DIGITAL INNOVATIONS IN INFRASTRUCTURE - BRINGING IDEAS TO LIFE

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ABSTRACT

Building infrastructure servicing the modern world can be very costly. Once built, operational and maintenance costs if under estimated can burden asset owners over the entire life cycle, often to the detriment of other projects. This poses significant challenges for those who are charged with looking after those assets. Unexpected impacts from natural disasters can reduce the lifetime and increase operational and maintenance costs. Increased or unexpected higher use of the asset also has the potential to reduce the operational lifetime. This was quite evident in New Zealand where infrastructure was heavily impacted by severe earthquakes occurring over the past decade. Global warming and climate change are also associated with reduced lifetimes and higher life cycle costs.

Over many years, Aurecon's teams across the globe have worked alongside our partners from governments at various levels to provide more effective solutions to infrastructure needs, reduce operational costs and increase lifespans. After the devastating earthquakes in New Zealand in 2010 to 2011 and 2016, new approaches were sought to assess damage and provide clearer, better and more concise information to decision makers to enable faster recovery. The new approaches were also used to offer better operational efficiencies with higher resilience, and to provide more clarity for longer term asset management.

This paper will, by way of example, review several local and central government infrastructure renewal projects where new innovative methods of data acquisition, data processing and visualisation were used to enable better and saver decision making. The interaction between engineers and other stakeholders such as local municipalities, central government agencies and the general public will be examined and the impact of new and innovative technologies will be critically discussed. These technologies include autonomous airborne and terrestrial unmanned vehicles equipped with imaging equipment able to generate highly accurate point clouds and interactive 3D models. The use of virtual and mixed reality environments for data review, analysis, stakeholder interaction and communication with the wider public will be presented by way of example. The use of Artificial Intelligence engines for highly accurate analysis of big data will be demonstrated and compared with more traditional methods. The benefits new technology brings to the modern infrastructure design, construction, operation and maintenance will be clearly shown. This paper will provide a snapshot of selected examples and describe work undertaken by many people in the wider global Aurecon Group for local and central government clients and how we brought ideas to life.

1 INTRODUCTION

> *‘**Climate change is real, and having a tangible effect on infrastructure and communities**, and increasingly placing infrastructure providers under extensive strain.*
> *Reactive management … is often distracting us from working on strategy, feasibility and design and delivery of resilient infrastructure...’*
>
> **Resilient Infrastructure Workshop 2018, Christchurch, NZ**

This paper was written on the back of the work undertaken over the past eight years following the Canterbury Earthquake Sequence in Christchurch in 2010, and the Kaikoura earthquake sequence in 2016. The key question for the reader should be: Are the topics discussed here going to be relevant in another context or is this paper solely related to earthquake damage and recovery efforts arising from major natural disasters? The authors believe that the lessons we learned working through our recovery will be equally relevant to others, struggling with disruption. The tools and techniques we developed, adopted or discarded should be relevant anywhere in the world as we believe they were developed around human centric needs for infrastructure provision.

Earthquakes are not the most disruptive of natural disasters. Some may argue that tsunamis, like those generated in Japan in 2011 and around the Indian Ocean in 2004, or large-scale flooding are far more destructive. Volcanic eruptions also may cause high human and economic impacts. Earthquakes and volcanism, with all their associated hazards certainly appear to affect a large population and impact economies. Arguably sea level rise due to climate change may be even more challenging to where we live and how it will stress aging infrastructure. Desertification and change in rainfall patterns may significantly affect where and how people live. In the past, where people were affected by disruptions often there was the option to shift to another place. Nomadic tribes manage resources slowly by moving around and allowing (sustainable) recovery of resources. However, our planetary population is rapidly approaching eight billion with no slowdown in sight. Most people nowadays are already living near vulnerable areas or areas that are likely to be affected by climate change related disruptions in the future. This paper is about infrastructure, we believe that our infrastructure will be severely stressed by maintaining our current standard of living or increasing the standard of living in certain geographic areas. Civil Engineering with all its specialties will be called upon to find new ways to either adapt existing infrastructure to accommodate new demands; or provide new infrastructure that will be more adaptable to future stressors than existing systems. How often is a newly opened road already congested or a water supply network already at capacity with little ability to increase in demand?

This paper shows several completed projects, where the authors designed, supervised and/or observed the delivery. The intent of the paper is to weave a story on how challenges were identified, addressed and overcome using innovation, digital tools and resilience. The authors hope that our combined experiences will help the reader to better understand challenges and opportunities associated working in modern infrastructure.

2 NEED FOR RESILIENT INFRASTRUCTURE

Adapting to change by an organism or system is called ‘resilience’. Resilience describes the ability of a system to react to disruptions and changes. Infrastructure resilience can be described and measured, with performance targets specific to an event.

The current renewal of infrastructure is a continuous process. In addition, there is the parallel process of managing the future demand for infrastructure that is subject to external stressors and disruptions. However, these future external stressors and disruptions are not understood; examples could range from population growth being more rapid than anticipated, the reaction to changes in the local climate or addressing impacts from natural disasters like floods, droughts, earthquakes or volcanism. Anticipating infrastructure needs over the projected lifespan of a piece of infrastructure is more akin to wizardry than engineering. Although, there are tools and techniques that can assist in finding solutions, the ability to predict infrastructure demands is very challenging.

Experience and research over the past few decades has indicated that resilient infrastructure, i.e. able to cope with short term stressors, is also much more able to adapt to slow changes. New materials, installation, construction and maintenance methods introduced over the past three decades mean that infrastructure provision is becoming more efficient. For example, plastic nowadays has widely replaced vitrified clay waste water pipes. As a result, construction and maintenance costs have generally decreased due to the wide availability of plastic, faster installation methods and their ability to deal with ground movement much better than rigid materials. Further, plastic pipes of larger diameters are possible, providing a significant increase in the cross-sectional area and therefore the ability to transfer larger volumes of liquid for little additional cost. Combining different materials such as spun concrete pipes with a polyethylene plastic lining increases the lifetime of the pipe and increases sustainability. Thus, composites are

> *‘Infrastructure resilience is the ability to reduce the magnitude and/or duration of disruptive events. The effectiveness of a* ***resilient infrastructure*** *depends upon its ability to anticipate, absorb, adapt to, and/or rapidly recover from a potentially disruptive event.’*
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> ***National Infrastructure Advisory Council, Homeland Security, USA***

being used more and more to find the optimal mix of material properties and their function. More recently the ability to rehabilitate older pipes with the use of inflatable liners provides a means to extend the service life without costly disruptions to dig out and replace.

After the earthquakes in Christchurch there was an urgent need to rebuild the damaged infrastructure and services. The majority of the infrastructure rebuild, however, was funded by insurances. This created the problem that replacement was meant to be ‘like for like’ and changes in say pipe diameter was considered ‘betterment’. The insurer only contributed funding for pipes of a similar diameter. However, modern materials were used for their obvious benefits and lower cost. The piped network in Christchurch has benefitted greatly from the replacement of the traditional materials over a large portion of the network. In many areas, the network was near the end of its service life and modern materials enabled easier construction methods and better resilience.

Other infrastructure projects were more complex, for example the replacement and repair of the marine revetment structure alongside a major roading corridor. This project was only funded to re-establish the structure to the original crest height with no provision for a potential increase in wave run up heights due to climate change. In this instance Council designers utilised smart engineering. The revetment was designed with the future crest heights increased further to resist future, bigger storm events by using armour rock sizes expected in 50 years. This caused a minimal increase of construction costs, i.e. there were minimal costs involved to specify the slightly larger rock armour required to dissipate the larger wave run up heights. This is an example where design decisions could specify an end product that has built in resilience. However this is also an example where we are relying on the current estimates of what the revetment structure will be exposed to in the future. Should there be a conversation between those setting the criteria and the engineers to determine the cost of allowing for additional resilience? In this situation the cost was minimal for additional future resilience – what would the cost have been to go up again to the “next level” of resilience for that structure and would it have been worth it?

The challenges to infrastructure resilience and smart engineering is the ability to recognise key issues at an early stage and predict their impact over the lifetime. More information, institutional knowledge and use of data have proven to underpin the ability to make smart decisions. Digital tools can collect, process, analyse and visualise the necessary information to make smart decisions.

3 DATA CAPTURE AND INFORMATION MANAGEMENT

Capturing relevant data is critical for all subsequent decision-making steps. Flawed data will not deliver correct outcomes no matter what analytical tool is used. Collecting information in a non-coherent and disorganised manner, or mismanagement of collated information will greatly compromise the user’s ability to analyse and interpret the data in any meaningful manner. Digital tools can greatly assist with data capture, checking data integrity at the time it is being collected and provide redundant storage preventing accidental or deliberate data loss. Further, digital tools can identify where the need for intervention is highest and allow monitoring of effect and change.

In Christchurch, following the earthquakes of 2010, the demand to assess infrastructure damage significantly increased after the initial earthquake and further escalated once the quantum of infrastructure damage was better understood. Broken facilities and lack of accommodation as well as reoccurring aftershocks provided little incentives for out of town staff to relocate to Christchurch. Many tasks included field work, inspections and interactions with clients, government officials and colleagues. This made offshoring or work sharing difficult, and created an immense resource pressure that was unable to be covered using traditional approaches to project delivery in the professional services industry. The need to deliver work in a more streamlined, smarter and innovative way was urgently needed.

Geospatial or Geographic Information Systems (GIS) are tools for the collation, storage, management and analysis of geospatial information. GIS can accept data from various consultants, external parties, client organisations and stakeholders. The key of any GIS platform is its ability to receive and share information streams. New Zealand had no appropriate GIS in place to collect, analyse or visualise any geospatial geotechnical or geological information. No sole government agency or entity managed geotechnical geospatial information or provided any standards to create a working GIS platform.

In Christchurch the volume of damage was staggering and resources were thin on the ground. The ability to capture data digitally in the field was recognised very early on and rudimentary programmes were established on mobile devices and tablets. Over time as more information was captured the need to integrate, compare and verify field data become critical. Data capture duplication was avoided as mobile devices updated and synchronised with the centralised data in real-time, enabling field teams to see on a map where other teams were working and where data gaps existed. Geofencing, by creating a virtual geographic perimeter, prevented field teams entering high hazard areas not readily detectable in the field. Digital information, such as property boundaries, geohazards, identified infrastructure assets, etc., were available to the field teams allowing the data to be captured much more quickly than conventional pen and paper methods.

The sudden flood of geospatial data from multiple field crews, comprising multiple agencies working on various projects necessitated the development of a geospatial data management tool. Although, multiple systems are commercially available an in-house GIS based document management and visualisation tool nicknamed GeoDocs was developed. The main feature of GeoDocs was its ability to georeference information, visually represent data and interact with other GIS databases, historically plagued by inter compatibility issues. GeoDocs enabled the tracking of individual documents through the various versions and approvals from the start of the document to the final issue. This tracking feature meant project managers could concentrate on managing deliverables and client requests, in a high stress environment where delivery of project milestones was paramount, knowing that the Quality Assurance was taken care of. Although, the above appears to be very similar to a conventional document and project management tool, GeoDocs enabled the team to see the data in various forms and follow the document trail visually. The “team” often comprised representatives from multiple organisations and all could be given appropriate access permissions. GeoDocs proved to be such a benefit to managing complex projects that it has become the main project control tool globally and it is now being used for tunnels, infrastructure, defence, environmental and building projects.

3.1 City of Tshwane Municipal Infrastructure Data Capture

Having already discussed the need to know the location and conditions of municipal infrastructure as bring critical for sound decision making, the City of Tshwane recognised the necessity and complexity of the task and commissioned a fully paper less data collection. The infrastructure assets covered in this assessment were: energy and electricity, solid waste and landfill provisions, roads and stormwater, water and sanitation, housing, community, buildings, and ICT infrastructure. The non-infrastructure Asset Registers includes: land, heritage assets, intangibles assets, investment assets; and finance leases. More than 30 data collection teams were deployed, logging the above infrastructure types. Field efforts were supported by a hands on, real time office based QA workflow to ensure high quality of data was captured. The verified and fully GRAP and mSCOA standards compliant asset register was immediately available to the city officials, with infrastructure asset hierarchy presented in terms of the updated asset management policy.

3.2 eThekwini Metropolitan Municipality’s Asset Management Initiative

At the core of eThekwini Metropolitan Municipality’s Asset Management Initiative was the asset field verification and identification which was primarily instituted to comply with financial regulations, however, the exercise also enabled asset management fundamentals by providing reliable and detailed asset information. The main objective of the initiative was to have a fully connected network of the medium voltage and low voltage electricity reticulation in GIS and to have a real world geographical representation of the electrical infrastructure. This project involved the capture of more than 900,000 electrical asset items, and their spatial locations and condition. The information was incorporated into a connected network environment as an alternative to initially requested GIS. By incorporating information into a network model and presentation of the data in a spatial environment enabled the utility provider to trace and follow networks from source to client adhering to actual network connectivity behaviour.

Connected Network Modelling proved to be a quality assurance enhancer through the identification of various network discrepancies and inter-dependencies such as enabling the identification of open points in the network. Traces could be done to identify the supply areas for the different equipment and various labelling issues in the control rooms could be identified, minimising various safety risks. It was also possible to compare the control panels with drawings of the control rooms with what is in the field. Moreover, it unlocked numerous resulting opportunities, such as the implementation of an Advanced Distribution Management System (ADMS) consisting of Outage Management (OMS) and Distribution Management (DMS) systems, which dramatically increase efficiency and form the bridge between engineering reality and emerging consumer needs. The advantage of the connected network model above traditional GIS databases is that it can provide an enhanced disaster recovery.

The success to view data and data streams dictated the next logical step, or evolution, of data management being visualisation and direct manipulation of geospatial information. This is especially important for infrastructure planning and design where multiple sources, often conflicting with each other, are available.

4 VISUALISATION

Neurophysiologist T Thompson estimates that 30-50% of the human brain is regularly employed for nothing else but visual processing, (Thompson, 2018). In Civil Engineering we rarely use this ability for planning, design or management of infrastructure. Often complex three dimensional (3D) problems, such as pipe routing or pipe conflict management is only shown on drawings in two dimensions (2D), despite in many cases, the 3D information being available. Rarely, if ever, are we using the temporal dimension in infrastructure planning and management, i.e. considering *when* and not just *where*, services are established or removed and how they interact or conflict over time.

Visualisation has leapt over the past few years as computer processing power has dramatically increased. Figure 1 below shows examples of computer created landscape visualisations in an increasing level of complexity and detail. This case shows a forest scene, but it could be any other object or theme. The purpose of Figure 1 is to show the increase level of complexity and detail able to be generated by computers. A high degree of visualisation, especially in virtual environments, can be very effective for hands-on design. In the example below, the right-hand picture, when viewed at 4k resolution is unable to be distinguished from reality.

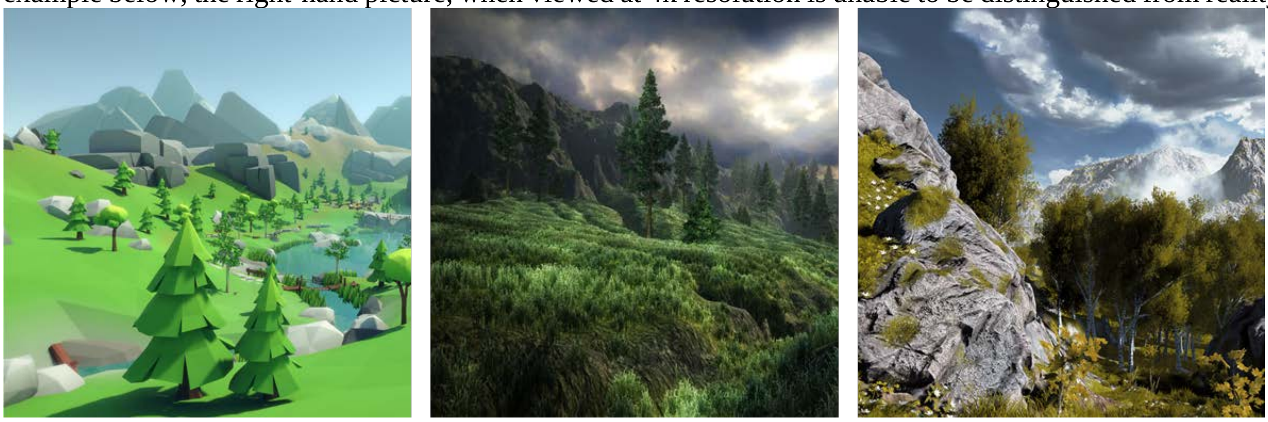


Figure 1 – Increasing level of complexity and detail able to be visualised. *(Photo on the right is indistinguishable from reality even at 4K resolutions)*

In the current market the infrastructure designer and manager derives a competitive advantage from their ability to analyse and visualise data rather than to just possess it. This drives many changes in the way consultants undertake their business and which tools they employ to communicate their ideas to clients and stakeholders. Software development in parallel with processing speed has also advanced over the past decade allowing for the faster processing of multiple images to spatially locate them and create complex high-resolution 3D digital models using a method of making measurements from photographs called photogrammetry. Figure 2 below shows a 3D mesh of the morphology of the cliff on the right-hand side and this is overlain with the full photogrammetry visual model on the left-hand side. The model is a tool to help engineers explain the complexity of the terrain and the challenges that will need to be overcome to work in such a high risk geotechnical environment in a far more powerful manner to stakeholders and the public.

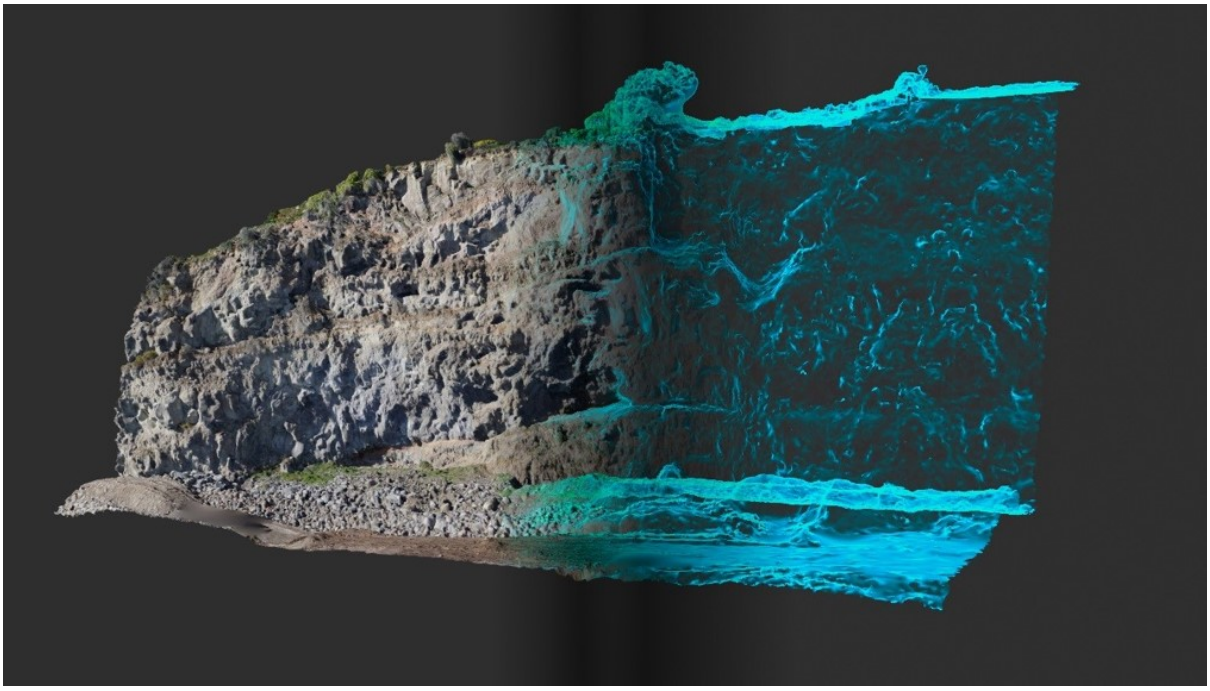


Figure 2 – 3D models assist us in understanding complex geometry and terrain (in this instance the images were captured by laser scanning and unmanned aerial vehicle photography)

The visualisation of civil engineering data can be done in many different environments and these are discussed below.

4.1 Virtual Reality

The Christchurch Bus Exchange is a large transportation hub that the Central Government recognised as being important for the recovery of the central business district. The design featured a fan shaped central bus bay for the buses to enter and reverse out, see Figure 3. The conventional design approach avoids reversing within a transport hub, however due to site constraints there were few (if any) alternatives. Aurecon used gaming technology to ensure that reversing will be safe for passengers and ensure that bus drivers have unpreceded situational awareness using multiple screens and cameras. The previous bus exchange did not require buses to be reversed and understandably many of the drivers were unconvinced, some drivers believed that reversing would be inherently unsafe. As the building and environment were prototypes the only option to try out the new scheme would have been a full scale test layout. As an alternative approach, the Aurecon team created the entire bus exchange in virtual reality. The environment was created using tools adapted from video game development and simulated virtually driving the buses into the exchange, operating within it and exiting the bus exchange. The bus driver used familiar controls for steering, acceleration and braking within a fully simulated environment to navigate a bus to a gate and reverse it out, see Figure 4. The virtual environment was changed to simulate different conditions the bus driver may encounter. Overall, the resistance and uncertainty around the proposed bus exchange layout from the drivers significantly decreased once they were able to experience what the new layout would actually be like once constructed.

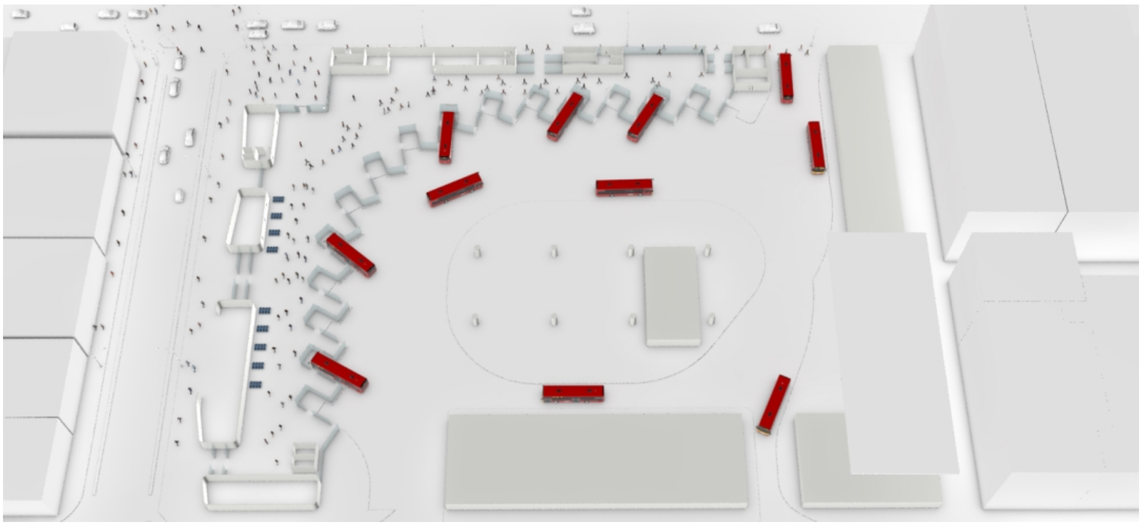


Figure 3 - Christchurch Bus Exchange Layout

Figure 4 - Bus driver using the virtual environment to navigate the Christchurch Bus Exchange

4.2 Augmented Reality

After the Kaikoura Earthquake in 2016, there was the need to widen old railway and roading tunnels that exist along this part of the Main North Trunk Line and State Highway to both repair the damage sustained during the earthquake and at the same time, taking the opportunity to upgrade the tunnels to meet current standards. Traditional survey techniques could have been used, but more rapid techniques were needed as these tunnels see high traffic volumes. An augmented reality solution, which is the overlaying of digital information on the real world, was developed to capture relevant data and visualise it using tablets field crews and engineers carry with them.

The tunnels were accurately surveyed with a laser scan to obtain a 3D model of the current condition of the tunnel. This was then compared with the proposed design, for example relating the clearances required for a train or truck to fit through the tunnel. The two data sets were compared to identify the differences and a heat map model was created to show the required changes. This however is difficult to accurately show on traditional drawings where the requirement may be for isolated blocks to be "trimmed back" to meet the design. The adopted approach was to present the data in augmented reality. High resolution cameras embedded in common smart phones and mobile tablets can capture high definition images. This view from the camera combined with the civil engineering design was used in the field to see where rock protrudes into the tunnel. In practice an engineer walks with their smartphone or tablet through the tunnel to see the differences. The device georeferences itself by recognising features on the portals or within the tunnel lining and provides key information on the screen.

Figure 5 – Augmented reality in use to determine tunnel improvement requirements

4.3 Mixed Reality

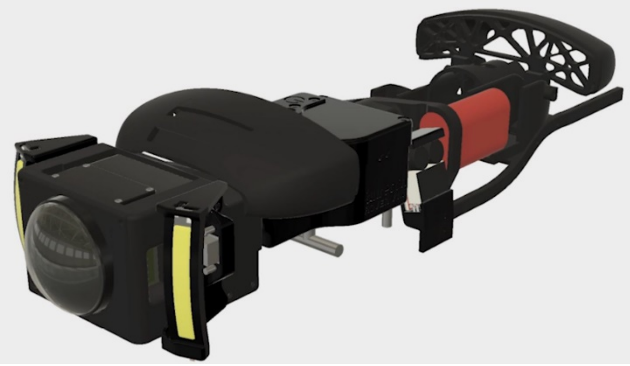
A landslide remediation project required the removal of 50,000m^3 of soil on a slope in Christchurch and the re-work of 70,000m^3 of material at the foot of an adjacent cliff to manage the risk of inundation to the main road below the site. The work was undertaken over a few months and required the continuous modifications of the talus slope at the foot of the cliff exposing people working below to rockfall hazards. The risk or exposure changed with the changes of the site and work being undertaken. Areas considered acceptable to work at in the morning could have an unacceptable exposure in the afternoon or vice versa.

To provide information on safe work areas Microsoft's HoloLens, a wearable computer, enabled the user to view an 'anchored' virtual 3D model of the site and walk around it seeing the high risk or 'no go' areas that were programmed into the HoloLens. This is mixed reality and the benefit of having users visually understanding where high risk areas were at any time was especially useful for site inductions and for collaborative discussions around the virtual 3D model that was typically one to two metres in size, 'anchored' to a meeting table in the real world.

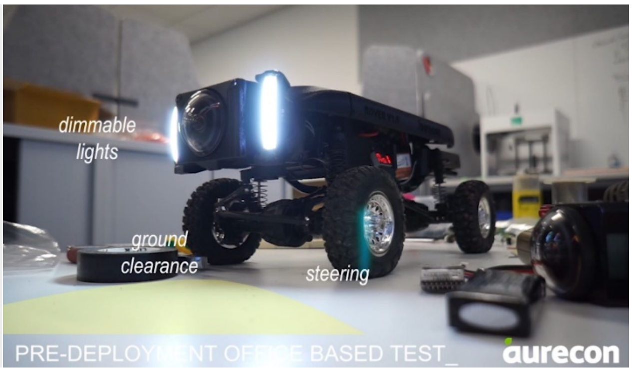
5. PHYSICAL ENVIRONMENTS

The Kaikoura earthquake in 2016 greatly impacted infrastructure, mainly the Main North Trunk line operated by KiwiRail and the State Highway 1 managed by the New Zealand Transport Agency (NZTA). The damage to rail and road was extensive and predominantly due to landslides, rockfall and tectonic uplift of up to 4m. The recovery will require more than four years of intensive repair and remediation work. Coastal rainfall has also triggered additional and ongoing slope instability which is likely to continue for the next five decades.

The roading and rail network includes long and narrow culverts, many of which were buried and damaged by landslide debris and the tectonic land movement. The roading authority identified the need to undertake safe and rapid inspections of the culverts, capture the data and observe changes over time. This was especially important for long term maintenance. Harnessing our internal innovation programme, our team developed a robotic, semi amphibious inspection vehicle able to easily traverse though 250mm diameter or bigger pipes and provide high resolution spatial data. The robotic rover was able to be designed and fabricated as a bespoke one-off tool using in-office rapid prototyping and 3D printing to build the main components and sets of spare parts. The entire project took less than 10 days from conception to field testing. See Figure 6 below.



a) 3D design of main structural components for 3D printing



b) final assembly and pre-deployment testing

c) in field operations

d) waterproof and shock proof chassis

Figure 6 – Robotic inspection vehicle development

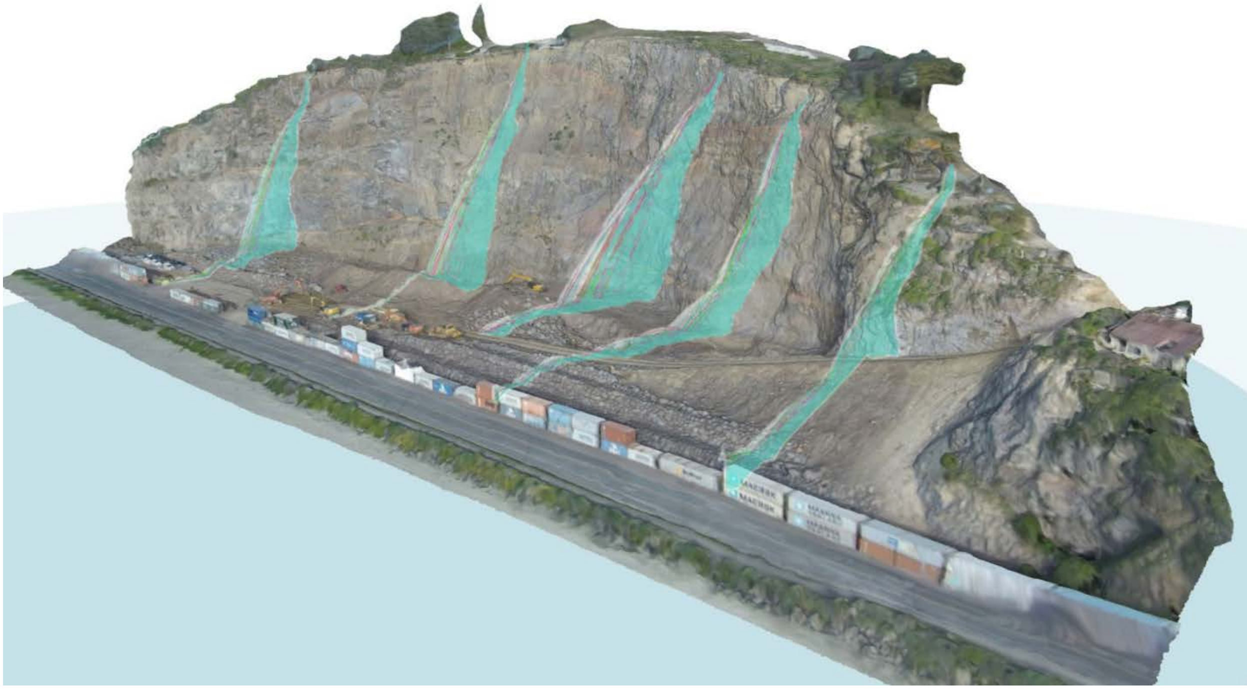
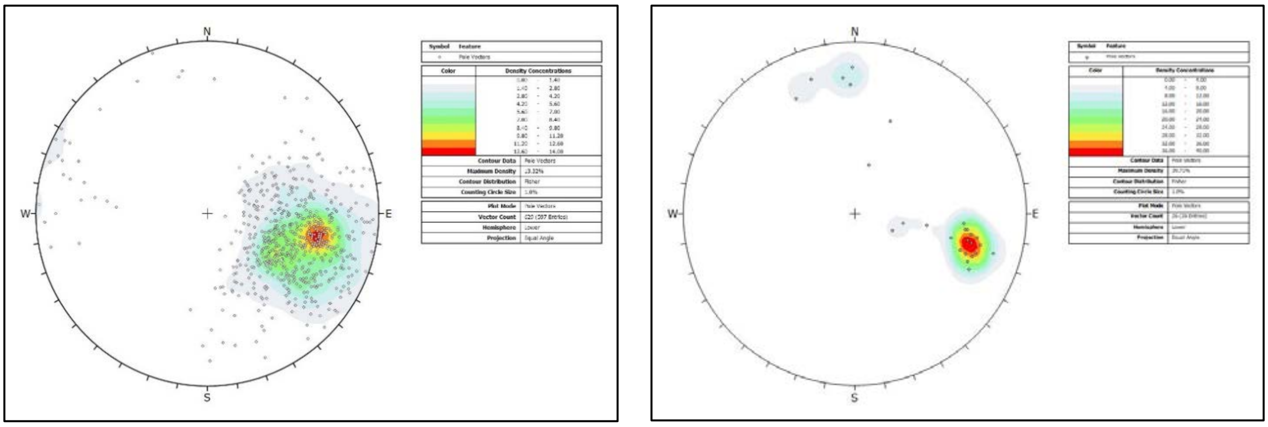


Figure 7 - 3D model with sectional rockfall analysis overlain showing areas where rockfall hazard extends over site traffic corridors

6 ANALYSIS OF COMPLEX DATA

We have discussed the various methods of capturing data to create and display 3D digital models. Although accurate creation of the models is important, the use of the models is more significant. We have used the models to extract accurate cross sections to undertake rockfall analysis of a cliff. The example in Figure 7 above shows sectional rockfall analyses through the 3D model. This turns the model into a tool for accurate site risk management, rather than just a representation of the site.

Further developments more recently use combined photogrammetry and laser scan models to extract data such as rock mass information on jointing orientations and identify failure planes in rock cliff faces to assess the risk of failure. Minimising time spent on site has significant health and safety benefits as well as reducing any disruption to infrastructure assets that may be near the rock slope. The data collected has been compared with traditional field methods and the two stereonets in Figure 7 show this comparison.



a) data collected from photogrammetry models b) data collected using traditional methods

Figure 7 – Comparison of the rock joint data gathered from the photogrammetry model (a) compared with minimal verification data collected on site using traditional methods (b).

7 PROBLEM SOLVING USING DIGITAL TOOLS

Design of new infrastructure and placement of it in the real world does present challenges as our urban environments already have many services under and over ground. To overcome some of these challenges the VR Placer tool was developed. Using photogrammetry, laser scanning and importing existing information a virtual representation of the site is created, showing where all over and underground services are located. Uncertainties of where services are actually located can be visualised by using either colour or shading gradients indicating to the user potential conflicts. The user then places the asset in the virtual environment and visually checks for any conflicts and that appropriate distances from other services are maintained. The VR Placer then exports the geospatial location of the new asset and generates information for field crews.

Figure 10 shows a view of what the user sees through the VR headset. The user has access to maps showing existing services and other physical items such as roads and driveways, power supplies, lamp poles, vegetation, etc. The user is then able to select the most appropriate location and orientation of the new asset in relation to existing structures, in the case shown in Figure 10, the user is placing an electrical supply cabinet for a new telecommunication mast.

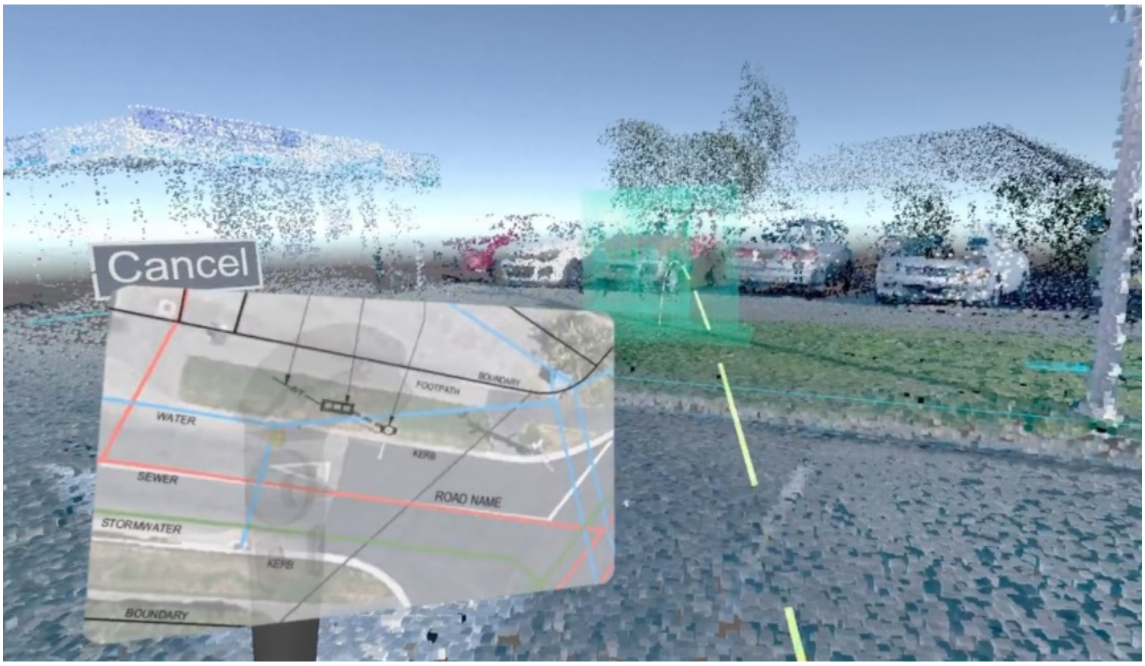


Figure 10 – “Screenshot” from the user’s 360 degree view in Virtual Reality - VR Placer

8 DISCUSSION

The above examples serve to illustrate how Civil Engineering and our industry sector are changing by embedding the latest technologies in design, construction and maintenance of infrastructure assets. Capturing and storing information about the surrounding environment will allow designs to be tested thoroughly in the digital world as ‘digital twins’, prior to real world construction. Using newer approaches to visualisation will show constraints and opportunities of a particular site. This will be especially important for site selection to reduce the impact from any natural or manmade hazards, leading to more resilient infrastructure systems.

Using computing, data management and visualisation enables designers to be more interactive with the design. Digital tools especially provide unparalleled opportunities in the infrastructure maintenance environment. Monitored data can easily determine what the expected conditions were meant to be against actual site conditions in real time. People maintaining assets can use mixed or augmented reality tools to access assets more safely, accurately and cost effectively.

Infrastructure resilience will be a function of the individual asset’s ability to react to disruptions. Digital tools will assist with design, construction and maintenance, including decommissioning of infrastructure. Capturing greater volumes of data will enable the designer to make informed decisions, including any impact of individual assets to a particular stressor. This will enable a risk based approach to infrastructure management which in turn will increase asset resilience. In the example from Kaikoura, New Zealand, where the culvert inspection vehicle will be used over the next few months, it is hoped that it will determine why certain culverts block regularly, which in turn will allow only those specific culverts to be either relocated or increased in cross-sectional area to reduce blockages. In the mid to long term it is expected this will reduce operational and maintenance costs.

Artificial intelligence and machine learning are increasingly being used to create and direct robotic tools or analyse large volumes of data enabling designers and stakeholders to make better decisions. Machine learning is already part of our digital suite of tools applied to projects with increasing regularity. For numerical modelling or prediction of system behaviour we already rely on computational analysis and machine learning, as humans are already unable to process the volume of data currently available, the associated complexity of this data only makes the situation worse.

9 CONCLUSIONS

Digital tools are well established and offer many advantages over conventional approaches. The authors believe that digital tools will first supplement and then make obsolete many traditional approaches making infrastructure safer and more cost efficient. This in turn should allow for greater resilience and investment optimisation for new infrastructure.

The authors' current project work is now identifying the extent machine learning and artificial intelligence can complete complex tasks with ever increasing finesse. What even 10 years ago was considered impossible, is rapidly becoming reality. We believe human effort is better directed at developing computational algorithms, that will rapidly surpass our cognitive speed and ability to process complex problems to find solutions, as we show in Figure 8 by way of example. Computational processes may also be less affected by observational bias or pre-set prejudice towards particular solutions.

Cheap, almost disposable, computer hardware such as Raspberry or Arduino systems create multi sensor platforms orders of magnitude smaller and faster than conventional hardware, allowing faster, cheaper and more accurate capturing of the real world into the digital environment. Computer processing power will continue to increase, which in turn will allow better visualisation of design and better appreciation of the real-world environment. Representation of a construction site in the digital environment and anticipation of interactions between infrastructure and building systems is no longer science fiction, it is state-of-the-art within our profession and here to stay. In New Zealand most complex infrastructure projects already are using virtual environments to test, compare and prototype designs in the digital/virtual world prior to implementation in the real world. We believe that design using better information will provide more resilient infrastructure solutions featuring lower lifecycle costs.

10 ACKNOWLEDGEMENTS

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11 REFERENCES

NZTA. (2018, June). Annual Report. Retrieved from https://nzta.govt.nz/resources/annual-report-nzta/
NZTA. (2018, June). Bridge Manual. Retrieved from https://www.nzta.govt.nz/resources/bridge-manual/
Thompson, T. (2018, 06). Quora. Retrieved from https://www.quora.com/How-much-processing-power-in-the-brain-is-dedicated-to-human-vision