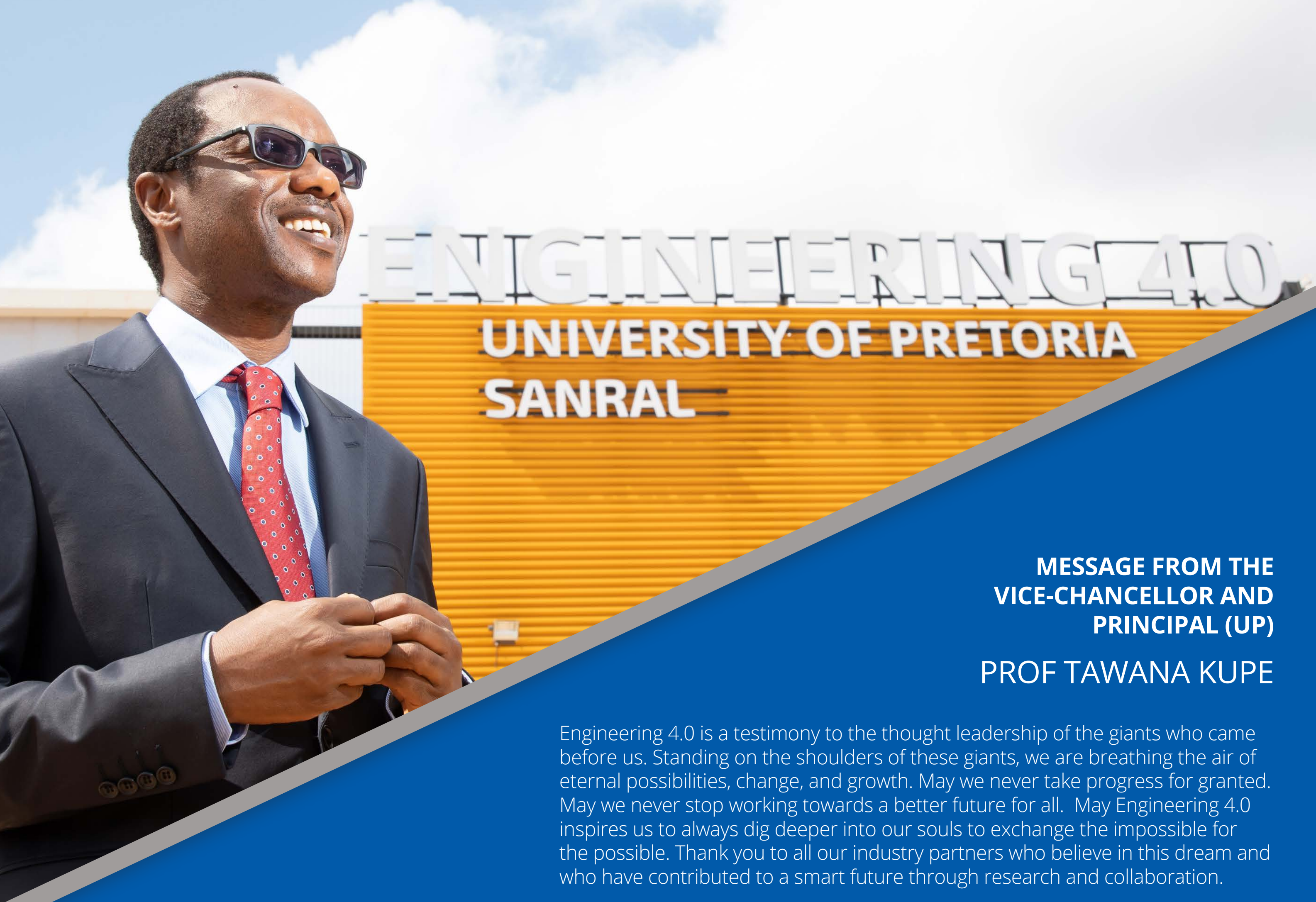

MESSAGE FROM THE VICE-CHANCELLOR AND PRINCIPAL (UP)

PROF TAWANA KUPE

Engineering 4.0 is a testimony to the thought leadership of the giants who came before us. Standing on the shoulders of these giants, we are breathing the air of eternal possibilities, change, and growth. May we never take progress for granted. May we never stop working towards a better future for all. May Engineering 4.0 inspires us to always dig deeper into our souls to exchange the impossible for the possible. Thank you to all our industry partners who believe in this dream and who have contributed to a smart future through research and collaboration.

MESSAGE FROM THE CHIEF EXECUTIVE OFFICER (SANRAL)

MR SKHUMBUZO MACOZOMA

The Engineering 4.0 facility symbolizes the intersection of skills development, cutting edge research, and the generation of much-needed innovation for application in the development and preservation of SA's road infrastructure.

UNIVERSITEIT VAN PRETORIA
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SANRAL
SOUTH AFRICAN NATIONAL ROADS AGENCY SOC LTD
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BUILDING SOUTH AFRICA THROUGH BETTER ROADS

FACULTY OF ENGINEERING, BUILT ENVIRONMENT AND INFORMATION TECHNOLOGY

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).

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.

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.

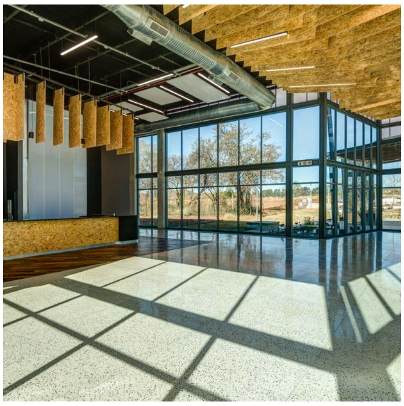
It is anticipated that the tripartite partnership will provide the following:

- 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.



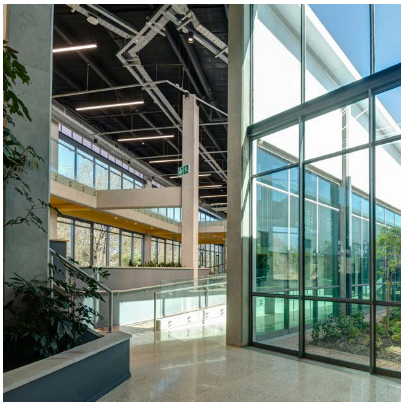
Designing

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

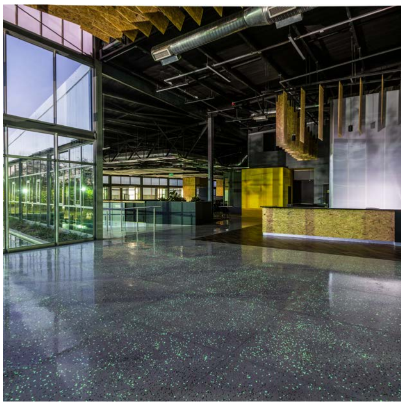
The design brief for Engineering 4.0 when the project was initiated in 2016 was to develop a facility that could operate as both a learning and a testing facility in an all-inclusive design. The building would have to accommodate a civil engineering laboratory with smaller laboratories, and should bring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

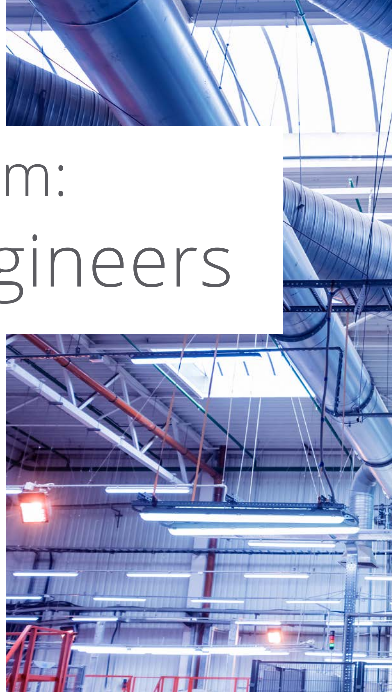
All external concrete walls have a tilt-up design, which involves the casting of wall elements in stacks and lifting them into position on pad foundations. This approach made sense due to the weak soil conditions and extensive foundations that would have been required if normal brick-type walls were 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.

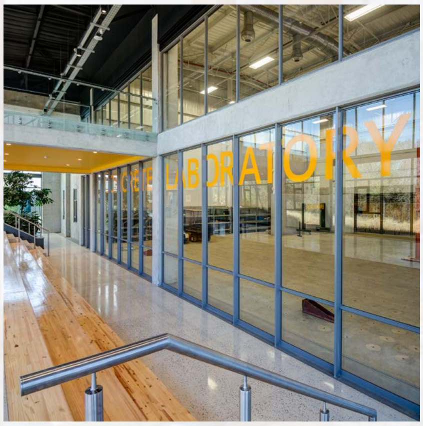
A living laboratory for Civil Engineering

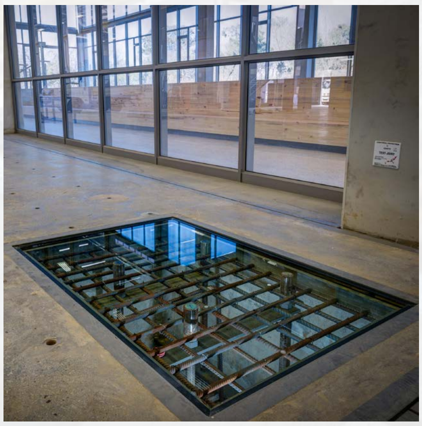
An important component of the training of civil engineers entails ensuring that graduates have superior knowledge of the development and maintenance of civil engineering infrastructure. The design and construction of the new building therefore includes elements that function as a living laboratory for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

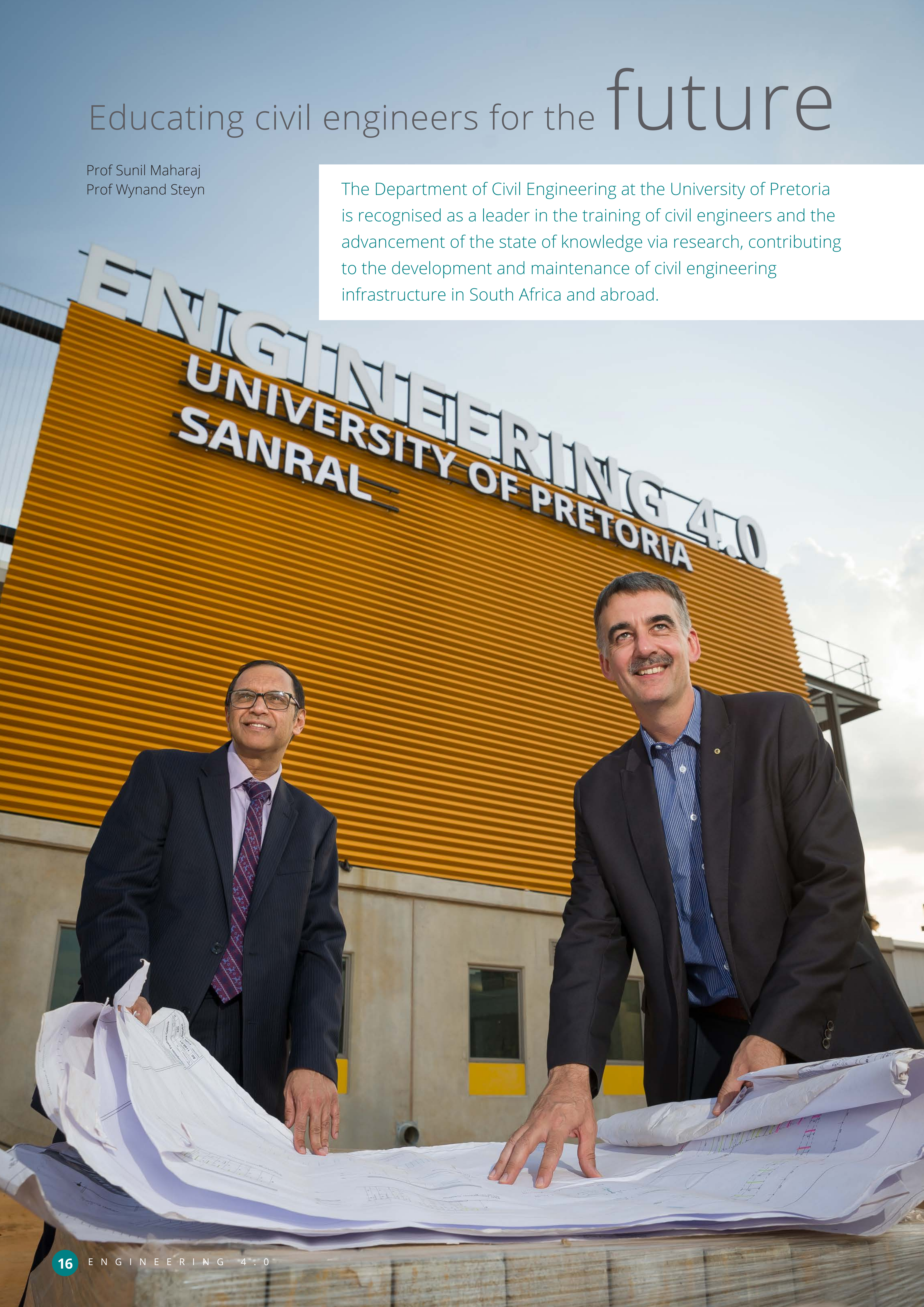
This creates an additional educational opportunity for lecturers from the Department, as well as other departments in the Faculty.

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. ❸

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/

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