Veterinary diagnostic sensors and remote sampling devices
- Sensors for agriculture, farming and conservation
- Energy-harvesting devices to power the additively manufactured devices

The aspiration is to facilitate low-cost and low-volume production technologies that will enhance scientific research and support local manufacturing infrastructure, extending to small-scale industrial enterprises. For the upscaling of additively manufactured devices, it will be crucial to work with local companies to pave the way for production and the deployment of intelligent printed devices across Africa. Collaborations have already been established with companies to assist with printing and packaging, as well as the pick-and-place of electronic components onto flexible substrates.

Discussions with local companies in areas of wireless communication and printed touch pads and circuitry have also been fruitful. The goal is to maintain and strengthen these networks with industry to establish a pipeline for the development and production of additively manufactured electronic devices and solutions for the future. This work has the potential to make a globally relevant and unique impact in Africa, and by establishing the infrastructure, equipment and expertise required to develop these solutions in South Africa, unique local solutions can be developed for local challenges.

The digital project manager: Resetting the way we work

Dr Giel Bekker

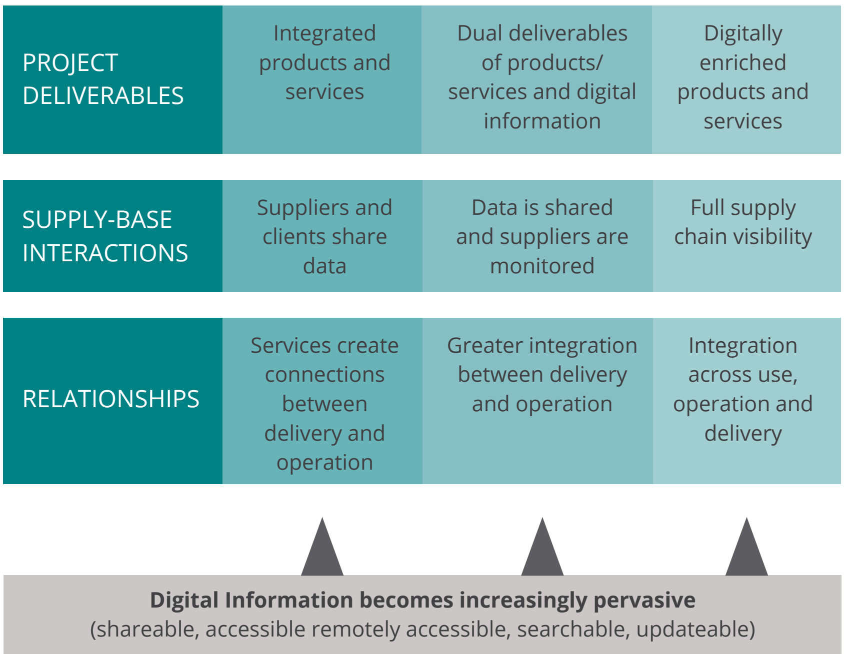
Recent work disruptions due to COVID-19 have necessitated the accelerated adoption of digital technologies as project management tools and methods.

A project manager is considered to be one of the most stressful occupations in engineering and technology management. Projects are energy-intensive, time-constrained and high-pressure endeavours. They bring together visions, business ideas, plans, drawings, materials, equipment, tools, human resources, infrastructure, logistics, as well as health and safety, to achieve the accomplishment of a final product. However, what projects deliver is changing. They are no longer just a physical product or service; they now also include a digital component.

Having started with mainframe scheduling in the 1960s, the evolution of computer applications accelerated in the 1980s when computer-aided design software emerged and expert systems became available on personal computers. With the exponential development of digital technology, project delivery models now incorporate supply chains, principal-agent relationships, as well as end-user and operator interaction. Extensive documentation has, to a large extent, been replaced by automated digital workflows and analytics, creating their own integrated ecosystem.

Project integration remains one of the most important and complex aspects of project management. Creating, maintaining and controlling the infamous "golden thread" of integration, from design to finance, implementation, operation and maintenance, remain a challenge. In the large capital project environment, the development of built information modelling (BIM) largely contributed to the integration and further enhancement of modularisation, providing projects with scaling capabilities.

The digital backbone and predesigned ecosystem make the underlying information searchable, remotely accessible, shareable and updatable across the project life-cycle. Jennifer Whyte, in an article published in *Project Management Journal* on how digital information transforms project delivery models (Whyte, 2019), refers to this digital evolution as being pervasive and migrating towards complete integration.



Integration solutions are made possible by increasingly pervasive digital information

Even though BIM is used at high levels of sophistication during the design phases, the use of this and related digital technologies has not come to fruition during the construction phases. Construction is not for the faint hearted, and those involved know what it is to work in dusty conditions and cramped on-site offices, being exposed to the rain and blistering sunshine every day, on the lookout for dangers caused by large equipment, material lifted high above one's head and many obstacles that may cause one to trip or bump one's head. It is also the phase where the most money is spent.

Over recent decades, the construction phase of large capital projects has seen minimal improvement. The reasons for the slow adoption of digital technology in construction can be attributed to, among other things, poor internet coverage at remote locations, design changes during construction, established systems and procedures, compliance requirements and some prevailing old-school habits of seasoned construction workers and foremen. With an industry under pressure, the "traditional" way of construction project management is changing to increasingly embrace digitisation to become more productive and fully integrated across the project life-cycle.

Over the past two years, more than 1 500 construction technology start-up companies have been formed to develop application solutions for the industry. The software and digital tools that these companies develop can be clustered according to the various management functions of construction, which include the following:

- Design management: The real-time availability of the latest drawings and on-field capturing of mark-ups
- Scheduling: Improved 4D capabilities and real-time progress tracking through infrared and drone applications
- Materials management: Real-time sensors and detectors that monitor the delivery and movement of materials
- Fieldwork: The real-time monitoring of crew movement and deployment
- Quality control: Mobile applications for snag lists and the immediate notification of non-compliances and defects to the respective responsible people
- Contract management: Updating and tracking contract compliance, records of communication and the management of payments
- Safety: Real-time safety monitoring and immediate alerts in the case of incidents
- Collaboration and coordination

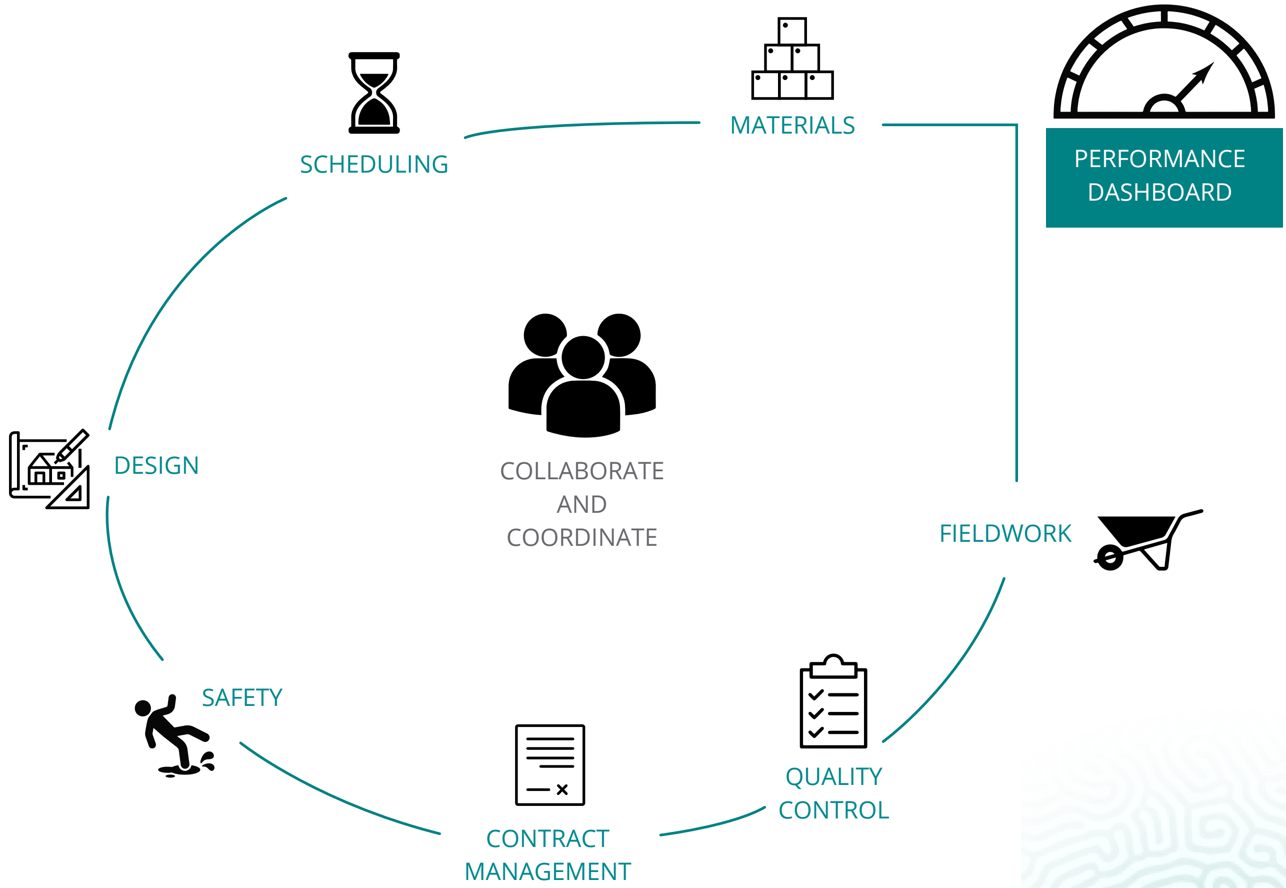
Until the beginning of 2020, all the abovementioned functions, with the exception of the last one, were digitised, but not yet fully managed in an integrated manner.

Over the past two years, more than 1 500 construction technology start-up companies have been formed to develop application solutions for the industry.

During the national lockdown brought about by the COVID-19 lockdown, collaboration and coordination were suddenly forced to go online with various platforms, such as Zoom, Microsoft Teams, Webex, Skype and GoToMeeting, being used extensively on project work with great success. Even though not yet quantified, reports indicate an improvement in project productivity and an increase in overall integration.

WITH THE EXPONENTIAL DEVELOPMENT OF DIGITAL TECHNOLOGY, PROJECT DELIVERY MODELS NOW INCORPORATE SUPPLY CHAINS, PRINCIPAL-AGENT RELATIONSHIPS, AS WELL AS END-USER AND OPERATOR INTERACTION. PROJECT INTEGRATION REMAINS ONE OF THE MOST IMPORTANT AND COMPLEX ASPECTS OF PROJECT MANAGEMENT.

Project management functions presented on a digital performance dashboard.



Performance dashboards have become more than a monthly status report, and are now almost a real-time reflection of the project at any given time.

With many applications to be deployed and refined in the near future, the challenge for the project manager will be to confront traditional work methods in a new digitised environment. The era of the digital project manager has dawned and this individual will be faced with the renewed challenge of digital collaboration and coordination.

Collaboration and coordination are key to any project, but if project managers want to get the most out of these digital tools, they will need to understand their own and other peoples' behaviour. Irrespective of which, or how many digital tools are deployed, people will remain central to achieving project outcomes and benefits.

Even though not yet quantified, reports indicate an improvement in project productivity and an increase in overall integration resulting from online collaboration and coordination platforms.

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The role of materials science in digital manufacturing

Hein Möller

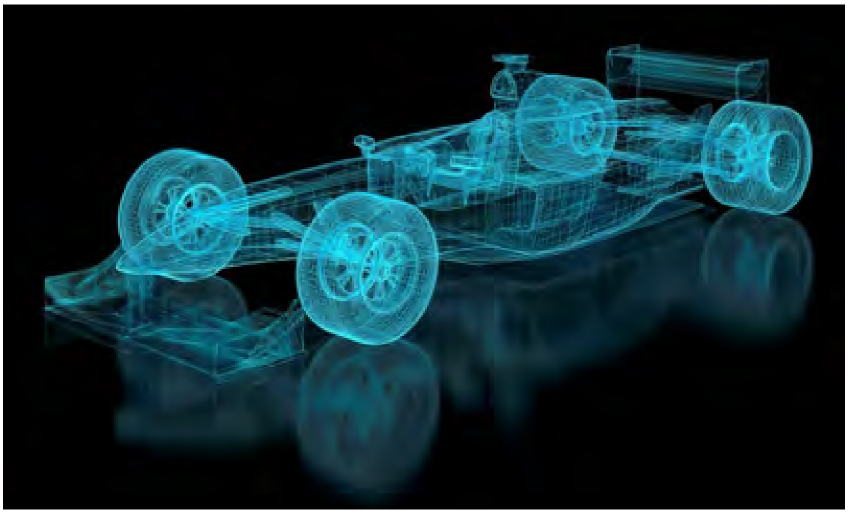
Materials have played a significant role throughout human history. In fact, our history has been defined by the materials that our ancestors have used in the past. The Stone Age was followed by the Bronze Age (characterised by an alloy or mixture of copper and tin), which was followed by the Iron Age.

More recently, materials have, in many cases, been the determining factor in the development of new technologies. The selection of the wrong material for a specific application has led to many failures. For example, the steel rivets that were used to join the plates of the "unsinkable" Titanic were almost as brittle as glass in the freezing waters of the Atlantic Ocean, where the ship hit an iceberg. Unfortunately, the materials scientists and metallurgical engineers at the time were unaware of this fact.

Currently we live in a period known as the Fourth Industrial Revolution (4IR). The 4IR can be described as a fusion of technologies that are blurring the lines between the physical, digital and biological worlds, collectively referred to as cyber-physical systems. In general, the 4IR is based on nine pillars: autonomous robots, simulation, system integration, the Internet of Things (IoT), cybersecurity, cloud computing, augmented reality, big data and additive manufacturing.

Materials science plays a crucial role in the advancement of the 4IR, especially in manufacturing. Digital manufacturing uses digital technology in the manufacturing process. It integrates having the necessary data at the correct place at the right time. Additive manufacturing is the industrial production name for 3D printing. It is a computer-controlled process that creates three-dimensional objects by depositing materials layer by layer. It uses computer-aided design and allows for the creation of objects with precise and complex geometric shapes.

Additive manufacturing is the opposite of traditional manufacturing, which often requires machining or other techniques to remove surplus material (subtractive manufacturing). At the moment, the materials that are used for additive manufacturing are mostly based on materials that have been developed for traditional subtractive manufacturing methods.



Materials have, in many cases, been the determining factor in the development of new technologies. Materials science plays a crucial role in the advancement of the 4IR, especially in manufacturing.

These materials are not necessarily the best choices for additive manufacturing, and it is up to materials scientists and metallurgical engineers to develop new materials that are best suited to the demands of digital manufacturing. Such new materials can create exciting new opportunities to develop products with properties that could otherwise not be achieved.

An example of such a new material is Scalmalloy®, an aluminium-magnesium-scandium powder alloy that was specifically designed for metal additive manufacturing. The alloy was developed by the German-based company APWorks and Airbus for aerospace applications. In July 2020, the governing body of Formula 1® added Scalmalloy® as an officially approved additive manufacturing material for use in the international racing car championship. According to the Swedish metal additive manufacturing company Freemelt®, "the metal 3D printing revolution is a materials game". Its 3D printer has specifically been designed to make materials that are not yet known to mankind.

The development of new materials is not limited to metals and alloys. Materials scientists are also conducting research on developing new polymer, ceramic and composite materials. For example, Markforged®, a 3D printer manufacturer, has recently announced the availability of a new flame-retardant composite material. The Onyx FR composite material is nylon with chopped carbon fibres. The main property of this material is its self-extinguishing capabilities, allowing it to prevent itself from burning. This sets it apart from traditional 3D printing thermoplastics and opens up more applications for 3D printing across automotive, aerospace and defence industries because it meets higher fire safety standards.

Greg Satell, who was named by the International Data Group (IDG) as one of the ten digital transformation influencers to follow today, wrote an opinion piece in December 2018 explaining why materials science may be the most important technology of the next decade. Traditionally, developing new materials has been a time-consuming and expensive process. To find the desired material properties, materials scientists and metallurgical engineers would sometimes have to test many materials one by one. Now, powerful simulation techniques, as well as sophisticated machine learning algorithms, are being used to develop new materials much more rapidly, and assist with possibilities that had never been considered before. Companies who are working in this field include Questek® and Alloyed®.

It is therefore clear that materials science is a technology that will shape the future of humankind. It will influence the progress of digital manufacturing and will be a necessity for the 4IR. Materials scientists and metallurgical engineers have a crucial role to play and are ensured of exciting and relevant careers.

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Expanding the University's

mining footprint

Prof Ronny Webber-Youngman

The University of Pretoria participates in the global mining arena through its transdisciplinary approach to research and innovation. Multiple research initiatives related to mining and minerals engineering are being conducted across various faculties and departments. The conducive environment that has been established for such transdisciplinary research at the University has led to the development of a mining footprint that examines various overlapping aspects of mining from different perspectives.

The quality of the University's research in this field was recognised internationally through its ranking in the Academic Ranking of World Universities (ARWU) in the top 100 universities in the world for mining and minerals engineering for 2019. This is not only based on the large volume of research on various aspects of mining and minerals engineering being conducted at UP, but also the quality of education, quality of researchers, research output and per capita academic performance of the institution.

The collective of these research efforts has a significant impact on the University's international rankings, as well as the visibility of the University's mining footprint. A key priority of the Department of Mining Engineering is to showcase the University's vast research in this field. This strategic intervention is aimed at integrating research emanating from the University's various faculties and departments that is related in some way or other to mining. The amplification of mining-related research in other faculties and departments also enhances mining as a career of choice.

Transdisciplinary research focuses, among others, on aspects such as society, health, the environment, the economy, engineering and technology. As such, it is in direct support of the Sustainable Development Goals (SDGs) of the United Nations. These universal goals emphasise that minerals are needed for modern societies. Furthermore, it takes cognisance of the fact that the dominant method for extracting minerals is still mining.

Within the Department, collaborative and cross-cutting contract research initiatives are coordinated and facilitated by the Mining Resilience Research Centre (MRRC). This research centre draws on the multidisciplinary resources within the University, matching the right skills sets to any mining problem.

Research that directly affects the minerals life cycle is conducted in the University's Minerals Cluster departments. This research includes the study of geological structures in the Department of Geology, the extraction of minerals in the Department of Mining Engineering and the processing of minerals in the Department of Materials Science and Metallurgical Engineering.

TRANSDISCIPLINARY MINING RESEARCH FOCUSES, AMONG OTHERS, ON ASPECTS SUCH AS SOCIETY, HEALTH, THE ENVIRONMENT, THE ECONOMY, ENGINEERING AND TECHNOLOGY.

The UP Minerals Cluster departments in synergy

INTERDISCIPLINARY RESEARCH

Research related to mining is conducted in almost all of the University's nine faculties, as well as in each of the four schools in the Faculty of Engineering, Built Environment and Information Technology. A selection of these research projects includes the following

Chemical Engineering

- Green time-delay chemical detonators
- The use of drones to study the extent of air pollution at open-cast mines
- The rehabilitation of polluted soil at mining sites
- The treatment of acid mine water
- Environmental engineering and water utilisation engineering research

Civil Engineering

- Mining haul road research
- Road design for driverless trucks
- In-pit crushing and conveying in an open-pit mining operation
- Advanced theory of multiple cells in a plastic geocell support pack

Materials Science and Metallurgical Engineering

- Minerals and Mining Law research projects
- Forensic engineering that impacts on mine health and safety incident investigation research

Mechanical and Aeronautical Engineering

- Collision management systems for mines to prevent accidents
- Energy and convectional heat transfer with applications in the mining industry

Mining Engineering

- An evaluation of a hydraulic splitting cylinder for breaking rock in deep-level mining
- An integrated problem-solving framework for discipline-specific professional development in mining engineering
- Some rock engineering aspects of multi-reef pillar extraction
- A limited equilibrium fracture zone model to investigate seismicity in coal mines
- Rockburst support in shallow-dipping tabular stopes at great depth
- Simulation of tabular mine face advance rates using a simplified fracture zone module
- Optimisation of the load-and-haul operation at an open-cast colliery

Technology Management

- The adoption of technology management tools in the coal-mining sector
- The use of maintenance technologies in the South African mining industry
- Exploring the appropriate leadership style balance for critical phases of a business process framework implementation in the South African coal-mining industry
- Enhancing the effectiveness and impact of digitisation in open-cast mining operations

Geology

- Remote sensing of magnetite for exploration
- Characterisation of contact metamorphosed and altered coal for utilisation
- Potential groundwater hazards related to coal mining and coal dumps
- Open-pit rock slope stability
- The assessment of seismic risk and hazards for tailing dams and other mine facilities

The Department's researchers are also focusing on a number of research topics that are pertinent to the sustainability of the mining industry, such as mechanisation and automation, mine design, rock engineering, rock-breaking and explosives engineering, and management and leadership.

Through the collaborative research being conducted on topics related to mining, the University can contribute solutions to complex industry-related mining problems, both locally and internationally.

Examining underground utilities with ground-penetrating radar

Louis Germishuys
Chris Cloete

Unintended damage to subsurface utilities during construction excavation is a major cause of disruption in electricity supply, telecommunications, water supply and other essential public services. Utility strikes are also a leading cause of hazardous liquid and natural gas accidents and cost billions of dollars each year. Research conducted in the Department of Construction Economics investigated the feasibility of using ground-penetrating radar to examine underground utilities.

Several non-destructive technologies are available for the examination of underground services. However, ground-penetrating radar is currently the preferred method. Ground-penetrating radar can detect non-metallic objects, which is its key advantage over other non-destructive technologies. The depth of utilities can be estimated using processing methods such as wave-speed estimation. Ground-penetrating radar has a higher resolution than other non-destructive technologies. The integration of ground-penetrating radar and global positioning system (GPS) technology ensures a high accuracy level in locating subsurface utilities in three dimensions.

Ground-penetrating radar is a geophysical instrument with a diverse range of applications. It has been widely used in locating underground services due to its advantages, such as fast data acquisition, cost efficiency when mapping large areas and high-resolution imagery for improved interpretation. However, the accuracy of subsurface mapping using ground-penetrating radar has often been overlooked due to a lack of understanding of the physical basis on which it operates, a lack of a standard methodology for data collection and a lack of reliable accuracy assessments.

Ground-penetrating radar is used to “see through” the ground, either to establish the structure of the soil or to find buried objects such as utilities made of metal, plastic or concrete. The variables of importance in using this technology are primarily the electromagnetic soil properties of relative permitivity, electrical conductivity and magnetic permeability, which affect how electromagnetic waves propagate and reflect in the subsurface. The aforementioned electromagnetic variables are influenced by the physical soil properties, such as saturation, mineralogy, porosity and soil texture.

The effectiveness of ground-penetrating radar was therefore tested under three different soil textures. Grain size is classified as clay if the particle diameter is less than 0.002 mm, as silt if it is between 0.002 and 0.06 mm, and as sand if it is between 0.06 and 2 mm. Soil texture refers to the relative proportions of clay, silt and sand particle sizes, irrespective of the mineralogical or chemical composition of the material.

The purpose of this study was not to quantify the impact or accurately define the relevant soil characteristics, but rather to prove that an impact exists, and to illustrate the practical problems associated with ground-penetrating radar when operating under different soil conditions.

TESTING APPROACH

Hydrometer analysis was used as the main method to determine soil particle size and, ultimately, soil texture. Sieve analysis results were used to examine the particle size distribution of larger grained material, and to distinguish soil from gravel. The laboratory tests do not reveal data for the soil in isolation, but rather provide results for the entire sample tested. Since the aim was to prove that soil conditions have an impact on the performance of ground-penetrating radar, the soil portion was isolated from the entire sample by only considering particle sizes less than 2 mm. The gravel portion of each sample was therefore excluded. The relative proportions of clay, silt and sand were then expressed as a percentage of the soil portion of the total sample. These percentages were then used to classify the soil texture in terms of the soil texture triangle of the United States Department of Agriculture (USDA).

The Leica DS-2000 utility detection radar device was used for the ground-penetrating radar testing. This device transmits two different electromagnetic waves (250 and 700 MHz). The higher-frequency electromagnetic waves allow for better resolution in detecting shallower objects. The lower-frequency electromagnetic waves allow for deeper penetration, but the imaging resolution is notably lower for ground-penetrating radar testing equipment.

The equipment was tested at three testing sites: the Montecasino Office Precinct, the Sandton Gate Development and the Rustenburg Effluent Treatment Plant.

The purpose of this study was not to quantify the impact or accurately define the relevant soil characteristics, but rather to prove that an impact exists, and to illustrate the practical problems associated with ground-penetrating radar when operating under different soil conditions.

RESULTS

- Montecasino Office Precinct: This site is situated in Magaliessig Extension 64, Johannesburg. The soil texture was classified as sandy loam according to the USDA's soil texture triangle. Ground-penetrating radar was effective under this soil texture, with accurate depth measurements. The response of the ground-penetrating radar was different, and better than that obtained at the other two test sites.
- Sandton Gate Development: This site is situated in Glenadrienne, Sandton, Johannesburg. The soil texture was classified as clay loam according to the USDA's soil texture triangle. Ground-penetrating radar was reasonably effective under this soil texture. However, the radar depth measurements were inaccurate and constantly shallower than the actual depths measured after exposing the services. The response of the ground-penetrating radar differed from that obtained at the other two test sites. The performance of the radar was not as good as at the first site, but better than at the third site.
- Rustenburg Effluent Treatment Plant: This site is situated on Brons Street, Rustenburg. The soil texture was classified as clay according to the USDA's soil texture triangle. Ground-penetrating radar was totally ineffective under this soil texture, and failed to detect any services. The device used was unable to detect a 75 mm-diameter PVC pipe installed as shallow as 345 mm below the natural ground level. The response of the ground-penetrating radar differed from that obtained at the other two sites, and was of no use.

Conclusions

It could be concluded that ground-penetrating radar performs well under sandy loam conditions with accurate depth measurements. Ground-penetrating radar was reasonably effective under clay loam soil. However, depth measurements were inaccurate. Ground-penetrating radar was ineffective under clay soil conditions. It was proven that different soil textures have an impact on the response of the ground-penetrating radar. It could also tentatively be concluded that the response of the ground-penetrating radar weakens as the size of the soil particle decreases.

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UP academic develops a new theory that will change our understanding of the universe

A new multidisciplinary scientific theory that may hold the key to understanding the secrets of the early universe is the outcome of 12 years of research by Prof Mohsen Sharifpur, an associate professor in the Department of Mechanical and Aeronautical Engineering. This theory also provides a perspective of the future of our universe.

One of the questions he has been tackling relates to the origins of the dark energy that causes galaxies to accelerate. He believes that none of the existing theories on the origin of the universe have been able to adequately answer this question. His theory, known as the Source and Sink Theory, is rooted in his desire to find answers to unanswered questions. By applying a multidisciplinary research approach, he believes that his theory may be able to answer these questions.

Based on his studies, he has found that – in nature – everything occurs in binary or opposite pairs, such as male and female, electrons and positrons, bipolar magnetic poles, matter and anti-matter. If there is a hot object, the heat will transfer to a cooler object by natural convection. These and other pieces of evidence could be samples of universal patterns, which help us to propose a new theory for the origin of the very early universe. Therefore, if we follow these patterns that are present in nature, and if a "Big Bang" did indeed result in the existence of the universe, we need to ask ourselves what its opposite partner is.

IN NATURE, EVERYTHING FOLLOWS A PATTERN, LIKE THE FLUID FLOW PATTERN IN FLUID MECHANICS. THE SAME IS TRUE FOR THE THEORETICAL BASES OF FLUID DYNAMICS, CONSTRUCTAL LAW AND PATTERNS IN NATURE LIKE THE FIBONACCI SEQUENCE AND FRACTAL GEOMETRY, BUT WHAT WE KNOW OF THESE FIELDS SEPARATELY IS NOT ENOUGH TO ANSWER SOME OF THE MOST PRESSING QUESTIONS OF THE UNIVERSE. PROF SHARIFPUR BELIEVES THAT THE ANSWERS TO THESE QUESTIONS MAY STEM FROM A UNIVERSAL LAW IN FLUID DYNAMICS, WHICH HAS APPLICATIONS IN COSMOLOGY.

In terms of his theory, if there is a source (of energy like the "Big Bang"), there must be at least one sink (to receive energy from the source) with a flow-like pattern from the source to the sink – and the energy in this process must be conserved. In general, sources and sinks are part of the science of fluid mechanics, as well as electronics. To apply this theory to cosmology, a source could emit energy and/or material, and a sink could receive energy and/or material by its gravity (curvature of space-time). Consequently, Prof Sharifpur believes that the energy that created our universe (the "Big Bang") must have been the pulse of a point source with its unique cosmic background radiation that flows towards a sink (or sinks). The cosmic microwave background radiation could also support this theory, just as it did the "Hot Big Bang" model.

Prof Sharifpur posits that everything in our galaxy moves like a pattern of fluid flow, from the earth to the solar system, and whatever we have been able to observe in our universe. The human body does this, plants do it as they grow, so do grain patterns, tornados, and the continents as they split. This phenomenon is also observed in the patterns of the earth's magnetic field and in being shielded from geomagnetic storms, the paths of the stars, stellar remnants and interstellar gas and dust around galaxies. If we therefore extend these patterns to the beginning of the universe (the pulse of a point source according to his theory), we can build a general theory of what happened there, and predict what could happen in the future.

A source could emit energy and/or material, and a sink could receive energy and/or material by its gravity. Consequently, the energy that created our universe (the "Big Bang") must have been the pulse of a point source with its unique cosmic background radiation that flows towards a sink (or sinks).

If our universe originated as a point source, which produces pulses of energy, at the same instant, there must have been at least one sink where the pulse moved towards the sink, like a fluid flow pattern. We can consider a Black Hole as a kind of sink, although many cosmologists believe that black holes were formed after the "Big Bang", and were not available at the instant of the "Big Bang" to produce the flow direction. However, according to Prof Sharifpur, known black holes at the centre of galaxies could be part of a moving pulse of our universe's point source and of the galaxy's acceleration into a sink.

Prof Sharifpur believes that applying his multidisciplinary Source and Sink Theory mathematically can offer an answer to each unanswered question. Using his new theory, it is possible to provide many different scenarios for the arrangement of the point source and sinks. Even a simple homogeneous spherical sink surrounding a point source can answer the unanswered questions of our universe.

In this way, dark energy is the resultant gravity vector of the sink, which acts on different parts of the pulse of the point source like galaxies (with a possible pattern like a fluid flow), which causes the acceleration of the galaxies. While the galaxies go to the sink (from all directions), the so-called expansion of the universe happens.

Prof Sharifpur says that some of the key differences between his theory and the standard Big Bang Theory are that the "Big Bang" only works in the field of cosmology, whereas his Source and Sink Theory is a multidisciplinary theory that has multiple applications, one of which is in cosmology to help understand the early universe. Dark energy and dark matter cannot be explained by the Big Bang Theory, whereas the origin of dark energy is easily explained using the Source and Sink Theory.

EVERYTHING IN OUR GALAXY MOVES LIKE A PATTERN OF FLUID FLOW, FROM THE EARTH TO THE SOLAR SYSTEM, AND WHATEVER WE HAVE BEEN ABLE TO OBSERVE IN OUR UNIVERSE. THE HUMAN BODY DOES THIS, PLANTS DO IT AS THEY GROW, SO DO GRAIN PATTERNS, TORNADOS, AND THE CONTINENTS AS THEY SPLIT. THIS PHENOMENON IS ALSO OBSERVED IN THE PATTERNS OF THE EARTH'S MAGNETIC FIELD AND IN BEING SHIELDED FROM GEOMAGNETIC STORMS, THE PATHS OF THE STARS, STELLAR REMNANTS AND INTERSTELLAR GAS AND DUST AROUND GALAXIES.

The Big Bang Theory is just about the point where it all started, but offers no idea as to where the galaxies are going or what their origins are, whereas the Source and Sink Theory provides an explanation of the universe before the "Big Bang" as a pulse of energy. The Source and Sink Theory suggests a point that is the source of the universe, which the Big Bang Theory does not.

This theory proposes the origins of dark energy, which the Big Bang Theory cannot explain, although it can observe the acceleration and expansion of the galaxies. The Source and Sink Theory, on the other hand, can predict and explain the acceleration and expansion of the galaxies. It can predict that this acceleration will gain even more speed because when the pulse goes to the sink, the equivalent gravity vector that acts on galaxies increases. While the Big Bang Theory supports cosmic microwave background radiation, it cannot explain why it is not exactly homogenous all around the universe, which the Source and Sink Theory can.

To explain how the Source and Sink Theory helps our understanding of the early universe, Prof Sharifpur likens it to being a superior or overarching theory of the origin of the universe. One of the scenarios of the Source and Sink Theory could be the Big Bang Theory (when the gravity of the sink is set to zero).

For Prof Sharifpur, the answers to the origin of the early universe, described in his Source and Sink Theory, are clearly based in science. He believes that the Big Bang Theory is based in philosophy. "It is an idea, not a provable fact," he says. Most of the scientists who have accepted the Big Bang Theory believe that there was nothing before the "Big Bang". However, the Source and Sink Theory offers a scientific explanation that there must have been at least one source and at least one sink available in the early universe, which allowed an energy transfer between them.

Another point of contention, according to Prof Sharifpur, is that the Big Bang Theory needs Inflation Theory to explain the size of the available universe, with the speed of the expansion being more than the speed of light after the "Big Bang". The Source and Sink Theory, in contrast, does not need Inflation Theory to explain the size of the universe, as it fully accounts for the fact that there must have been a kind of space between the source and the sink from the beginning.

The theories of Einstein and others like Alexander Friedmann and Alan Guth all have some basis in fact, and all have evidence to support them, just like the Source and Sink Theory. However, for Prof Sharifpur, who has spent more than a decade working on this theory, this is only the beginning. Much more research needs to be done by applying this theory and its mathematical models to countless other scenarios. He believes that this requires the help of scientists to consider this theory and work on developing it further.

Prof Sharifpur relishes the impact that his research has had on our understanding of the early universe and the meaning behind it all. His Source and Sink Theory offers a remarkable starting point to answer what lies behind and at the beginning of all the mysteries of the universe.

He published a research article on his theory in the *Journal of Theoretical Physics* in March 2020. He believes his theory has not received the attention it deserves, possibly because the COVID-19 pandemic has been receiving so much attention around the world, or because the scientific community is not yet ready for a new theory in this area.

Fact or fiction:
Do battery electric vehicles really save costs?

David Walwyn

The global automobile market is changing. Purchases of new cars equipped with an internal combustion engine are declining, and the major car manufacturers are jostling for a share in the new market for battery electric vehicles. Many manufacturers, including Tesla, have already launched battery electric vehicles, and it is projected that, by 2030, 45% of new car sales will be those of battery electric vehicles. A study conducted in the Graduate School of Technology Management (GSTM) compared the advantages and disadvantages from a techno-economic point of view.

The transition from the internal combustion engine to a battery-operated vehicle is driven by rising concerns over poor air quality, carbon dioxide emissions and the falling costs of electricity generation based on renewable energy technologies. Street traffic, consisting mainly of passenger vehicles, accounts for about 18% of global carbon emissions, according to the United States Environmental Protection Agency (USEPA), and the decarbonisation of the present global fleet of more than 650 million automobiles is an important priority if the goals of the 2015 United Nations Climate Change Conference are to be realised. Furthermore, high levels of pollution due to the use of internal combustion engines are estimated to cause the loss of about four million life-years per year.

To date, battery electric vehicles have been more expensive to purchase than internal combustion engines and only marginally less expensive to maintain. However, these ownership economics are changing. The real price and operating costs of battery electric vehicles are falling, as is the associated environmental impact. Consumers now face a more equitable set of choices, the evaluation of which requires a rather daunting set of financial calculations.

To date, battery electric vehicles have been more expensive to purchase than internal combustion engines and only marginally less expensive to maintain. However, these ownership economics are changing.

THE INPUT ASSUMPTIONS

There are multiple options in the purchase of a car, including manufacturer, model, maintenance contracts, and age of the vehicle. A recent compilation for the USA by the Office of Energy Efficiency and Renewable Energy's Vehicle Technologies lists 67 passenger battery electric vehicle models, covering a range of engine sizes, battery capacities and transmissions. Moreover, there are many thousands of internal combustion engines from which consumers can choose.

Apart from the choice of the car itself, there are endless options available to the consumer in terms of how the car will be used (distance travelled), where it will be used and how it is refuelled. It is assumed that the average distance travelled per year will be 15 000 km, that the car will be purchased under a financing scheme with a nominal interest rate of 10.75% (equivalent to 5.5% in real terms) and that the car's costs will be evaluated over 10 years. No maintenance plan has been included; maintenance costs will be incurred annually as indicated in Table 1. Finally, the exchange rate is assumed to be R18.66 per US$ and the calorific value is assumed to be 31.6 MJ per litre of petrol.

The values for carbon emissions and energy return on energy invested depend on the assumptions for the source of electrical power. In this model, three scenarios for electricity supply have been included: Eskom power, which is assumed to be exclusively coal-derived, direct supply from an independent power producer using onshore wind technology, and own supply using rooftop solar and a dedicated charging station.

Table 1: Comparison of the input specifications for the internal combustion engine and a battery electric vehicle[1]

SPECIFICATION	CHEVROLET SPARK (INTERNAL COMBUSTION ENGINE)	CHEVROLET BOLT (BATTERY ELECTRIC VEHICLE)
Engine size	1.4 litre	160 kW
Fuel economy	7.2 litres e/100 km	2.0
Car size	Four-door hatchback 	Four-door hatchback 
Price	$17 500	$36 200
Maintenance cost (per year for ten years)	$1,140	$856

Table 2: Input specifications for primary energy source[2]

	INTERNAL COMBUSTION ENGINE (CRUDE OIL)	BATTERY ELECTRIC VEHICLE (COAL)	BATTERY ELECTRIC VEHICLE (UTILITY WIND)	BATTERY ELECTRIC VEHICLE (ROOFTOP SOLAR WITH STORAGE)
Energy efficiency primary source to wheels	77%	27%	82%	82%
Fuel cost	R13.76/litre	R1.50/kWh	R0.80/kWh	R3.33/kWh
CO_2 emissions	74.0	264	19.4	20.0

ECONOMICS EVALUATION

An economic evaluation of options can be undertaken using the annual worth approach, which uses the annualised value of the capital charges together with the annual maintenance and operational costs, or using the levelised cost of transport.

The latter is based on the levelised cost-of-energy methodology, which is widely used and reported in the literature. Both approaches give the same result, except in the case of inflation, where it is easier to work in real rather than nominal values.

Table 3: Results of the analysis[3]

	INTERNAL COMBUSTION ENGINE (CRUDE OIL)	BATTERY ELECTRIC VEHICLE (COAL)	BATTERY ELECTRIC VEHICLE (UTILITY WIND)	BATTERY ELECTRIC VEHICLE (ROOFTOP SOLAR WITH STORAGE)
Annual fuel cost (2020 R)	R14 861	R3 488	R1 860	R7 742
Annual worth (2020 R)	R79 414	R108 991	R107 363	R113 245
Levelised cost of transport (2020 R/km)	R5.29	R7.27	R7.16	R7.55
Energy input	296 MJ	206 MJ	68 MJ	68 MJ
Energy returned on energy invested	15%	22%	66%	66%
CO_2 emissions (kg/100 km)	218.83	544.39	13.23	13.61
CO_2 emissions (kg/year)	32 824	81 659	1 985	2 041
Multiple-criteria decision-making result	52.2%	39.7%	59.8%	57.3%

1 **Source:** www.consumerreports.org/cars/compare/?cars=10359&cars=10597

2 & 3 **Source:** McKinsey (2010), Helmers and Marx (2012)

It is clear that the high capital cost of battery electric vehicles overwhelms any savings on fuel or maintenance costs that will be realised during the operation of the vehicle. Based on straight economic considerations, battery electric vehicles are 35% more expensive per kilometre travelled than the equivalent internal combustion engine. This disparity has led several countries to introduce market incentives to accelerate the adoption of battery electric vehicles and mitigate the impact of fossil fuel-based alternatives on air quality.

It is predicted that the cost difference will reduce over time, and that, in the United Kingdom, battery electric vehicles will become cheaper than internal combustion engines by 2024, perhaps even sooner, should the present government grant of £3 500 be retained. The levelised cost of transport for battery electric vehicles will decline as volumes of cars increase and the product moves down the learning curve, as has been experienced in other products, including photovoltaic cells and wind turbines.

As may be expected, the carbon emissions for battery electric vehicles, where electrical power is derived from a renewable resource, is 6% that of the internal combustion engine. However, battery electric vehicles that are recharged using power obtained from coal release an equivalent of 2.5 times the mass of CO_2 relative to the internal combustion engine, making this an unattractive option from the perspective of environmental impact.

The most attractive option for the purchase of a new vehicle would be a battery electric vehicle with power purchased directly from a wind utility.

FRAMEWORK FOR DECISION MAKING

Cost is not the only important factor in a car purchase decision. Other factors include environmental impact, integration with other energy needs and usage requirements. One approach is to use a multiple-criteria decision-making framework, which can accommodate a number of considerations, each of which carries a weighting factor. A list of the parameters, together with their associated weighting factor, is given in Table 4. The final values are calculated by normalising each parameter using the maximum within each category and then multiplying it by the weighting factor. The final assessment of each option is obtained from the sum of the values for each parameter.

Based on the framework and the 2020 values, the most attractive option for the purchase of a new vehicle would be a battery electric vehicle with power purchased directly from a wind utility. Unfortunately, consumers do not yet have the flexibility of specifying from which technology source they wish to obtain their electricity, although this option exists in some countries and is a growing trend within energy markets.

Table 4: Multiple-criteria decision-making factors for evaluating the purchase of a car

PARAMETER	INDICATOR	WEIGHTING FACTOR (%)
Economic	Annual equivalent operating cost (ZAR)	50%
Environmental impact	Annual CO_2 emissions (kg/year)	20%
User specification	Distance travelled per day	10%
Energy integration	Integration with rooftop solar	20%

Conclusion

Comparing alternatives depends on the types of questions that are being asked. The comparison of possible alternatives in the purchase of a new light vehicle is important in providing clarity to prospective customers, who face a flood of information, often contradictory, about the relative advantages and disadvantages of each technology.

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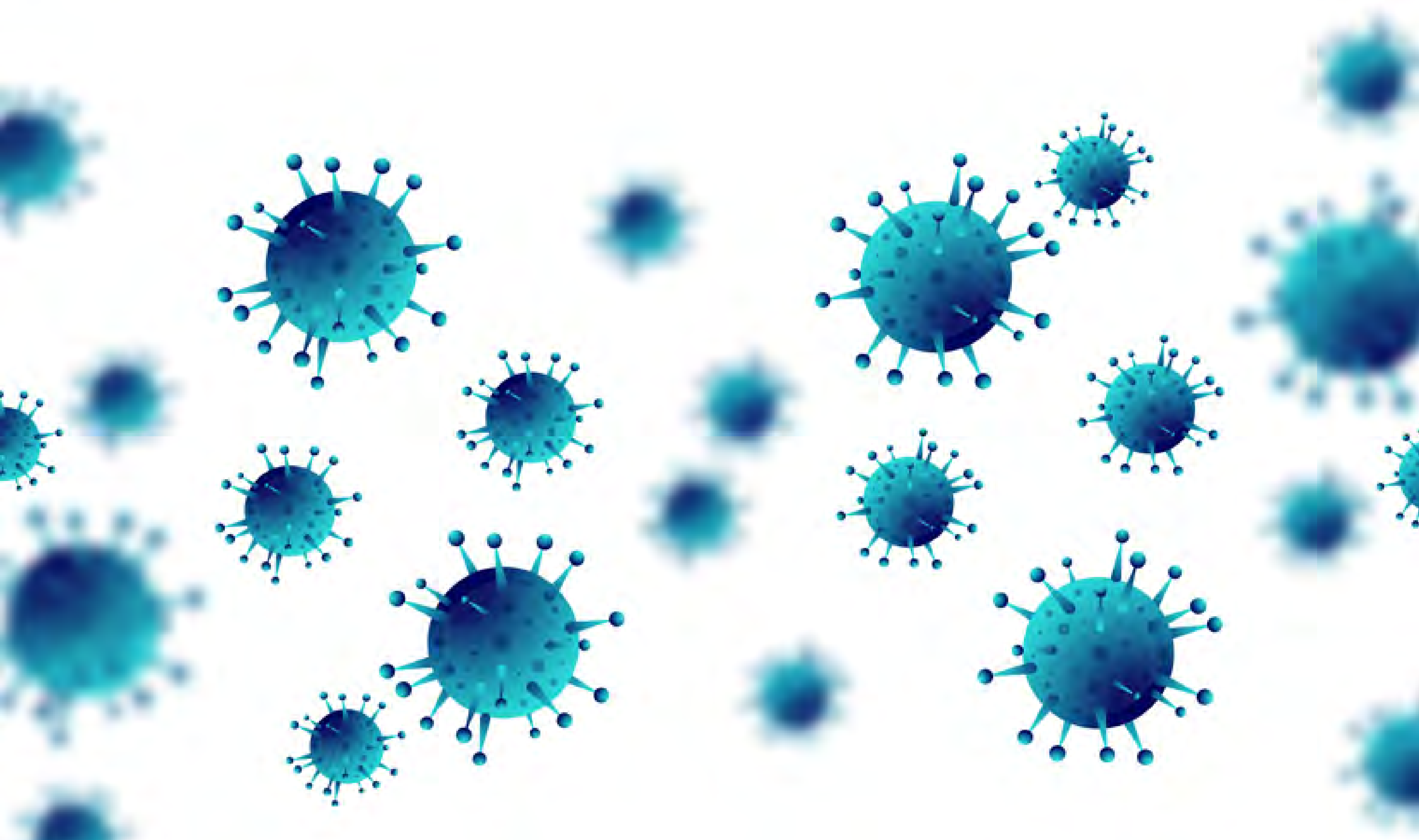


Optimised lockdown strategies for South Africa to curb the spread of COVID-19

Dr Laurentz Olivier
Stefan Botha
Prof Ian Craig

During the COVID-19 pandemic, many governments around the world implemented tiered lockdown strategies with varying degrees of stringency. Lockdown levels are typically increased when the disease spreads, and reduced when it abates. Researchers in the Department of Electrical, Electronic and Computer Engineering have developed an epidemiological model to determine the most optimal lockdown strategy to curb the spread of the pandemic.

The South African government formulated five lockdown levels with additional allowances in terms of permitted activities for each level to systematically restore economic activity. The model that was developed to determine the epidemiological impact of the lockdown levels imposed used data for the period 23 March to 16 August 2020. The model was adapted with varying values for the spread rate under varying lockdown levels. Finally, a hybrid model predictive control was implemented to determine the optimal lockdown level over time for different policy scenarios: a "flattening the curve" scenario and a "balancing lives and livelihoods" scenario.

THE EPIDEMIOLOGICAL IMPACT OF THE LOCKDOWN LEVELS

From an epidemiological point of view, the early strict lockdown measures imposed by the President of South Africa were successful, but great harm was done to an economy that was already weak before the COVID-19 pandemic started. As a result, significant pressure was applied to relax the lockdown measures, even though the number of infectious individuals was still growing exponentially.

Under the scenario where "flattening the curve" was the goal, the healthcare capacity, expressed in terms of the number of beds available in hospitals' intensive care units (ICUs), was largely respected, but the lockdown would be long and severe. The detrimental cumulative economic impact of such a long and severe lockdown would be very high.

In terms of the other scenario, which introduced a policy known as "balancing lives and livelihoods", increased economic activity was permitted by reducing the lockdown levels earlier. This would have the effect of violating the imposed limit of beds in hospitals' ICUs, but more livelihoods would be saved, and poverty could be reduced.

A final parameter to be considered was that of the population's compliance with lockdown regulations, which was noted to be reducing the longer a particular lockdown level continued. To curb waning compliance, the lockdown level was increased in the model and extended to the point where the economic loss would be too great and lockdown would be ended rather abruptly.

MODELLING THE DIFFERENT SCENARIOS

The simulation of the "flattening the curve" policy scenario revealed that implementing lockdown at the correct time and at the correct level would allow the active number of confirmed infectious cases to hardly violate the capacity limit of hospitals' ICUs. The lockdown was implemented relatively early (37 days after the start of the simulation on 18 April 2020) and lasted for 77 days. In terms of the modelling exercise, this scenario would likely have devastating effects for the economy.

The simulation of the "balancing lives and livelihoods" policy scenario showed the implementation of lockdown up to Level 5 to try and curb the spread of the virus, albeit somewhat later than in the "flattening the curve" scenario to alleviate some of the economic impacts of the lockdown. After a couple of weeks on Level 5, the cumulative economic impact was shown to increase to the extent that the level could be reduced, despite the capacity of hospitals' ICUs being exceeded, in an attempt to curb economic losses. This policy balances lives and livelihoods by delaying the start of Level 5 lockdown by a week and reducing the total time on this level. The advantage of this policy was that the peak in the maximum number of cases could be delayed, as opposed to having no policy in place at all. In addition to winning time, this scenario provided an estimate of the additional number of COVID-19-specific ICU beds required. This implied that if the economic impact of each level of lockdown could be quantified beforehand, temporary ICU facilities could be procured to the point where lockdown might be eased earlier to limit the cumulative economic impact, while the ICU limit could still be respected.

However, this scenario needed to be considered against the population's compliance with the lockdown regulations, which appeared to wane over time. After an initial decrease, the level of compliance in the model was set to increase each time the lockdown level was reduced. This is because there are fewer regulations on lower levels, and the level of compliance with those regulations will likely be higher initially. After the initial surge, compliance was predicted to again reduce in a linear fashion, increasing the spread of the virus. The effect of non-compliance is seen in the higher number of confirmed infectious cases. To curb waning compliance, the lockdown level would be increased and extended to the point where the economic loss would be too great and lockdown would be ended rather abruptly.

ACCORDING TO THIS MODEL, IN JUNE 2020, THE RESEARCHERS PREDICTED A PEAK OF 70 000 ACTIVE CASES BY LATE OCTOBER 2020, WITH AN UPPER LIMIT OF 300 000. THE MODEL ALSO PREDICTED A TOTAL NUMBER OF DEATHS RANGING FROM ABOUT 10 000 TO 90 000 (NOMINAL VALUE OF 22 000) WHEN THE RATE OF TRANSMISSION IS VARIED BY ABOUT 10%. THESE PREDICTIONS ARE, HOWEVER, DEPENDENT ON THE DISEASE CONTROL MEASURES IN PLACE, THE ADHERENCE OF THE POPULATION TO THESE MEASURES, AND THE RATE AT WHICH POSITIVE CASES CAN BE IDENTIFIED AND ISOLATED.

Urban green space design is essential for wellbeing

Dr Ida Breed

The importance of being able to access open spaces, especially green spaces in urban environments, has never been more evident than during the current state of social distancing and restriction of movement brought on by the COVID-19 pandemic. This was especially significant during the first levels of the nationwide lockdown. Urban green space design is not only essential for wellbeing, but can provide a refuge for the country's rich biodiversity.

The inclusion of a greater variety of ecosystem services in multi-functional urban green areas is vital to demonstrate the myriad benefits of green spaces in the global south where they are often taken for granted. However, very little research has been conducted on ecosystem services in urban green spaces in South Africa.

To remedy this, research in the Landscape Architecture Programme of the Department of Architecture is focused on the needs of urban inhabitants, alongside biodiversity conservation. This research was inspired by a desire to see more quality green open spaces in South Africa that can be used by dwellers of densely developed and disadvantaged urban areas to escape the confines of the city.

To this end, the research team started investigating the introduction of plant species in open spaces in South Africa that would promote the country's vast biodiversity and provide places for social interaction with a local distinctiveness.

South Africa has a rich biological diversity of species and is ranked the third-most biodiverse country in the world. While the Cape Floral Kingdom with its fynbos biome is the richest and most diverse in South Africa, the second-most diverse biome, which is well suited to cultivation in the country's open spaces, is its grassland species. The research team's consideration of these species for inclusion in open spaces is rooted in the fact that urban areas can play an important role in promoting and conserving the country's biodiversity by understanding what is termed the "urban ecology".

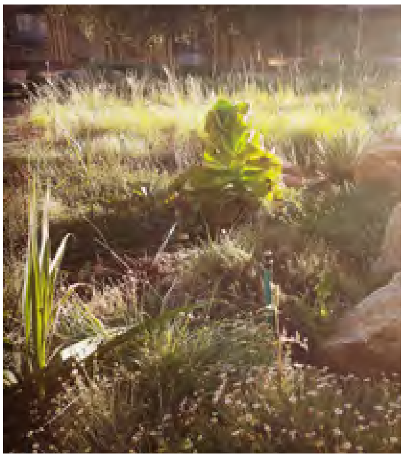
This led to the Department's initiation of a research programme to study biodiversity and ecosystem services in the City of Tshwane. The aim of this programme, funded by the National Research Foundation (NRF) and the University of Pretoria's Research Development Programme, is to introduce native vegetation ecologies in urban spaces where they previously existed. Wild grassland species that are planted in open spaces can also be more resilient in the provision of a variety of ecosystem services, and can improve the habitat and shape human preference. Such plant species do not only include grasses, but also a variety of bulbs and herbaceous forbs that could attract and provide refuge for a greater diversity of birds and insects that also act as pollinators.

Despite the ecological and social benefits, such "wilder" urban areas are not commonly appreciated and require thoughtful management for mainstream acceptance. A variety of social factors such as values and demographics shape specific demands for the aesthetics of urban areas over time, and need to be considered to link demand with the supply of urban green spaces through design and planning.

The aim of this programme is to introduce native vegetation ecologies in urban spaces where they previously existed.

The programme, which commenced in 2017, entailed the establishment of two experimental biodiversity gardens in areas of the University's campus that are open to the public. The reason for this location was not just to test the characteristics of these plant species and their suitability for establishment in urban open spaces, but also to test public perception of the plant species in terms of their ornamental value.

The first experimental garden covers an area of 200 m^2 that forms part of the Future Africa Complex on the University's Innovation Africa Campus. The second covers an area of 100 m^2
that forms part of the Javett Art Centre and Mapungubwe Collection Museum in Lynnwood Road, adjoining the University's Hatfield Campus. These two gardens have typical urban conditions of small patch sizes that are fairly isolated. They could therefore enable researchers to monitor plant survival in urban contexts, and explore the degree to which native plants could contribute to ecosystem functions, biodiversity, sense of place and even food production. Over 60 grassland species – both flowering and non-flowering – were introduced into these experimental gardens. Based on the research findings, it will be possible for practicing landscape architects to select native vegetation for establishment in urban environments, thereby increasing local biodiversity and



contributing to both the intangible sense of place and tangible services such as the provision of edible and medicinal plants.

By the beginning of 2020, the experimental gardens had already been established for a full year. The members of the research team could thus document their initial promising findings on whether preconceived native grassland plant assemblages constructed in typical urban settings would promote biodiversity in Tshwane, as measured through insect activity. They will also be identifying some of the local social perceptions of such interventions.

Based on their findings, the next step will be to determine and demonstrate the socio-ecological potential for biodiversity enhancement in urban areas through ecological landscape design processes, and to identify and illustrate principles that could guide such interventions for landscape designers and horticulturalists in practice. These plant species may have an application beyond urban open spaces, and may also be of interest to individuals who are keen on cultivating a wilder aesthetic in water-wise and low-maintenance gardens. They may also be of interest to municipal landscaping services for use in public areas in the city such as road islands.

For more information about the project visit https://www.futureafrica.science/index.php/hub/npc
Instagram: *best.native.gardens*

An online response to the global pandemic

Among its other consequences, the nationwide lockdown that was brought about by the rapid spread of COVID-19 made unprecedented demands on the higher education sector in terms of its important function of teaching and learning. However, the University of Pretoria's lecturers rose to the challenge by changing their method of transferring knowledge to a completely online system literally overnight.

While the terms hybrid and blended learning are sometimes used interchangeably, the University makes a distinction between the two approaches. The blended approach to teaching and learning is a combination of traditional contact teaching, enhanced by the use of online learning both inside and outside the classroom. The blended approach uses technology to enhance traditional methods of teaching and learning without reducing the number of contact hours. The hybrid approach to teaching and learning, on the other hand, is characterised by different combinations of contact and online delivery. A lecturer will decide to replace some contact time with online teaching time. The modules are therefore redesigned from an instructional design perspective to ensure integration and coherence, and to achieve the aims of the hybrid model.

The Faculty of Engineering, Built Environment and Information Technology decided to embrace online teaching and assessment in its entirety during the lockdown, with no physical student contact whatsoever. Most of the Faculty's lecturers saw this disruption as an opportunity to introduce new ways of teaching and learning by following new, innovative approaches that will, in all likelihood, form part of a new approach to teaching and learning to be explored even further in the future.

In a recent survey conducted among more than 10 000 students in the Faculty, about 90% of the sample, who had participated in online activities during this period, indicated that they had been well prepared to use the online tools provided by the University of Pretoria during the lockdown. This gave the Faculty's management an indication that its students were coping in the online environment, and had adapted successfully to the approach that had been put in place for lecturers to continue with their academic programmes.

Some of the key challenges faced by students in rolling out the online learning programme included data availability for students and access to laptops. The University reacted to these challenges by providing loan computers to students who did not have the financial means to buy their own computers, and by providing data to students to enable them to connect to the online tools used by the Faculty to enable students to continue with their studies.

THE FACULTY DECIDED TO EMBRACE ONLINE TEACHING AND ASSESSMENT IN ITS ENTIRETY DURING THE LOCKDOWN, WITH NO PHYSICAL STUDENT CONTACT WHATSOEVER. MOST OF THE FACULTY'S LECTURERS SAW THIS DISRUPTION AS AN OPPORTUNITY TO INTRODUCE NEW WAYS OF TEACHING AND LEARNING BY FOLLOWING NEW, INNOVATIVE APPROACHES THAT WILL, IN ALL LIKELIHOOD, FORM PART OF A NEW APPROACH TO TEACHING AND LEARNING TO BE EXPLORED EVEN FURTHER IN THE FUTURE.

The role of AI in teaching and learning

Prof Nelishia Pillay

As we move into the Fourth Industrial Revolution (4IR), artificial intelligence (AI) is playing an imperative role in the way we teach and learn. Several innovations can be implemented in the near future, including automated tutors and teaching assistants, genetic programming and learning analytics, chatbots and bookbots.

Students can receive individualised tuition through the use of intelligent tutoring systems. Innovations that are already in use internationally include Jill Watson, an automated teaching assistant at the Georgia Institute of Technology (Georgia Tech) in Atlanta, Georgia, in the USA, that provides responses to student queries with a 97% accuracy rate. Pearson and McGraw-Hill, a corporation based in New York City that provides international educational services, has embraced this innovation as well with its development of Smartbook 2 and Pearson Mastering, two AI systems that provide individualised feedback to learners.

Artificial intelligence techniques, such as genetic programming, have also been used for the automated design of learning environments, including web-based courseware, digital learning environments, online courses and pedagogical agents. AI has also facilitated automated assessment. In China, AI-driven systems are used to automate the assessment of essays at schools, while Pearson has incorporated automated assessment in writing and mathematics learning tools. Automated assessment has also made an impact in the training of surgeons, psychometric testing and talent assessment.

Learning analytics, which uses machine learning techniques, has proven to be effective in predicting student learning difficulties and providing support to students. This technique can predict whether a student will fail or pass, the grade the student will obtain and specific learning difficulties a student will experience. Such techniques are already being incorporated into learning management systems, for example the predictive analytics tool that forms part of Blackboard (ClickUP).

Chatbots are also starting to play an important role in teaching and learning. A chatbot is basically a computer programme that fundamentally simulates human conversation. It allows a form of interaction between a human being and a machine, which takes place via messages or voice commands. It is programmed to work independently of a human operator. While early chatbots were text-based, the more recent iterations can converse in a natural language and use AI techniques to learn and adapt their communication to the needs of the particular student with whom they are conversing. Chatbots are used internationally to provide students with advice on university operations and logistics, such as lecture venues, admission procedures, timetables and financial advice.

Cornell University in New York has employed CourseQ for this purpose, while Georgia State employs "Pounce", a custom virtual assistant, and Deakin University in Melbourne, Australia, employs "Genie", a smart personal assistant. At the University of Tampa in Florida, chatbots provide students with mental health support. They have also been used to assist students to learn a language by conversing with the student in the target language.

Another area in which AI and robotics are contributing to education is the automation of tasks in libraries, making the concept of a smart library a reality. These tasks include automated cataloging, classification and periodical indexing. This has facilitated 24-hour self-borrowing, return and renewal. Artificial intelligence and robotics have also played a role in intelligent warehouse management. Bookbot can locate a selected book from millions of books on shelves in only five minutes.

In the University of Pretoria's Department of Library Services, a robot, called Libby, became the first humanoid to be introduced in a library in Africa. Libby joined the staff of the Merensky 2 Library in 2019 as a library consultant, advising students about the library, telling them where to find specific books, directing students to the relevant subject librarian, and marketing the library.

As the role played by AI in teaching and learning increases, so several challenges are identified. One of these is how to prepare students and graduates for the advent of AI, and also how to promote AI literacy. An initiative to address this challenge has been launched at the University in the form of the Artificial Intelligence Student Society (AISS). This is a multidisciplinary student society that promotes AI literacy and innovation. It was founded in February 2019 by three students from the departments of Philosophy, Industrial Engineering and Computer Science, and has about 500 members from various disciplines within the University. The value of a society such as this in the University environment lies in the crucial role it plays in debunking the fearful misconceptions held by the population about the threat of AI being incorporated into our daily lives. Currently, the AISS is running a chatbot competition where students are developing chatbots to improve the quality of student and campus life.

A second initiative at the University, in which the Department of Computer Science played a role, in collaboration with the Department for Education Innovation, is the development of AIPods, which will be incorporated into the University's Future for Work project to provide students with an overview of the role AI will play in their chosen career. The ten AIPods that have been developed cover an introduction to AI and the impact that AI is making in careers related to qualifications in each of the University's nine faculties.

Innovations such as these will certainly ensure that the University of Pretoria can take its rightful place in utilising disruptive technologies to enhance effective teaching and learning.

Interactive learning through
gaming simulation

Prof Christo Venter

Lecturers in the Department of Civil Engineering and the Department of Town and Regional Planning have initiated a unique approach to the teaching of integrated land use-transportation planning at an undergraduate level through the use of gaming simulation.

Simulation-based approaches particularly benefit students who prefer visual and active learning.

Preliminary research in the field of interactive teaching and learning revealed that simulation-based approaches particularly benefit students who prefer visual and active learning. The lecturers therefore developed a computer game – UPTown – as a bespoke application that integrates commercial software with a locally developed interface to simulate the development of a hypothetical town over a 30-year timeframe. Students take on the specific roles of either a public sector planner or a private sector real estate developer during the game. This allows them to explore the problems of conflicting objectives and to discover the value of cooperative planning in the land use and transport development process.

The game was designed specifically to help students explore the linkages between infrastructure investment, land development, and city efficiency and equity outcomes by guiding the spatial and economic development of a hypothetical city over time. Its innovation lies in the way it asks students to simulate the decisions of both public sector planners and profit-seeking developers, and the interactions between them. This allows them to discover the value of collaboration and integration, not only across professional disciplines, but also between the public and private sectors.

The students who take on the role of planners are forced to consider land-use development and transport demand, and are encouraged to start the game by developing a spatial development strategy for managing the growth of the town for the coming decade to ensure the coordination of zoning and investment decisions. The developers, on the other hand, have the ultimate objective of maximising the profits to be derived from developing and selling or renting out building stock. The programme simulates land values and construction costs based on the size, type and location of new development, and then calculates the developers' profits based on the floor space that is actually occupied.

It is precisely the linkage between public sector planning and private sector investment decisions that gives the game its collaborative nature. Neither the planners nor the developers can control each other's actions. The actions of a third group of role players – private households and businesses – are not controlled directly by either group, but are simulated externally.

A key feature of the game is that it takes the performance of both planners and developers into account when determining the overall performance score for the town. Thus, each group benefits from the other group reaching its objectives.

The game is included in the curriculum of the final-year Infrastructure Planning course. This allows it to build on prior knowledge of technical topics, such as traffic engineering, engineering economics and numerical methods, while drawing on a more mature, complex understanding of societal issues.

The course is presented as a mixture of lectures, and discussion and practical sessions, with six contact hours a week spread over 13 weeks.

The classes, which are co-taught by lecturers from both the Department of Civil Engineering and the Department of Town and Regional Planning, introduce theoretical concepts and start to explore their implications for planning practice in South Africa. The in-depth exploration of issues is left for the practical sessions, which is where the simulation game plays an important role.

The assessment of the students' performance reveals that the game has significantly enhanced their mastery of the course content. Students who faced more complex and open-ended tasks, such as those of a planner, as opposed to those of a private sector developer, performed better, reaching higher levels of competence earlier on in the game. It appears that being forced to grapple with complexity and a larger action space leads to a better grasp of the material and an improved achievement of the learning outcomes.

The lecturers have found that the game's insistence on cooperation as a mode of interaction between private and public sector actors is particularly useful as a learning strategy.

This is also a key innovation over existing urban simulation software as it allowed the students to experience the benefits of collaboration with those who have different objectives from their own. This is a key skill that is required in a multidisciplinary environment such as that in which graduate civil engineers will find themselves when they enter the world of work. In the process, they learn syncretic thinking, clear communication and compromise. The role-playing simulation approach allows students to explore experientially what it means to be a planner or a developer, thus preparing students for their eventual entry into a community of practice.

Computer-based simulation is considered to be a promising tool to enhance classroom instruction and to respond to the changing learning styles of contemporary students, including a greater preference for social and active learning methods. Similar initiatives can be emulated by educators who wish to develop new approaches to respond to contemporary students' preferences for more active and social learning styles.

Taking teaching and learning to the next level

The University of Pretoria's commitment to ensuring that its teaching and learning initiatives enable students to excel and graduate in the minimum time set out for a degree, and to continue to pursue postgraduate studies, is entrenched in a culture of excellence. With the assistance of the Department of Higher Education and Training (DHET) in the form of the Scholarship of Teaching and Learning (SOTL) grant, its academics have the opportunity to develop projects that will enhance their teaching and learning outcomes.

The DHET's SOTL grants are awarded to academics to undertake research into the teaching of their discipline with the aim of developing their teaching and research capacity and improving student learning. The funds form part of the University's Teaching Development Grant. The purpose of this grant is to promote institutional research to improve teaching and student learning and success.

In 2019, the Faculty of Engineering, Built Environment and Information Technology was fortunate to receive ten such grants across its three schools, which enabled the related research to be conducted in 2020.

Dr Ida Breed

Department of Architecture

BIOPHILIC ECOLOGICAL DESIGN: TRANSFORMATIVE LEARNING IN THE DESIGN STUDIO

This study is based on the hypothesis that interacting with real-life settings in design assignments as part of learners' formation could benefit from a biophilic affinity for the living world to foster both experiential and transformative learning. It verifies the degree to which the exposure to real-life social and environmental living complexities in design projects stimulates learners' learning processes and improves the final design outcomes.

Prof Alta van der Merwe

Dean's Office

ENGINEERING DIAGNOSTIC TEST

An engineering diagnostic test, which was written by all first-year Engineering students, was evaluated to determine its internal and external validity as a predictor of student success. This evaluation determined that the test was not measuring clear constructs, while the readiness test was found to be a weak predictor of engineering success. Considering other data, there were also no clear indicators of student success. In response to this, research is being conducted to target the issues of spatial visualisation and psycho-social skills more narrowly, as well as to conduct focus group interviews to interrogate students' perceptions.

Prof Ken Craig

Department of Mechanical and Aeronautical Engineering

THE DEVELOPMENT OF A 3D APP FOR THE VISUALISATION AND UNDERSTANDING OF THERMODYNAMIC PROPERTIES, PROCESSES AND CYCLES

The first implementation of the 3D app is to aid in the understanding and interpretation of the thermodynamic properties of water. The database containing these properties was developed from current work in thermodynamic relations using free energy. Eight inter-related thermodynamic relations were incorporated into the database for rendering as 3D surfaces, with a fourth variable plotted using contours on this 3D surface.

Prof Carina de Villiers

Department of Informatics

THE DEVELOPMENT OF A SOFTWARE APPLICATION FOR THE IMPROVEMENT OF ASSESSMENT PRACTICES IN HIGHER EDUCATION

To examine the phenomenon of scholarly assessment, a research project would be conducted to find an answer to the question: "How can a more scholarly approach towards assessment design be improved?" The research question would culminate in the development of an assessment application, embedded in a cognitive taxonomy, to provide structured guidance to university lecturers towards a more scholarly approach when designing assessment instruments such as test and examination papers.

Dr Marie Hattingh

Department of Informatics

TOWARDS A KNOWLEDGE CONVERSION PLATFORM TO SUPPORT INFORMATION SYSTEMS ANALYSIS AND DESIGN TO PRODUCE INDUSTRY-READY GRADUATES

The purpose of this research study was to develop a web-based platform that would facilitate the learning of INF 271 and INF 370 students. The INF 271 module provides an important foundation for preparing students to successfully complete the INF 370 capstone project. The initial framework of the platform has been developed and includes theoretical content, examples, lessons learnt and links to videos to two of the main study units of the module. The initial version of the platform has been released and feedback has been obtained.

Dr Riana Steyn

Department of Informatics

HYBRID LEARNING: THE IMPACT OF USING INFOGRAPHICS AND A STUDENT-DESIGNED TEXTBOOK ON HIGHER EDUCATION STUDENTS (PHASE 2)

A significant finding of research conducted on hybrid learning is that the members of Generation Z rely heavily on their peers for assistance, even though literature says their social skills are underdeveloped. This means that, as academics, we need to understand this generation and how they prefer to study, and then create content and tools for them so that they can indeed broaden their own knowledge and become lifelong learners.

Dr Lizette Weilbach

Department of Informatics

USING COLLABORATION TOOLS TO ENHANCE, SUPPORT AND ASSESS INFORMATION SYSTEMS ANALYSIS AND DESIGN (ISAD) TEAMWORK

The purpose of this research was to understand the way in which collaboration tools could assist with team construction and the enhancement, support and assessment of teamwork. To gain a deeper understanding of the factors that contribute to successful teamwork, data was gathered on the way in which students form project teams. This data has been linked to the iPeer assessment done throughout the year, as well as on the eventual project outcomes and success of each team.

Dr Marita Turpin

Department of Informatics

EVALUATING THE EFFECTIVENESS OF TEACHING CRITICAL THINKING, PROBLEM SOLVING AND DESIGN THINKING TO FIRST-YEAR INFORMATICS STUDENTS

Key findings related to the first-year Critical Thinking and Problem-solving module included evidence of the value of exposing students to a Maker philosophy, as well as design thinking, when presented with tasks that required creative problem solving. From feedback surveys, it was found that the teaching of critical thinking assisted students not only to analyse arguments, but also to better read and understand their exam questions and better evaluate online information.

Dr Adriana Botha

Department for Education Innovation

IMPLEMENTING AN ONLINE TOOL FOR TEAMWORK ASSESSMENT IN REAL TIME: A FACULTY INITIATIVE ACROSS DISCIPLINES

The iPeer tool can be used for teamwork assessment and provides insight into team dynamics and individual performance. Sufficient data was attained to inform the design of an e-learning resource for "teamwork fundamentals". The envisaged resource will create a learning opportunity for all students in the Faculty. A national and international collaborative network has been established to expand the iPeer project to better serve the Faculty's students in teamwork across all borders and disciplines.

Prof Nelishia Pillay

Department of Computer Science

USING GENETIC PROGRAMMING AND EXPLAINABLE ARTIFICIAL INTELLIGENCE FOR PREDICTING STUDENT PERFORMANCE

The main aim of this research study was to employ genetic programming to predict student performance. Two models were evolved using genetic programming. The first was a regression module to predict the student's mark. The second was a decision tree classifier to predict whether the student would pass or fail. The approaches were applied to two Computer Science modules. Both models were found to predict the final mark and result based on the students' semester marks. This would facilitate identifying students that would not pass and put support mechanisms like boot camps in place to assist these students. ❶

The application of

VR technology

in mining engineering

The Department of Mining Engineering's Virtual Reality Centre was established in 2015 with the financial assistance of Kumba Iron Ore. The purpose of this world-class addition to the University's facilities was to enhance education, training and research in operational risk across industries through an innovative approach to information optimisation and visualisation by incorporating immersive technology such as augmented reality (AR) and virtual reality (VR).

With the establishment of the AEL Intelligent Blasting Chair for Innovative Rock-breaking Technology in 2018, the Virtual Reality Centre could be utilised to simulate three-dimensional blasting techniques and to visualise new research. This would establish the University as a centre of excellence for emerging rock-breaking technologies.

The AEL Intelligent Blasting Chair is a joint initiative between the Department of Mining Engineering and the Department of Electrical, Electronic and Computer Engineering, which exploits the Department of Mining Engineering's AR and VR expertise and facilities to strengthen AEL's market and technology leadership position. In the process, it supports groundbreaking projects to resolve pressing issues in the mining industry.

Under the leadership of Prof William Spiteri, an extraordinary professor in the Department of Mining Engineering, three projects have been launched in the Chair, which have achieved significant milestones over the past two years.

THE DEVELOPMENT OF A FLYROCK MEASUREMENT TECHNIQUE

This project in the Department of Mining Engineering entails the development of a quantitative measuring technique to physically capture and study the in-flight motion of flyrock to improve on predictive models and to better understand the causative factors. It was originally initiated through a request from Glencore coal mine to assist with the evaluation of its mathematical model and its empirical standards for predicting the safety radii to protect equipment and personnel from flyrock.

The insight obtained from this project highlighted the dearth of work done in the past, internationally, in an attempt to understand this phenomenon. The present study started with a more extensive literature review, which showed that – despite the numerous and theoretical predictive models developed over the past ten years – no definitive measuring technique to properly test these theories exists. The next step was to identify the most appropriate technology to measure the flight path of flyrock in the aftermath of a blast.

Photogrammetry was selected as the technique most likely to succeed. Normally, photogrammetry involves taking several photographs of a static object from different angles using a single camera. The photographic data is then manipulated to yield a 3D image of the object. In the case of flyrock monitoring, the process had to be reversed to a technique where several cameras were used to capture a moving object. The data would then be manipulated to depict the trajectory of the flyrock in 3D. This technique was developed and perfected by employing a clay pigeon sling in a controlled and demarcated space. Finally, the multiple camera system was deployed in a quarry where photographs of flyrock were successfully captured by all the cameras.

The study is currently concentrating on converting the quarry photographic data into a point cloud form from which the trajectory of the flyrock can be calculated. Subsequent work will focus on extracting positional and physical data of the flyrock fragments from the photographic data using existing photogrammetric and stereo mapping software. Once the positional data can be obtained within an acceptable margin of error (±1 cm), the research can shift towards the analysis and interpretation of the data based on ballistic principles.

The ultimate goal is to determine two coordinates for the flyrock: its final landing position and the point of origin. This output will enable mines to build historic databases of the operation's flyrock. It will also enable researchers to quantitatively investigate the effect of various blasting parameters on the risk of flyrock, and will enable the visualisation of the data for training and educational purposes.

THE APPLICATION OF VR TECHNOLOGY TO ENHANCE LEARNING

The VR training project in the Department of Mining Engineering identified the need to digitise the current training that is being conducted for the Intellishot® electronic detonator product using a flipped classroom approach.

This entailed the development of three elements. The first element comprises a theory component using six e-learning courses, which the trainees work through at their own time and pace, with additional support provided where necessary. This is followed by face-to-face training to fill knowledge gaps. The trainee is then introduced to the VR programme and works through a facilitated perfect blast (with voice-overs, as well as facilitator explanations). This takes the trainees into a trouble-shooting phase.

Once the trainees have worked through the perfect blast, they work through a second round without facilitation, where two errors are randomly displayed. The trainees then apply what they have learned about solving errors. Finally, they complete a VR assessment, where they are required to conduct a live blast.

THE CONVERSION OF VISUAL DATA INTO 3D IMAGES

This project in the Department of Electrical, Electronic and Computer Engineering is developing techniques to convert visual data, such as video footage obtained by a drone flying over an open-pit mine, into three-dimensional (3D) VR and AR images. The knowledge base for converting point cloud data into 3D VR and AR images had not been available within the Department of Electrical, Electronic and Computer Engineering prior to the commencement of this project.

The initial phase of the project has been completed and various demonstrations have been held to progressively show the levels achieved. To improve the quality of VR visualisation, an approach using mixed-medium and high-resolution meshes has been developed. The approach entails the use of a medium-resolution mesh for general navigation, switching to a high-resolution mesh when approaching objects or features in the environment.

The integration of large 3D models extracted from point clouds and other data into the Unity and Unreal engines must overcome the memory and object count limitations of the engines. Although the initial partitioning (segmentation) results were disappointing, an improved segmentation algorithm has been developed that is optimised for the generation of segments used for VR visualisation. However, the algorithm is currently only serial in nature as it requires long run times for large point clouds.

Career mentorship ensures that graduates are ready for work

Dr Martina Jordaan

The value of a degree from the University of Pretoria was further reinforced in 2019, when a survey revealed that 93% of its alumni were employed within six months of graduation, according to Prof Norman Duncan, Vice-Principal: Academic. It is, therefore, necessary to train students to not only find employment after they graduate, but also to excel at those careers and become leaders in their industries.

Career mentorship has been identified as an important element of developing work-ready graduates. In light of this, the University launched a Career Mentorship pilot programme in 2019 as part of its Ready for Work initiative. This programme was aimed at getting the involvement of alumni in the mentoring of final-year students in the School of Engineering. It aimed to develop work-related skills and confidence related to the engineering profession and to build effective career networks.

Mentoring can be described as the relationship between two people, where the mentor has the knowledge, expertise and insight to assist in the development and growth of the mentee. Through mentorship, a career can be guided and assistance provided in the induction of a profession, as well as through progress and promotion.

Mentoring can be seen as an interlinking task and can take on various forms. The outcomes can be positive for the individual involved, depending on their commitment and investment of time in the process.

The students in the School of Engineering who were selected to participate in the Career Mentorship pilot programme, conducted from April to July 2019, had to indicate why they would like to be part of the programme. The names of potential mentors were provided by the University's Alumni Office, as well as the engineering consultancy, Aurecon. Eventually, 33 students and 24 mentors participated in the programme. The mentors, who varied from early-career engineers to senior professionals, had the option of choosing the mentees they thought they would be able to mentor.

The mentorship process included two meetings, either online or face-to-face, and one job shadowing session. The mentors and mentees could decide on the topics they wished to discuss. The following themes were typically addressed:

- How to cope with the new work environment
- The process of becoming a registered engineer
- The work experience of the mentor
- How to develop management skills
- How to apply for a job

As both mentors and mentees had demanding schedules, which often made it logistically challenging to meet, they often communicated via email or telephone calls. The main reflection of the mentors on the programmes was that they enjoyed watching someone grow personally. It gave them personal satisfaction and the opportunity to give back to the University.

At a function held on 16 July 2019 to acknowledge the work of the mentors and the involvement of the mentees, Prof Duncan reflected: "Of course UP alumni will assist us significantly in preparing our graduates for the workplace by joining us in this career-mentoring endeavour in the knowledge that current mentees will one day give back by mentoring others in future."

Following the success of the pilot programme, it was extended to the remainder of the Faculty of Engineering, Built Environment and Information Technology, as well as the Faculty of Theology, in 2020. There are currently 90 students and 78 mentors involved in the programme.

In a survey upon completion of the programme, the mentees reflected positively on the programme and felt that the mentors had made a difference in their lives. The students indicated that they especially enjoyed the job shadowing day.

Career mentorship has been identified as an important element of developing work-ready graduates. The Career Mentorship pilot programme aimed to develop work-related skills and confidence related to the engineering profession and to build effective career networks among final-year students in the School of Engineering.

Students had the following to say about the programme:

"The programme gave me the opportunity to interact with someone who is already in the industry and to learn from them about what I am currently studying."

"I gained a broader perspective of what the workplace expects. I learnt from the mistakes the mentor made and was able to plan my career in such a way as to avoid those mistakes. I gained a network partner I can contact if I need more information or help in future."

"The programme allowed me to interact and learn from someone who is already in the industry."

The mentors, on the other hand, also reflected positively on the programme:

"Until I was integrated into the workplace, I realised that I still needed to learn to function as an engineer in a very fast-paced industry."

"The enthusiasm and willingness of the mentees to listen and question what I had to say was very positive. The mentees went out after the sessions and researched what had been discussed, and that made me feel that I was contributing to their future success."

STAR COMMUNITY-BASED PROJECT MODULE ALUMNI PARTICIPATE IN THE CAREER MENTORSHIP PILOT PROGRAMME

Paul Ssali

"It is by standing on the shoulders of giants that we are able to see further. It is critical to the development of the key skills required for our country's development. The only way to empower people is by empowering them to empower themselves, and that can be done by learning from those that have gone before us."

Altus Bisschoff

"I could easily see that my mentor was an expert in her field and knew what she was talking about. The one thing that she told me that stood out was that you, as a person, are solely responsible for your happiness in the workplace (that is under normal circumstances, excluding situations such as terrible bosses or ridiculous working environments). If you are unhappy, you have the power to change that."

Artificial intelligence literacy and information ethics for a 4IR society

Rachel Fischer

The term "Fourth Industrial Revolution (4IR)" often conjures up images of robots, drones, functioning e-government systems, e-passports and biometric scans. Klaus Schwab's vision of artificial intelligence, robotics, the Internet of Things, autonomous vehicles, 3D printing, nanotechnology, biotechnology, materials science, energy storage and quantum computing inspires endless opportunities for progress and development in a variety of spheres, including the physical, digital, medical and educational dimensions.

What the 4IR specifically enables is the opportunity to conduct simple, everyday activities remotely, effectively and with less human intervention. The sense of individual agency is strengthened as citizens are no longer limited by bureaucratic processes vis-à-vis formal office space. The demarcation between formal and informal spaces has become blurred, presenting the possibility to reimagine "the office", "the university" and "the home".

However, for all these possibilities and opportunities, there are challenges too. If the 4IR is reliant on trustworthy and stable information and communication technology (ICT), electric and physical infrastructure, what are the implications if a country does not have these? Furthermore, if those with the requisite access, skills and abilities predominantly engage with the 4IR, what does this mean for those who do not have these? Will the lag in ICT development and accessibility exacerbate the digital divide?

According to Njuguna Ndung'u and Landry Signé, the 4IR and digitisation can transform Africa into a global powerhouse. They argue that the "spread of digital technologies can empower the poor with access to information, job opportunities and services that improve their standard of living". Making financial platforms (mobile banking) and education (massive open online courses and mobile education platforms) more readily available to vulnerable groups, such as women, children and the elderly, would support their ability to participate in the knowledge economy, leading to their ability to become drivers for sustainable poverty eradication.

Unfortunately, much of the emphasis on the 4IR revolves around digital and physical transformation, without considering the basic skills and literacies that are required to utilise these platforms, applications and processes. In so doing, it is imperative for formal education to prioritise the development and distribution of initiatives that are focused on digital, media and information literacies.

The University of Pretoria is a key proponent in this space, as the Department of Information Science has been researching, teaching and promoting information literacy for some time. An example includes the book *Navigating information literacy: Your information society survival toolkit*, written by staff members Theo Bothma, Erica Cosijn, Ina Fourie and Cecilia Penzhorn in 2006. The Department also offers the Academic Information Management 101 (AIM 101) module to all the University's first-year students. The scope of the module is to find, evaluate, process, manage and present information resources for academic purposes using appropriate technology, to apply effective search strategies in different technological environments, to demonstrate the ethical and fair use of information resources, and to integrate 21st-century communications into the management of academic information. These are essential skills requirement for the 4IR.

The Department of Information science also presents the Masters in Information Technology, Stream B, which specialises in Library and Information Science. The masters programme has been restructured from 2020 onwards, to specifically engage with LIS in light of the 4IR. The aim of programme:

- To build capacity to empower the next generation of library and information professionals with knowledge and skills to apply modern information communication and technology (ICT), in order to support academics and research.
- The programme is intended for middle management level Library and Information Science (LIS) professionals involved in managing ICT or working in ICT-intensive environments in libraries and information services and faculty members at Library and Information Science schools.

In addition, the Department hosts the African Centre of Excellence for Information Ethics (ACEIE), which regularly collaborates with the United Nations Educational, Scientific and Cultural Organisation (Unesco) and the International Centre for Information Ethics (ICIE).

Since 2012, the ACEIE has been researching and developing information ethics books and a digital wellness toolkit that specifically target communities and schools to supplement information technology (IT) skills with information ethics and information literacy awareness.

Unesco seeks to enable media and information literate societies with its Information for All Programme (IFAP) and its media and information literacy projects, including the Global Alliance for Partnerships on Media and Information Literacy (GAPMIL), the Media and Information Literacy University Network, and Media and Information Literacy: Critical-thinking, Creativity, Literacy, Intercultural, Citizenship, Knowledge and Sustainability (MIL CLICKS).

On the one hand, the University of Pretoria is a champion for the Global South, advocating grass-roots development, equality and improved literacy. On the other, collaboration with entities of the Global North provides the opportunity to engage with the higher-level implications of artificial intelligence (AI) and the 4IR. One such collaboration is with the University of Alberta in Canada.

The ICIE released the 28th edition of its official journal, *International Review of Information Ethics (IRIE)*, in 2020, hosted on a new open journal system platform. This signalled the official migration from Germany to Canada. The first issue on this platform featured articles on artificial intelligence, ethics and society. Research presentations delivered at the Artificial Intelligence, Ethics and Society Conference, 2019, hosted by the University of Alberta's Kule Institute for Advanced Study, were selected for publication.

Overall, this issue considered how nations can contribute to building a healthy AI sector through policy, research and innovation. The articles that were included considered a variety of themes, ranging from ethical best practices for industry to government developing responsible AI services, aligning cultural and societal values in AI design, the role of researchers from the social sciences and humanities in ethical innovation in the AI sector and methods for interdisciplinary and intersectoral collaboration on responsible AI.

This journal has pioneered ethics in technology and information studies for almost two decades. Featuring topics that range from gaming to artificial intelligence, the IRIE has presented some of the most thought-provoking conversations of the digital age. As the world learns to deal with COVID-19, its global information societies are set to face several new information and technology challenges, where leadership in information ethics and information literacy will become more critical than ever.

The IRIE therefore promises to carry forward the academic tradition of addressing the ethics of new challenges started by Dr Rafael Capurro, founder of the IRIE and the ICIE. The relaunch of the journal accompanies the relaunch of the Centre, which is also now supported by the University of Alberta.

The journal's team of managing editors reflects a balance of expertise that carries forward the original vision of the journal and its founders, while aligning it to the academic vision of the Kule Institute for Advanced Study, benefiting from the University of Alberta's open journal system. The editorial team comprises Jared Bielby (Editor-in-Chief), Rachel Fischer (Deputy Editor and Co-Chair of the ICIE), Mihaela Ilovan (Project Manager and Librarian) and Geoffrey Rockwell (Assistant Editor).

Promoting collaboration between entities of the Global North and the Global South therefore stimulates thought-provoking considerations that are not only related to the opportunities of the 4IR, but also the inherent social responsibilities of government, academia and civil society.

JCP students contribute to the fight against COVID-19

Students in the Faculty enrolled in the Community-based Project (JCP) module were enthusiastic in offering their time and effort in response to the COVID-19 pandemic.

FACE MASKS

Several groups of students in the Faculty made face masks and delivered them to non-profit organisations and surrounding schools in their neighbourhoods. These students revealed how grateful they were for the opportunity to participate in community service during the pandemic. Many of the students had to learn new skills, but came to the realisation that this pandemic affects the poor and disadvantaged the most.

COMPUTER REPAIRS

Electrical, electronic and computer engineering students continued to make a positive contribution to society during the pandemic. Five students gave a helping hand to a non-profit organisation in Mabopane by fixing its computer laboratory so that it could be used by the community. Some of the computers were repaired, while upgraded software packages for educational purposes were installed to improve the skills of the community.

ONLINE TEACHING AND LEARNING

Students collaborated with local schools to find innovative ways to ensure that teaching and learning continues online while the country was in lockdown to contain the spread of COVID-19. The projects in which the students were involved required new and unique levels of interaction with the community. Support included developing PowerPoint presentations, updating mark sheets, making online forms available and creating databases. Students also assisted in finding solutions for teachers to allow learners to upload assignments.

A SOLUTION FOR HOMELESS SHELTERS

Two students in the Department of Electrical, Electronic and Computer Engineering developed a mobile application (app) for members of the homeless shelters that form part of the Tshwane Homelessness Forum to access assistance during the pandemic. This app enables shelters to communicate more quickly with warehouses about their needs. The students reflected that this was their way of taking their existing skill set and giving back to the community.

New HODs appointed in the Faculty

DEPARTMENT OF CHEMICAL ENGINEERING

Prof Michael Daramola has been appointed as the new Head of Department in the Department of Chemical Engineering. He is the recipient of several awards for his research endeavours, including being one of the final nominees for the 2019/20 National Science and Technology Forum (NSTF)-South32 Awards in the TW Kambule-NSTF Award: Researcher category and in the Engineering Research Capacity Development Award category.

His primary research focus lies in chemical and bioprocess engineering, focusing on nanomaterials (nanoparticles and nanocomposites) and their applications. In bioresource engineering, he applies chemical and biotechnology concepts to develop chemical, biochemical or biotechnological strategies and processes for the treatment and valorisation of waste materials into value-added products.

Prof Daramola's extensive experience in teaching and research spans more than 15 years, while the international exposure he has acquired has sharpened his professional growth and development as a researcher and lecturer.

His vision is for the department to be a second-to-none Department of Chemical Engineering, recognised for academic excellence and innovative research that empowers people to shape the future of the University of Pretoria, South Africa, Africa and developing countries at large, in particular, shaping our post-COVID-19 future.

His mission as Head of Department is for the department to be a second-to-none Department of Chemical Engineering that advances education, scholarship, knowledge and understanding through teaching and innovative research for the benefit of the individual, society and the world at large.

The strategic goals Prof Daramola is pursuing for the Department are to achieve the following:

- Excellence in teaching and learning
- Excellence in research and postgraduate supervision
- Excellence in administration, engineering training and consultancy services
- Sustainability in operational capacity and staff professional development.

The key elements of the Department's strategic plan to achieve these goals include the following:

- **Engage**

Be the most productive department in the Faculty and the University through Faculty and University engagement, national and international engagement, building winning partnerships, and marketing and communication.

- **Empower**

Empowering our people by placing students at the heart of what we do (creating a transformative student experience) and empowering both academic and support staff members.

- **Invest**

Investing in our academic portfolio through excellent teaching and learning, excellent research and innovation, and focusing on research and innovative enterprise.

- **Sustain**

Ensuring a sustainable future through shape, size and academic sustainability, operational and financial sustainability, environmental sustainability, and transformation and internationalisation.

He believes that teaching and learning in Chemical Engineering, coupled with cutting-edge research activities in the Department, should equip graduates with the skills and critical thinking abilities to be employers of labour, creators of wealth, custodians of the environment, and providers of sustainable solutions to environmental and societal problems.

DEPARTMENT OF ELECTRICAL, ELECTRONIC AND COMPUTER ENGINEERING

Prof Raj Naidoo, former Director of Smart Grid Research, has been appointed as the new Head of the Department of Electrical, Electronic and Computer Engineering from 1 September 2020 for a four-year term. Prof Naidoo has extensive experience in power and energy systems. His expertise ranges from power and energy systems to product development in the area where the Internet of Things meets the power grid. He has consulted for a number of blue-chip companies and worked for Eskom in the fields of power quality and network planning. He has supervised a number of master's and PhD students in the field and has published papers at leading conferences and peer-reviewed journals.

His vision for the Department is as follows:

- **Build resilience**

"COVID-19 will not be the last disruption that higher education will encounter. We will have to create long-lasting changes to South Africa's higher education sector for survival. This will affect the way we deliver teaching and research. We are living in extraordinary times where "the normal" and "this is how it works" is challenged daily. My vision is for the Department is to build resilience to be able to deal with surprises, changes and unexpected setbacks in a healthy manner; staying personally motivated in times of constant changes, and ensuring that colleagues and students remain healthy, maintain high energy levels and are able to adapt to the changing environment."

- **Ensure undergraduate student success**

"It is very unlikely that we will teach in the same way as before. We will have to design new ways of teaching, while considering the needs of our students. We will adopt the leading international trends of hybrid learning, within the Faculty framework. I will also be focusing on high-failure modules, understand learners' needs and increase communication through the use of online tools."

- **Foster and sustain a transformed, inclusive, and equitable university community**

"We will have to formulate new strategies to ensure that the staff profile is inclusive and equitable. Strategies to create diversity will include identifying students at an undergraduate or postgraduate level and mentoring them for an academic career."

- **Improve research outputs by a minimum of 10%**

"I aim to do this by providing guidance to increase research outputs. I would also like to establish high-performing, extraordinary appointments and international collaborations, and increase departmental funding, as well as recruiting high-quality postgraduate students. There is a strong drive both locally and internationally on the creation of smart cities. I feel that our Department can contribute positively to this through our focus on the Fourth Industrial Revolution (4IR)."

- **Strengthen the Department's national and international profile**

"I will be spending a lot of time working to increase our international collaborations as this will have a direct impact on our international ranking. Some of our activities will include participation in key national working groups with a high impact on the economy, increased interviews with the media to showcase our achievements, increased collaborations through centres, institutes, chairs and hubs, and increased visibility through community engagement."

- **Improve the Department's operational efficiencies and reduce paper usage**

"Our departmental processes have yet to fully leverage the benefits of digitisation. I have already started engaging at a functional level with our function heads to evaluate our existing processes and design new processes, while leveraging technology to improve departmental processes that will reduce duplication, increase transparency and improve students' and staff's experience."

Industry collaboration

Murray & Roberts Chair in Industry Leadership 4.0

The purpose of this newly established research chair is to provide specialised skills and capacity building that are essential to the implementation of optimised systems related to the Fourth Industrial Revolution, particularly as they relate to the mining and minerals-related industries.

When considering the challenges facing the mining industry in the future, it is evident that leadership and the implementation of new technology will go hand in hand.

Within these contexts, leaders will necessarily have to contend with increasingly complex decision making, while exercising emotional intelligence and inspiring, motivating and dealing with this complexity in an uncertain world. More than ever, graduates are entering the workplace at a time when introspective leaders are needed, who will be able to continually challenge and develop their analytical ability and leadership effectiveness.

According to Head of the Department of Mining Engineering, Prof Ronny Webber-Youngman, engineering is one of the careers that will be central to this highly technical landscape. In recognition of the fact that there was no pre-career leadership preparation programme for future leaders in this field, the Department of Mining Engineering launched a Mining Engineering Leadership Academy (MELA) in 2009, with the objective of providing students entering the workplace with improved self-awareness, interpersonal communication skills, and the ability to work in multidisciplinary settings and in diverse groups spanning many generations.

The Murray & Roberts Chair in Industry Leadership 4.0 illustrates the Department's innovative approach to grooming future leaders. Focused leadership training will enable companies to become more competitive and sustainable.

Chair in Data-driven Wood Structural Engineering

York Timbers, the largest solid wood processor in South Africa, has signed a funding agreement with the University of Pretoria (UP) to establish a Chair in Data-driven Wood Structural Engineering to promote a more sustainable built environment and the African bio-economy.

This strategic partnership will establish a transdisciplinary research programme that is focused on the entire innovation chain, from genome-based breeding to the structural engineering of advanced engineered wood products. A number of UP's departments and entities, particularly from the Faculty of Engineering, Built Environment and Information Technology and the Faculty of Natural and Agricultural Sciences, will be involved in the programme.

According to the CEO of York Timbers, Piet van Zyl, the company is committed to stimulating the development of a sustainable, mass timber construction industry in South Africa based on advanced engineered wood products from locally grown forest plantations. The collaboration with UP is of critical importance to ensure that this vision is realised.

Faculty bursary initiatives

The Faculty greatly appreciates the support it receives from industry in the form of bursaries for deserving students These initiatives enables the Faculty to nurture exceptional talent in innovators who will make a difference in the world.

1. **Huawei Technologies South Africa** has awarded nine undergraduate, honours and master's bursaries to the value of R1.1 million to students based on their academic achievements. Not only will these grants assist these students to further their studies, they will also get the opportunity to work at Huawei Technologies upon completion of their degrees.

2. The Department of Mining Engineering, in partnership with **African Rainbow Minerals**, launched the African Rainbow Minerals Postgraduate Bursary Initiative, which will support postgraduate students in mineral sciences and complementary fields, such as finance, management and information technology.

Exceptional female leaders

Mining alumna appointed to two prestigious positions in the University and the Faculty

Nozipho Dlamini is an alumna of the Department of Mining Engineering, where she also obtained her honours degree, following this up with a master's degree in Technology Management from the Graduate School of Technology Management. She is currently a Technical Services Manager at one of South Africa's most productive underground coal mines, Anglo American's Greenside Colliery.

Dlamini believes in contributing to the development of the industry, and in 2020 was proud to be appointed the first female Vice-President of the South African Colliery Managers Association (SACMA) – a professional body for managers in the South African coal-mining industry. Through all of her success, the University of Pretoria holds a special place in her heart, and she is always willing to serve the institution. It is therefore with great pride that she accepted two high-profile advisory positions in 2020 to support the University and the Faculty. The first was as a member of the Board of the University's Convocation, where she acts in an advisory capacity on alumni matters for the University, as well as for the Vice-Chancellor and Principal. The second was as a member of the Mining Engineering Advisory Board, which comprises leaders from industry and academia who advise the Department of Mining Engineering on industry trends to keep its programmes relevant and highly recognised.

Interior architecture lecturer appointed to international taskforce

Zakkiya Khan, a lecturer in the Interior Architecture programme in the Department of Architecture, has been appointed to serve on a global educational policy taskforce for the International Federation of Interior Architects/ Designers (IFI).

The IFI is the global voice and authority for professional interior architects and designers. It is the singular international federating body for organisations in these professions. The IFI acts as a global forum for the exchange and development of knowledge and experience in worldwide education, research and practice. It connects the international community to further the impact, influence and application of the design of interiors, promote global social responsibility and raise the status of the profession worldwide.

The special global educational policy taskforce will formulate a current interiors education stance worthy of the evolution of the interiors discipline. With extended community input into various stages of this initiative, the taskforce members will take charge of drafting a refreshed education policy document. This up-to-date education policy will be further employed as the basis for the evaluation of future curricula and the accreditation of interior architecture and design education programmes, as and when applicable.

Participation in the taskforce is a prestigious activity and an endorsement of the Faculty's interior architecture programme. As an educational member of the IFI, the Department of Architecture ensures that students of interior architecture receive a globally relevant quality education.

Academic excellence

NSTF-South32 Awards

The Faculty is proud to house one of the winners of the 2019/20 NSTF-South32 Awards of the National Science and Technology Forum (NSTF).

Known as the 'Science Oscars' of South Africa, these awards are the most comprehensive and sought-after national awards of their kind in the country and recognise outstanding contributions to science, engineering and technology. Prof Josua Meyer (top left), Head of the Department of Mechanical and Aeronautical Engineering, won the male category of the Engineering Research Capacity Development Award. Prof Walter Focke (bottom left), Director of the Institute of Applied Materials in the Department of Chemical Engineering, was also a finalist in the same category.

SAICSIT Pioneer Award

Prof Carina de Villiers, Head of the Department of Informatics, has received the Pioneer Award from the South African Institute of Computer Scientists and Information Technologists (SAICSIT).

The award recognises individuals who have played pioneering roles in promoting computer science and information technology as academic disciplines in South Africa.

Best paper awards

Researchers in the Faculty strive to produce exceptional academic work. This has been recognised through several best paper awards.

Prof Ronny Webber-Youngman and Dr Johann Uys, both from the Department of Mining Engineering, received the best paper award from the international Society of Mining Professors. The paper, titled "A 4.0D™ Leadership Model for mining and related industries in the context of the Fourth Industrial Revolution", explores the development of this model.

Dr George Thopil from the Graduate School of Technology Management (GSTM), along with his master's student, Norah Mahlangu, received the award for Best Paper from the Southern African Institute of Industrial Engineering. This paper, titled "Life cycle analysis of external costs of a parabolic trough concentrated solar power plant", evaluated external impacts and costs for climate change, human health, loss of biodiversity, the local effects on crops and damage to materials.

During the 14th International Conference on Heat Transfer, Fluid Mechanics and Thermodynamics, four papers from the Clean Energy Research Group (CERG) in the Department of Mechanical and Aeronautical Engineering received best paper awards. The researchers responsible for these papers are Prof Ken Craig, Dr Marilize Everts and PhD student Wilhelm van den Bergh. The CERG is led by Prof Josua Meyer, one of the Faculty's National Research Foundation (NRF) A-rated researchers.

Student achievements

Corobrik regional architecture award

Annemie Vermeulen, an alumna of the Department of Architecture, won the 33rd annual Corobrik regional architecture award.

Annemie is one of eight young architects from top South African universities to receive this award in recognition of her design talent and innovation. Her dissertation was titled “Exploring the potential of latent space in the inner city of Pretoria: Toward architectural remedies for regenerating and weaving latent urban fabric and spaces”. The dissertation re-imagines architecture from separated built objects to threads of spaces interlinked by open areas that encourage interaction between different city users.

SAIMM Student Colloquium

Two of the Faculty’s students received recognition for their excellent projects at the 16th Annual Student Colloquium of the Southern African Institute of Mining and Metallurgy (SAIMM).

This event is intended to give the best students in the fields of mining and metallurgy an opportunity to present their final-year projects, and industry experts have the opportunity to meet top young professionals who are about to embark on their careers in industry. Shonny Thuketana from the Department of Materials Science and Metallurgical Engineering placed first, and Lulama Mthembu from the Department of Mining Engineering placed third.

2019 Greenovate Awards

The Greenovate Awards resulted from the collaborative efforts between Growthpoint Properties and the Green Building Council South Africa (GBCSA). Its intention is to encourage students to learn about green buildings and sustainability.

The research project of Henno de Villiers and Liné Grobler from the Department of Construction Economics was named the 2019 winner. Their research project was called "Pushing back Day Zero – water-saving strategies for me and you".

Challenge accepted!

Each year, student teams from the Faculty fare extremely well in local intervarsity engineering challenges. These students demonstrate their ability to translate the knowledge gained in their study programmes into real-world solutions.

The Faculty’s teams were awarded the Best University certificate in the 2019 Aeronautical Society of South Africa Intervarsity Flight Competition after they took first and third places. Here, final-year aeronautical engineering students built their own model aircraft and competed in the Balls Speed Race. The University of Pretoria’s TuksBaja team also emerged as the overall winner in this year’s action-packed Baja South Africa Competition of the Society of Automotive Engineers (SAE). This is an international engineering design competition in which undergraduate students have to conceptualise, design, manufacture and test an off-road car that complies with strict safety rules.

Academic activities

Course for Managers in Risk Management

The Faculty's Department of Mining Engineering launched a specialised Course for Managers in Risk Management (c-MiRM) in collaboration with Enterprises University of Pretoria.

The c-MiRM is aligned with internationally benchmarked risk management standards, and comprises seven modules with interactive assignments. It can be taken as a series of short courses over one, three or four days, as a two-day refresher course, or as a longer Fundamentals Programme (12 contact sessions over 10 months) or an Advanced Programme (17 contact sessions over six months). The course presenter, Albert van der Vyver, is an experienced risk management consultant with a wealth of experience in the mining sector. He is internationally recognised for his expertise in safety, health and environmental risk management, and assessment.

CODATA-RDA Research Data Summer School

The Faculty's Department of Information Science, in collaboration with the Data-Intensive Research Initiative of South Africa (DIRISA), South African Centre for Digital Language Resources (SADiLaR) and Network of Data and Information Curation Communities (NeDICC), presented a CODATA-RDA Research Data summer school in January 2020.

This is the first summer school presented in South Africa and provided early career researchers with foundational data science skills. The participants were exposed to several useful tools and technologies, while also gaining technical skills for responsible and reproduceable research practices. This will enable the students to work with their data in the transparent, effective and efficient manner required by 21st-century research practices.

Third Technology and Innovation Conference

The University of Pretoria, in collaboration with Gerotek, Applus IDIADA and the CSIR, hosted the Third Technology and Innovation Conference on the theme: "Automotive development for Africa: Local challenges and technology solutions".

The conference included two keynote addresses: "Create a Dream" by Carel Snyman, in which he described his journey of developing battery electric vehicles in South Africa for South Africa, and "Public Transport Strategic Plan" by MEC Jacob Mamabolo, in which he emphasised the cost of road accidents to society and the economy.

#1 The Faculty's Department of Materials Science and Metallurgical Engineering has been ranked top in South Africa by the Minerals Education Trust Fund.

The Minerals Education Trust Fund (METF) was established by the minerals and mining industry in South Africa, with a view to bolstering universities' activities in this sector. South African mining and minerals companies contribute annually to the fund to enhance the sustainability of specific departments at universities. Graduates from the Department are highly sought after in industry.

Increasing access to science and engineering education in South Africa

Faculty support for Eskom Expo for Young Scientists

Representatives from the Faculty attend the Eskom Expo for Young Scientists each year to identify learners with potential in the fields of science and engineering.

This year, the Faculty awarded bursaries to two deserving learners at the International Science Fair (ISF). Momelezi Nokele from Mthatha High School, whose project was titled "Waste-water: Energy for the future", was provisionally accepted for studies in mechanical engineering, and Sahiba Adam from the Abdullah Bin Salaam Islamic Centre (ABSIC) School impressed the judges with her project titled "Artificial intelligence to save electricity".

During October 2019, Executive Director of the Eskom Expo for Young Scientists ISF, Parthy Chetty, entered into discussions with both the Dean of the Faculty, Prof Sunil Maharaj, and the Deputy-Dean: Research and Postgraduate Education, Prof Jan Eloff, regarding expanded collaboration between the Expo and the Faculty. Although the bursaries offered by the University attract some of the most talented participants in the Expo, Eskom has indicated a need to explore the possibility of closer relationships, for example by pioneering a mentorship programme and inviting key judges from the Faculty to participate in the Expo. He emphasised the fact that since many of the participating learners, especially those from the townships, never have an opportunity to see or speak to a real engineer or scientist, interaction with academics has a remarkably positive impact on them as it makes them realise that it is possible to achieve their goals and change their lives.

An agreement was reached between the Faculty and the Eskom Expo to recruit more senior students to be trained on-site as judges. This partnership is also beneficial to the Faculty as it attracts more students to the fields of engineering and information technology, and stimulates them to register for postgraduate programmes in which the focus is more on research.

EBIT Curriculum Transformation Committee (CTC)

The Faculty's transformation efforts are supported by the EBIT-CTC, a structure that assesses teaching and learning in accordance with the UP Curriculum Transformation Framework. The Committee is the custodian of the Faculty Transformation Plan.

According to Prof Tawana Kupe, Vice-Chancellor and Principal of the University of Pretoria, the institution is a transforming agent that strives to make life-improving contributions to society, and to create a future for all where everyone is welcome. A future-orientated Faculty must continuously encourage transformation that will last by enabling all stakeholders to co-create a new embracing institutional culture. The ability to do this will enable both the University and the Faculty to become a force to be reckoned with on the global stage.

LAST WORD

The roots of science and physics:

Sir Isaac Newton

– the mathematical genius

As legend has it, a young Isaac Newton was sitting under an apple tree, contemplating the mysteries of the universe, when an apple fell from the tree and hit him on the head. In a flash of insight, he came to realise that the force that made the apple fall to the ground was the same force that kept the planets in their orbits around the sun and the moon in its orbit around the earth. This is commonly perceived to be the origin of the theory of gravity.

AFTER DINNER, THE WEATHER BEING WARM, WE WENT INTO THE GARDEN AND DRANK TEA UNDER THE SHADE OF SOME APPLE TREES... HE TOLD ME HE WAS JUST IN THE SAME SITUATION AS WHEN FORMERLY THE NOTION OF GRAVITATION CAME INTO HIS MIND. IT WAS OCCASIONED BY THE FALL OF AN APPLE, AS HE SAT IN CONTEMPLATIVE MOOD. WHY SHOULD THAT APPLE ALWAYS DESCEND PERPENDICULARLY TO THE GROUND, HE THOUGHT TO HIMSELF...

William Stukeley, biographer

How true this legend is, is open to debate, but one thing is certain. Sir Isaac Newton was one of the disruptive thinkers of his time, whose theories have gone on to shape everything from science and physics to engineering.

Born on Christmas Day in 1642, Newton is best known for having invented calculus in the mid- to late-1660s (almost a decade before Leibniz did so independently, and ultimately more influentially), and for having formulated the theory of universal gravity. Yet, he also made major discoveries in optics, beginning in the mid-1660s and spanning four decades. During the course of his 60 years of intense intellectual activity, he put no less effort into chemical and alchemical research, and into theology and biblical studies, as he put into mathematics and physics.

He is regarded as the first, and possibly the greatest, of all scientists. His discoveries and method transformed the nature and practice of learning, facilitating the modern world to such an extent that he has a good claim to be the most influential thinker that ever lived. The publication of his *Principia* in 1687, the single-most important work in the transformation of early modern natural philosophy into modern physical science, made him a dominant figure in Britain. As a result, “Newtonianism”, in one form or another, became firmly rooted in Britain in the first decade of the 18th century.

However, Newton’s influence on the continent was delayed by the strong opposition to his theory of gravity by leading figures such as Christiaan Huygens and Gottfried Leibniz, both of whom saw his theory as invoking an occult power of action at a distance in the absence of Newton having proposed a contact mechanism by means of which forces of gravity could act.

As the promise of the theory of gravity became increasingly substantiated between the 1740s and 1750s, Newton became an equally dominant figure, and “Newtonianism” flourished in Europe as well. What physics now refers to as “Newtonian mechanics” and “Newtonian science” consists mostly of the results achieved in the latter half of the 18th century.

NEWTON'S EARLY YEARS

His father, a farmer, died at the age of 36, before Newton was born. He grew up in Lincolnshire, in the east of England. His mother remarried in 1646, leaving him to be raised by his maternal grandparents. Many biographers point to the trauma of the separation from his mother as the root of many of his emotional issues. His childhood years were a turbulent time in the history of England. The English Civil War had begun in 1642, King Charles was beheaded in 1649, and Oliver Cromwell ruled as Lord Protector from 1653 until 1658, followed by his son Richard from 1658 to 1659, leading to the restoration of the monarchy under Charles II in 1660.

A simplified version of Sir Isaac Newton's family tree.

THE CAMBRIDGE YEARS

Newton's initial education in Trinity College at Cambridge University was classical, focusing on Aristotlean rhetoric, logic, ethics and physics. By 1664, he had begun reaching beyond the standard curriculum, reading, for example, the 1656 Latin edition of Descartes' *Principles of Philosophy*. He also started teaching himself mathematics, taking notes on works by Oughtred, Viète, Wallis and Descartes. In less than 18 months, he had mastered the entire body of mathematics known to the West.

During a period of almost two years between 1665 and 1667, during which time the university was closed due to the Bubonic Plague, he made his experimental discoveries in optics and developed the mathematical theory of uniform circular motion, in the process noting the relationship between the inverse square and Kepler's rule relating the square of the planetary periods to the cube of their mean distance from the sun. This led to his "discovery" of gravity.

Historians of science are still in awe of how much he achieved in so little time. According to DT Whiteside, the pre-eminent expert on Newton's mathematics, "Never did 17th-century man build up so great a store of mathematical expertise, much of his own discovery, in so short a time", while Derek Gjertsen wrote that: "in a remarkably short period, the 24-year-old student created modern mathematics, mechanics and optics. There is nothing remotely like it in the history of thought."

By late 1666, he had become *de facto* the leading mathematician in the world, having extended his earlier examination of cutting-edge problems into the discovery of calculus. He returned to Trinity College as a Fellow in 1667, where he continued his research in optics, constructing his first reflecting telescope in 1669. In October 1669, he assumed the position of Lucasian Professor of Mathematics.

> **…IF IT UNIVERSALLY APPEARS, BY EXPERIMENTS AND ASTRONOMICAL OBSERVATIONS, THAT ALL BODIES ABOUT THE EARTH GRAVITATE TOWARDS THE EARTH…THAT THE MOON LIKEWISE…GRAVITATES TOWARDS THE EARTH; THAT…OUR SEA GRAVITATES TOWARDS THE MOON; AND ALL THE PLANETS MUTUALLY ONE TOWARDS ANOTHER; AND THE COMETS IN LIKE MANNER TOWARDS THE SUN; WE MUST…UNIVERSALLY ALLOW THAT ALL BODIES WHATSOEVER ARE ENDOWED WITH A PRINCIPLE OF MUTUAL GRAVITATION."**
>
> *Sir Isaac Newton,* Principia

Over the course of the next 15 years, he presented lectures and performed research in a variety of areas. By 1671, he had completed most of a treatise-length account of calculus, which he then found no-one would publish. This failure appears to have diverted his interest in mathematics from calculus for some time. His lectures between 1670 and 1672 concerned optics, with a range of experiments presented in detail.

Newton went public with his work in optics early in 1672, submitting material that was published in the *Philosophical Transactions of the Royal Society*. With these findings, he proved himself to be a man ahead of his time. This led to four years of exchanges with various figures who challenged his claims, including Robert Hooke and Christiaan Huygens. Before he largely isolated himself in the late 1670s, he had also engaged in a series of long exchanges in the mid-1670s, most notably with John Collins and Gottfried Leibniz, concerning his work on calculus. Thus, although they remained unpublished, Newton's advances in mathematics scarcely remained a secret.

Between 1684 and 1687, Newton concentrated his energies on the research that would develop into his 500-page *Principia*, with its 192 derived propositions. Initially, the work was to have a two-book structure, but it subsequently filled three books. The publication of this research thrust the 44-year old Newton into the forefront of natural philosophy, forever ending his life of comparative isolation.

The first two books set out the laws of forces of motion, while the third, which he called his "system of the world", showed the application of these laws, including the theory of universal gravitation. In the third book, he succeeded in synthesising the two major strands of natural philosophy: Galileo's theories of earthly mechanics, and Kepler's theories of celestial mechanics. Prior to this, no-one had come close to marrying these two disciplines, yet Newton accomplished it single-handedly in the space of two decades.

The Frontispiece of Voltaire's *Elements del la Philosophie de Newton*

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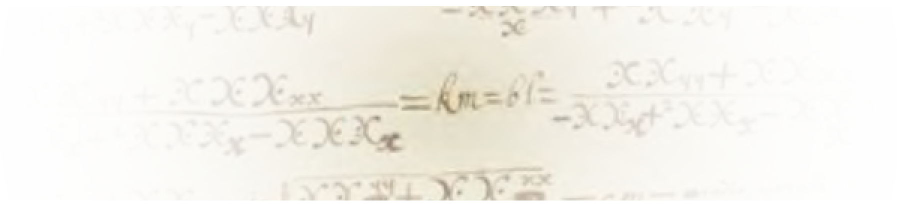
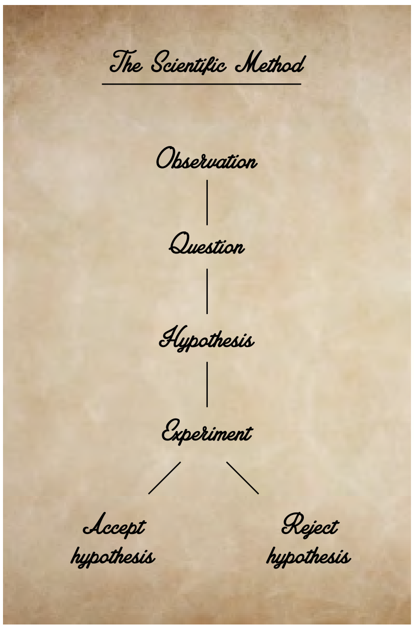


Previously, natural philosophers had relied on logic, authority and sometimes experience, and the result was speculation, hypothesis and opinion. However, Newton demonstrated a new way of doing philosophy (or research). This was known as the scientific method. He insisted on having specific phenomena decide each element of theory, with the goal of limiting the provisional aspect of theory as much as possible to the step of inductively generalising from the specific phenomena. Arguments based on induction should thus be nullified by the hypotheses. The scientific method he developed is still in use today.



The commitment to empirically driven science was a hallmark of the Royal Society. Newton took this commitment further by displaying how a rich set of theoretical results can be secured through well-designed experiments and mathematical theory. The success of those after him building on these theoretical results completed the process of transforming natural philosophy into empirical science.

Due to Newton's ideas of force and motion, attraction and orbits, a young astronomer, Edmond Halley, became one of his greatest disciples. Based on Newton's calculations, Halley amazed the public with his prediction that the comet of 1682 (known as Halley's Comet) would return every 76 years. In 1715, he also used Newton's system to predict a total solar eclipse.

In Newton's introduction to his three famous laws of motion, he redefined time and space to give them meaning. Centuries later, Albert Einstein would prove a very different account of time and space in his theory of relativity. However, he himself rejected claims that he had "disproved" Newton's theory, stating: "Let no-one suppose that the mighty work of Newton can really be superseded by this or any other theory."

Credit: Britannica

Newton's laws of motion

Law 1: Every body perseveres in its state of being at rest or of moving uniformly straight forward, except insofar as it is compelled to change its state by force impressed.

Law 2: The change of momentum of a body is proportional to the impulse impressed on the body, and happens along the straight line on which that impulse is impressed.

Law 3: For a force there is always an equal and opposite reaction: or the forces of two bodies on each other are always equal and are directed in opposite directions.

In January 1689, following the Glorious Revolution at the end of 1688, Newton was elected to represent Cambridge University in the Convention Parliament, which he did until January 1690. During this time, he formed friendships with John Locke and Nicolas Fatio de Duillier. In 1689, he met Christiaan Huygens for two extended discussions. Perhaps because of disappointment with Huygens not being convinced by his argument for universal gravity, Newton initiated a radical rewriting of *Principia*. During this time, he also wrote his principal treatise in alchemy, *Praxis*.

He allowed Locke to read some of his writings on the subject, and made a renewed effort to revise his work on calculus in a form suitable for publication. He also carried out experiments on diffraction with the intent of completing his *Optics*, only to withhold the manuscript from publication because of dissatisfaction with its treatment of diffraction. He also abandoned his radical revision of *Principia* in 1693 when he suffered a nervous breakdown. In the two years following his recovery, he continued his experiments in chemistry, and put substantial effort into trying to refine and extend the gravity-based theory of the lunar orbit in *Principia*, but with less success than he had hoped.


Credit: National Geographic

THE LONDON YEARS

In early 1696, Newton accepted the position of Warden of the Mint, a position he held until he became Master of the Mint at the end of 1699. He again represented Cambridge University in Parliament for 16 months from 1701, the year in which he resigned his Fellowship at Trinity College and the Lucasian Professorship. He was elected President of the Royal Society in 1703 and was knighted by Queen Anne in 1705. Newton thus became a figure of imminent authority in London.

Although he obviously had far less time available to devote to solitary research, he did not entirely cease to be productive. The first edition of his *Optics* finally appeared in 1704, appended to which were two mathematical treatises, his first work on calculus to appear in print. This edition was followed by a Latin edition in 1706 and a second English edition in 1717, each containing important queries on key topics in natural philosophy beyond those in its predecessor. In the queries, Newton gave free reign to his scientific imagination. In doing so, he proved himself to be breathtakingly prescient, for the queries seemed to foreshadow many aspects of modern physics, from the mechanism of electricity to quantum physics, from gravitational lensing to $e = mc^2$. They even approach the unified theory of natural forces that remains the holy grail of physics to this day.

Newton's ultimate goal in *Principia* had been to derive a theory that unified the macroscopic scale of the chemicals in his alchemist's crucible. He had been unable to prove such a theory, but in his final query, he described his thinking on the matter: "Have not the small particles of bodies certain powers, virtues or forces by which they act at a distance, not only upon the rays of light for reflecting, refracting and inflecting them, but also upon one another for producing a great part of the phenomena of nature? For it is well known that bodies act one upon another by the attractions of gravity, magnetism and electricity, and these instances show the tenor and course of nature, and make it not improbable but that there may be more attractive powers than these."

This passage has been interpreted as describing how atoms attract and interact with each other (the theory of chemical valencies), possibly even foreshadowing the discovery of subatomic forces, such as nuclear forces and electrostatic energy, anticipating much of the modern model of physics.

Other earlier work in mathematics began to appear in print, including a work on algebra, *Arithmetica Universalis* in 1707 and *De Analysi*, and a tract on finite differences, *Methodis Differentialis* in 1711. The second edition of *Principia*, on which Newton had begun work in 1709 at the age of 66, was published in 1713.

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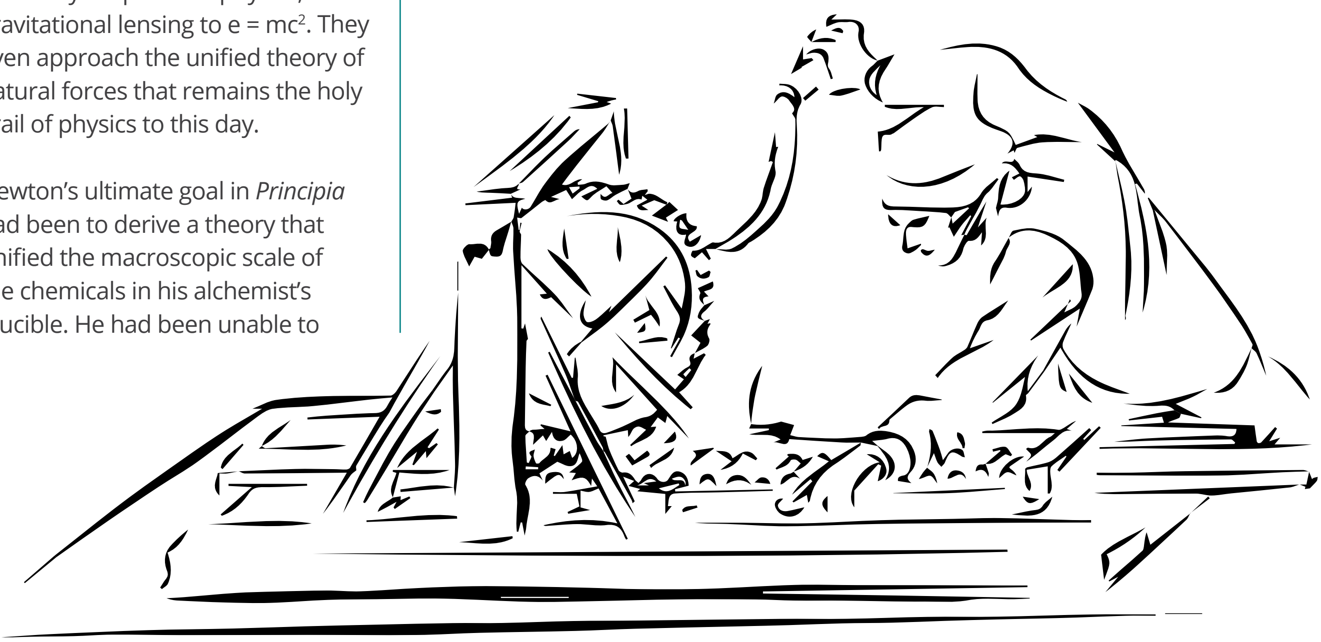


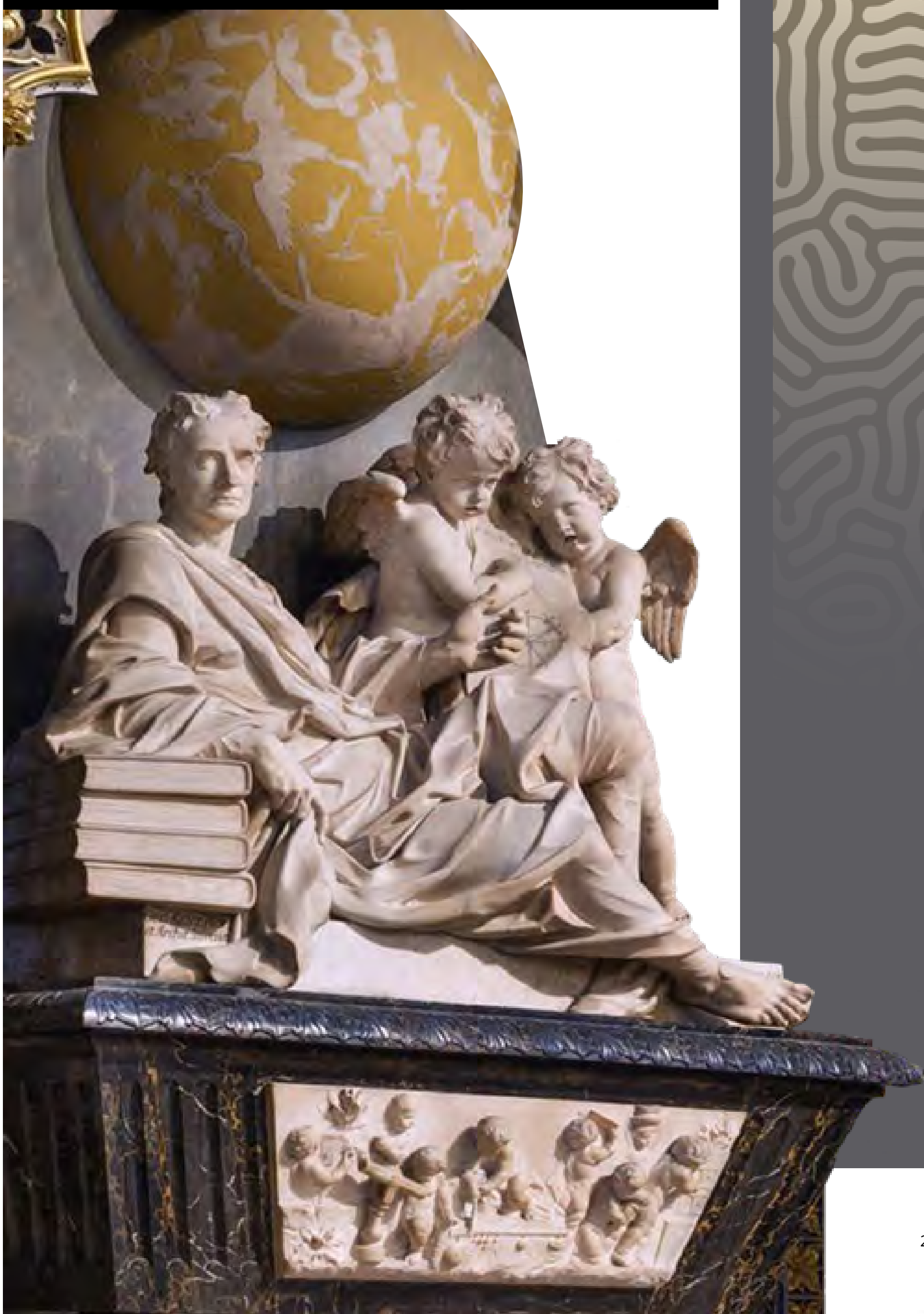
The Mint's milling or edging machine.

THE FINAL YEARS

Although the original plan for a radical restructuring of *Principia* had long been abandoned, the fact that virtually every page received some modifications in the second edition shows how carefully Newton reconsidered everything in it. Important parts were substantially rewritten, not only in response to continental criticism, but also because of new data, including data from experiments on resistant forces carried out in London.

Focused effort on the third edition began in 1723, when Newton was 80 years old. While the revisions were far less extensive than those of the second edition, this edition contained substantive additions and modifications, and surely has claim to being the edition that represents his most considered views.

Newton died on 20 March 1727 at the age of 84, and was afforded a grand state burial in Westminster Abbey, possibly the first man to have been so honoured for his intellectual achievements alone. His contemporaries' conception of him nevertheless continued to expand as a consequence of various posthumous publications.



In memoriam: Prof Paul Kruger

It is with great sadness that the editorial staff of *Innovate* learnt of the passing of Prof Paul Kruger on 11 December 2019. As a former Head of the Department of Industrial and Systems Engineering, Prof Kruger initiated the series of articles published as "Last Word" in *Innovate* in 2011, in which he focused on the life and work of the world's great scientists who played a role in the development of engineering theory. This series, compiled by Prof Kruger until 2018, soon became a highlight for many readers. Although Prof Kruger retired in 2009, he continued to serve as a part-time professor in the Department of Industrial and Systems Engineering until 2015. He obtained all his qualifications (undergraduate and postgraduate) from the University of Pretoria. He was also a founding member of both the South African Institute of Industrial Engineering and the Operations Research Society of South Africa.