HARNESSING INNOVATIVE 3-DIMENSIONAL DIGITAL DESIGN TO REDUCE SEWAGE OVERFLOWS

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ABSTRACT

Digital revolution within the water design industry – how are we really benefiting? This paper demonstrates how one Aurecon design team has embraced the advantages of current digital innovations to enhance the traditional design process.

Using the example of a small-sized yet technically complex project with many mutually interactive elements of design needing to be coordinated, the design team made a conscious decision at the start of the design process to utilise various industry leading 3-dimensional (3D) modelling software packages. However, this decision was taken much further than just undertaking 3D design modelling – the design team purposefully integrated the results from each modelling package into a cohesive, interactive modelling 'space' for the project. This paper provides details on this data coordination and integration process, and how the integrated model was used to produce the detailed design faster and more accurately than using traditional methods by removing the need for manual design updates for each design iteration.

The project hydraulic functionality was particularly sensitive to the physical arrangement and levels of the final designed storage structure and associated structures such as the overflow weir. This project provides an example of how the customary gap between theoretical hydraulic modelling and detailed engineering design can be effectively bridged by a design team who can use the hydraulic model to successfully support the design optimisation process. In particular the design team was driven to find balance between reducing the construction complexity and reducing the cost.

This paper then describes how the project 3D model used was updated to incorporate other key design and construction constraints on the project such as the predicted future sea level rise, and local geotechnical conditions. Changes to the hydraulic design model, and to the baseline 3D geological and surface terrain model in turn informed the detailed structural and mechanical design. The ability to coordinate 3D information between each model was key to getting this optimisation completed quickly and without the risk of manual error. By using and integrating the various 3D models, the whole project design (structural, mechanical, hydraulic, geotechnical and civil) was produced as a coordinated package and completed in a shorter time period compared with a traditional design process and without the risk of mis-aligned design elements.

In summary, using the hydraulic model and coordinated 3D design models has meant that the project engineers were able to quickly and accurately develop a cost effective, constructible configuration for the storage structure, whilst also robustly demonstrating that the project would result in a more than 95% reduction in total annual wastewater flows to the foreshore. The client has also been delivered a design that will be faster, safer and easier to construct.

KEYWORDS

3D digital design, hydraulic modelling, hydraulic design

PRESENTER PROFILE

Margaret is an engineer and Technical Director at Aurecon with over 20 years' experience in the design and construction of 'three-waters' infrastructure projects, with a passion for finding elegant ways to manage wastewater. Cross-pollination between the design and modelling processes – as this paper demonstrates - has long been her passion.

1 INTRODUCTION

The power of digital design technology can improve and enhance upon the foundations of traditional engineering design. This paper uses a project example to explore whether the application of currently available 3D digital design technology can deliver superior outputs efficiently.

The project is the design of a combined wastewater storage structure, and this paper explains how digital technology was applied throughout the investigation and design process. The discussion focusses on three specific aspects of digital technology and how they each provided specific value to the project. These aspects were:

1. Use of aerial photogrammetry and terrestrial LiDAR scanning to enhance the use of digital design models.
2. Using digital 3D geology tools and aerial photogrammetry to identify the optimal design.
3. Hydraulic modelling and design.

The paper also provides brief commentary into how the design team is using the digital design models as a pre-construction baseline for monitoring construction effects and activities as the physical construction works are carried out.

2 PROJECT DESCRIPTION

The project was for the design and construction of a new wastewater storage structure adjacent to the foreshore of one of New Zealand's larger cities. The purpose of the structure was to capture and store discharge from a number of existing overflow points (in the form of manhole weirs) from the adjacent wastewater network, which currently spill regularly whenever small rainfall events occur and the wastewater network fills to capacity. The proposed storage aimed to reduce the volume and frequency of wastewater discharging into the foreshore and marine environment, as well as to consolidate the overflow sites to a single location. The stored wastewater would then be pumped back to a nearby wastewater trunk sewer pipeline when sufficient system capacity was available.

The regular beach overflows caused by an aging sewer network servicing the catchment brought water quality problems, aesthetic complaints and potential public health risks. In addition, one of the aging marine sewer outfalls had failed, causing the spilling wastewater overflows to be discharged directly onto the foreshore and being highly visible at low tide. All of this was occurring within an area designated to be a high amenity urban beach, which in future would form part of a wider development plan seeking to maximise public use and enjoyment of a popular waterfront area.

Due to the very apparent environmental impacts of the failing combined network, the project was under pressure to be completed as quickly and efficiently as possible. The design team therefore needed to develop a technical solution that would minimise risk to the client *and* facilitate a straightforward and economic construction of the project. The location of the project within a popular urban foreshore area meant that there was an immediate appreciation for the complexity of the project, with the design requiring optimisation between many sensitive technical and non-technical constraints. The next sections describe how 3D digital design was utilised to overcome these constraints and coordinate an elegant project solution.

3 DIGITAL ENGINEERING DESIGN

Anecdotally, the design team was aware that many other civil infrastructure projects have historically had poor outcomes[1] frequently due to the significant impact of unforeseen underground conditions including geological and geotechnical characteristics, and also due to the presence of unknown underground utility services. Design technology is now readily available to help prevent these unsuccessful outcomes, which in turn informed the decision in the early stages of the project when it was decided that 3D technology will be used to undertake the design completely. The initial plan was therefore to create a 3D model of the storage structure and its surrounds. As information from the comprehensive site investigations was gathered, it would allow the design team to capture information on both ground conditions and utilities, and to use design technology to improve the delivered design. It was also predicted that the 3D modelling would speed up the design process by allowing the design team to work together on a single design model.

3.1 3D PROJECT DESIGN – SOFTWARE PACKAGE INTEGRATION

The use of 3D modelling for design is not uncommon within the design industry. However, integrating 3D models and data from many different component designs has a much smaller industry track record. On this project the design team utilised and integrated six different specialist 3D design models (software used included: *Revit, Civil3D, Leapfrog, 12D, Inventor* and *Recap*). Data from aerial photography and scanning, and terrestrial LiDAR scanning was also brought into the model. This application of the digital software allowed the team to bring together 3D information on existing infrastructure and the new storage structure design seamlessly into a single all-inclusive model. The complete above- and below- ground 3D model supported the team in visualising the final design. Collaboration was facilitated as all the team was able to access and view other design elements and site constraints at any time during the design phase. A schematic diagram showing the relationship of the various software packages over the project duration is in Figure 1.

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[1] These poor outcomes may typically be evidenced by delays to construction programmes, and also by final project construction costs that far exceed the original construction budget.

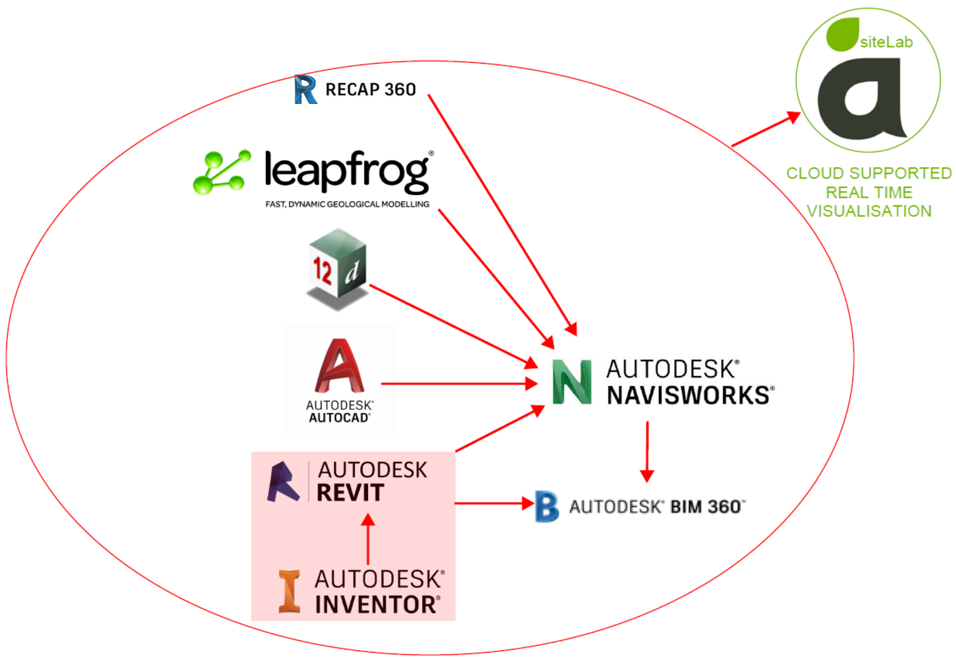

Figure 1: Schematic of Software Interaction during Project Design

Construction issues such as poor ground conditions were able to be identified and the storage structure design adjusted to accommodate areas of poor ground; similarly clashes with underground utilities were identified and avoided by repositioning the structure to provide suitable clearance. All of the model integration was managed in-house without the need for special services or support from the software suppliers.

To ensure that changes made in one area of design were reflected within the others, *BIM360 Team* was used for model sharing with the design team, and *Navisworks* used to collate the various models. The information from the aerial and terrestrial LiDAR scans were used to develop 3D point cloud models of the entire project surface area.

Due to the flat foreshore topography, the hydraulic performance of the storage structure was particularly sensitive to the physical arrangement of built assets. Through 3D digital modelling the design team performed multiple design iterations to optimise the design and ultimately reduce the volume and frequency of wastewater spills predicted once the storage structure has been constructed. The digital models were also instrumental in supporting a thorough Safety in Design process including informing the various project workshops. Through integrated digital models, the project team was able to bring multi-disciplinary teams together and help the client to better visualise the project, its difficulties, and the complexities of the built asset. This knowledge is expected to reduce the site construction and operational hazards, provide clarity around the necessary construction methodologies for the selected construction contractor, and support an accelerated construction programme due to the depth of information available about the proposed works.

Three less common 3D design elements contributed to the final quality design, each of these are discussed in more detail within Sections 4 to 6.

4 AERIAL PHOTOGRAMMETRY AND TERRESTRIAL LIDAR SCANNING

A major success of this project design was the way which aerial photogrammetry and terrestrial LiDAR scanning was incorporated into the 3D design models, providing a pre-construction baseline of the ground surface levels and surface features including buildings and vegetation, prior to commencement of construction excavation. Potential disturbances due to construction activities could be evaluated against this baseline, and 3D visualisations of the final structure within the foreshore landscape were used during engagement with project stakeholders. This had the benefit of representing the complexities of the project and its impacts, in a transparent and engaging manner benefitting those without the background to interpret traditional 2-dimensional engineering drawings.

The 3D design models including the surface feature model were subsequently used to develop a virtual reality (VR) model of the storage structure system as an additional visualisation tool for stakeholder engagement. The VR model animated typical overflow events and illustrated how the storage structure would detain the wastewater to prevent further contamination of the local foreshore environment. The VR model was developed for a very different purpose than the design models, being prepared as a means to convey technical design information in a clear, non-confrontational format that could be understood by the general public. Refer to Figure 2 for an extract of the VR model clip.

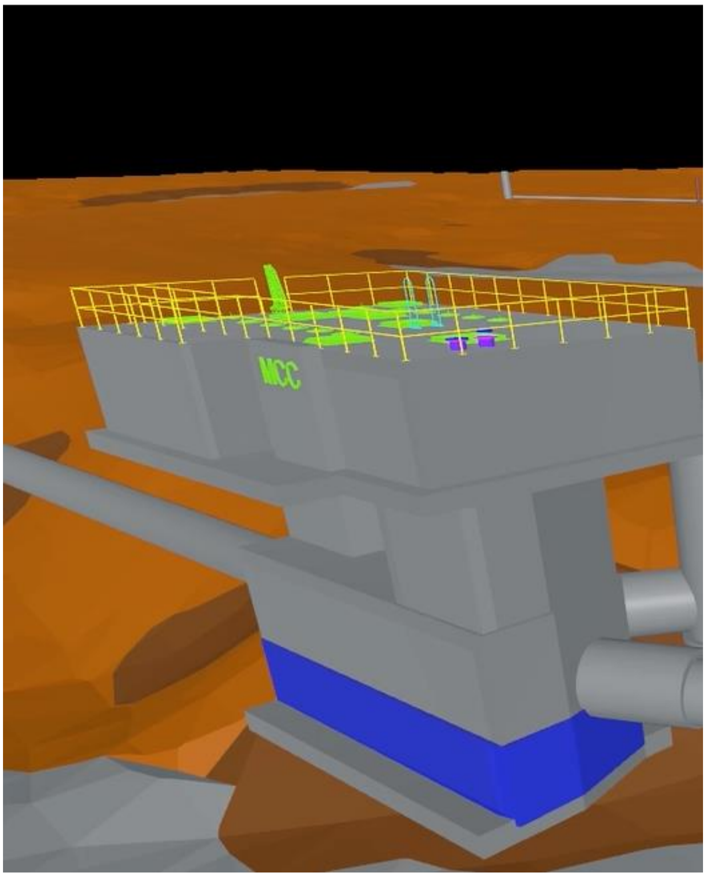

Figure 2: Snapshot portion of the project VR model

5 DIGITAL 3D GEOLOGY AND AERIAL PHOTOGRAMMETRY

Being located on the foreshore, the proposed combined wastewater storage structure will be located within variable ground conditions – one side of the site consists of more uniform clay soils (the typical soils of the area) with the other side of the site located within fill material of varying nature and depth, historically placed overtop soft marine soils. Irregular ground conditions such as these can frequently result in severe problems during construction.

Another major success of this project design was the way which aerial photogrammetry and terrestrial LiDAR scanning was incorporated into the 3D geological models, allowing the design team to identify sub-surface features such as filled paleo-valleys and the boundary from natural ground to fill material. Refer to Figure 3 for an excerpt from the 3D geological model. This 3D information was then used by the structural design engineers to develop the specific detailed structural design for the project, allowing for the specific variable nature of the ground conditions. The 3D geological information was also used to inform the Safety in Design process whereby the specific methods of ground excavation, dewatering and construction would be determined based on the design team knowledge of the site above and below ground. Stakeholders have also been provided advanced warning of the likely effects of the construction works such as vibration and noise, as the methodology has allowed these factors to be more accurately assessed.

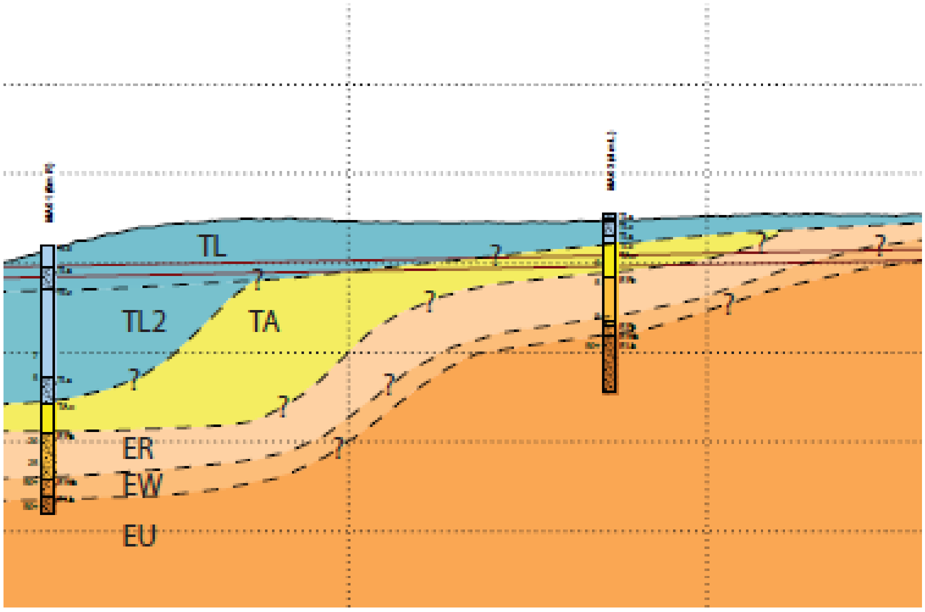

Figure 3: Extract of 3D geological and surface model

6 HYDRAULIC MODELLING

The client's existing network hydraulic model was adopted and modified to provide a basis to evaluate and quantify the benefits of various design options for the project. Complex projects such as this often require a balance between minimising the construction complexity and cost, whilst maximising the project benefit towards its objectives or targets. The iterative modelling process undertaken for this project provides a clear example of how hydraulic modelling can support the detailed design optimisation process, quantifying the performance of many proposed system iterations under different scenarios in an efficient manner. The integration of hydraulic modelling to the design methodology allowed informed decisions to be made in detailed engineering design and wider planning initiatives.

The hydraulic model was amended to include an initial version of the storage structure into the existing network, utilising gravity connections to convey spills from the existing combined overflow weirs to the proposed storage structure. The network model results quantified the frequency and volume of overflow in the existing and proposed systems under various design and long-time series rainfall scenarios, along with storm tides and predicted rising sea water levels, providing an initial assessment of the proposed system performance from a high level.

The hydraulic model was further applied in the overall process of optimising the storage structure system's location, size and functionality, as well as design of the outlet and return pump station. Hydraulic model results were used to contrast the performance of different iterations of design against each other, based on the frequency and magnitude of overflows predicted in various rainfall and tidal scenarios.

By using the hydraulic model as a key input to design, the project engineers were able to develop a cost effective and constructible configuration for the storage structure, whilst reducing the annual volume of wastewater overflowing into the receiving environment by over 95%.

7 ULTIMATE PROJECT BENEFITS

7.1 DESIGN QUALITY AND PACE

By undertaking the design using an integrated 3D model, the design process for the entire project was completed very efficiently – a detailed design that would typically take several months to complete was produced in less than six weeks. Besides allowing the client to meet their ambitious delivery programme there were cost savings for the client as a result of the shorter design period.

Detailed review of the design by an independent construction contractor has confirmed that the design is of high-quality, constructible, cost-effective, and that a robust solution to the overflow problem has been provided by balancing the various project constraints including the sensitive hydraulic performance of the whole system. This demonstrates how the use of the 3D models has supported the design team in developing a high-quality design that has met the client project objectives. Further benefit is expected during construction, the value of early identification and measurement of construction risks will be evident when the works are constructed safely, and within the time-frame and budget expected by the client.

7.2 CONSTRUCTION MONITORING

The 3D surface model, and the developed virtual reality models can also be used during construction for live-tracking of site activities by combining measured site data, such as vibration and noise into the design model. It is envisaged that this will provide the client with up-to-date and detailed understanding of the impacts of construction and allow better engagement with stakeholders affected by the construction works.

8 3D DIGITAL DESIGN LESSONS

The project was technically complex due to its compact environment, with many different elements of design needing to be coordinated due to their mutual interaction. This project has illustrated that digital design technology is available to assist the industry to efficiently and effectively optimise the design of complex options and solutions. Three particular aspects of the 3D design have been described, being:

1. Use of aerial photogrammetry and terrestrial LiDAR scanning to enhance the use of digital design models. This has allowed better stakeholder engagement from preparation of 3D visualisations of the project works. The data can also be used for future management and tracking of surface disruption during and after construction.
2. Using digital 3D geology tools and aerial photogrammetry to identify the optimal design. In particular the variable ground conditions were able to be modelled in 3D allowing specific structural design to suit the site conditions.
3. Hydraulic modelling iterations were used to optimise the sensitive hydraulic design of the storage structure, confirming the expected environmental benefits of the

project including an annual reduction in wastewater spills to the foreshore of more than 95%.

A cohesive, interactive modelling 'space' was created for this project, amalgamating the different modelling packages. This allowed the design team to work collaboratively across disciplines of engineering on a single design model. Traditionally projects similar to this have encountered shortcomings due to miscommunication and miscoordination, this project features a digital methodology that succeeds in mitigating these challenges. The final design was produced more effectively, and in more detail than using traditional design methods by removing the need for manual design updates for each design iteration. The designers believe that the final 3D design has also allowed for better management of potential construction effects and risks with the 3D model being used to inform the project Safety in Design process, and also the stakeholder engagement.

9 CONCLUSION

The use of 3D digital design software under the integrated modelling 'space' methodology described in this paper simplifies the multifaceted coordination required to successfully deliver a design of this complexity. In summary, using the hydraulic model and coordinated 3D digital design models has meant that the project engineers were able to quickly and accurately develop a cost effective, constructible configuration for the storage structure, whilst also demonstrating that the project would result in a more than 95% reduction in total annual wastewater flows to the foreshore. The client has been delivered a design that will be faster, safer and easier to construct.

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