Bridging Design and Delivery: Platform-Based Automation of Temporary Works and the Rise of Productization of Engineering Services

Swansea University
Prifysgol Abertawe

Matthew Hall

Zienkiewicz Institute for Modelling, Data and AI

Faculty of Science and Engineering

Swansea University

Submitted to Swansea University in fulfilment of the requirements for the Degree of

Doctor of Philosophy

August 2025

Declarations

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed.....................[redacted]..

Date...11/11/25

This thesis is the result of my own investigations, except where otherwise stated. Other sources are acknowledged by footnotes giving explicit references. A bibliography is appended.

Signed..................[redacted]...

Date...11/11/25

I hereby give consent for my thesis, if accepted, to be available for electronic sharing

Signed..............[redacted]...

Date.. 11/11/25

The University's ethical procedures have been followed and, where appropriate, that ethical approval has been granted.

Signed............[redacted]...

Date.. 11/11/25

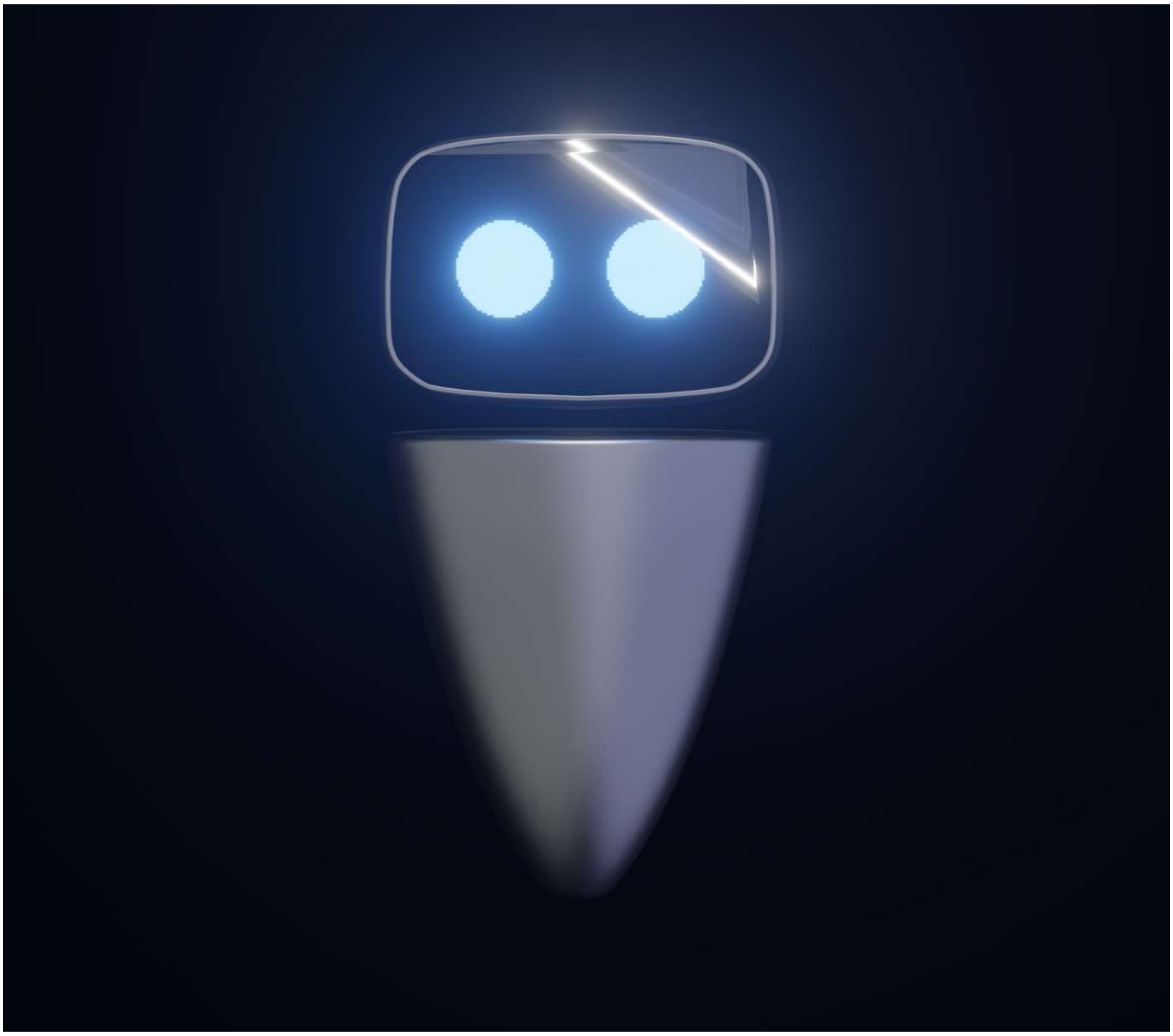


Figure 1: Charlie Bot mascot of Digital Civils

Acknowledgements

There is a huge number of people that I would like to thank that have helped me in my journey through this PhD first and foremost Prof. Chenfeng Li, who almost 10 years ago now, I was introduced to via Bill Hewlett at Costain, who saw that the spirit of exploration and innovation excited me hugely, and was willing to take me on and take me under his wing. “If he is that passionate and determined, then he is capable of surviving a PhD”.

I would like to thank Bill Hewlett and Steve Hall who originally took me on at Costain with a different background than the traditional route in Civils. Bill had an interest in diversity of thought being introduced. This proved to be my greatest strength in industry and enabled me to thrive by leaning into thinking differently and coming up with different concepts. His encouragement to attend the PhD has enabled a long string of events to enable me to create something truly unique and assist industry at a meaningful level.

Thank you to Abouzar Jahanshahi and Roger Tice at Richter, who have heavily invested up front into delivering the platform which is now its own separate company that they have partnered me with. Their encouragement and passion are contagious, and I adore them for enabling true unhindered experimental innovation for the greater good of the industry.

To my Wife and Family who have been incredibly proud of me taking on this process, their love and support throughout this long period has kept me going.

Abstract

This thesis presents the culmination of a nine-year, part-time research journey into the automation of temporary works design, resulting in the creation of “Charlie” — a fully operational, web-based platform capable of generating complete civil engineering design packages on demand. Developed and proven in commercial operation, the system delivers calculations, drawings, risk assessments, certification, and sustainability reporting within minutes, challenging the traditional time-based consultancy model.

By productising engineering expertise into fixed-cost, repeatable outputs, Charlie demonstrates a scalable alternative to the “hours in = revenue” paradigm, enabling faster site mobilisation and reducing the risk associated with delays. Its end-to-end automation removes repetitive manual tasks while maintaining human oversight, freeing engineers to focus on higher-value decisions. Sustainability is embedded from the outset, with integrated optioneering and lifecycle CO_2e reporting aligned to PAS 2080, allowing carbon performance to be evaluated and optimised in real time without additional client cost.

The research makes a dual contribution: first, in delivering a technically robust, commercially viable automation service for temporary works; second, in reframing how consultancy services can operate by integrating advanced digital tools, lean delivery principles, and embedded sustainability into the core business model. By uniting engineering rigour with platform-based delivery, the work offers a replicable framework for improving speed, consistency, and environmental responsibility in infrastructure projects, providing a pathway for the civil engineering profession to adopt more complex and innovative methodologies without increasing delivery cost.

CONTENTS

Introduction

This Thesis has been changed many times since its beginning, as a part time student to Swansea, it has been an eight-year long journey. Which has led to many different levels of thinking being evolved around what is important, what it means to be a PhD holder and the importance of experimentation and challenging the norms.

The first four years at Swansea was based around learning finite element method and developing new algorithms for industry, with a deep dive looking into reinforcement stability, however this seemed futile at the time. Particularly for my specialism within civil engineering for temporary structures. The answer not to build these structures tall and thin was too obvious. A new finite element method to analyse these specific structures. may have gained me the certification to acquire a PhD, but I felt that it would have little effect in changing the industry. Even to create any new finite element tool seemed insignificant since we are always time constrained, and often the additional cost of modelling and running finite element analysis outweighed the minor incremental cost of materials saved while bringing us closer to the edge of failure opening risk.

I sought to challenge the idea that the industry could majorly benefit from becoming more up to date with the latest technologies. To make the most of new tools available by overhauling their concepts of digitization. Through the thesis I look at many different areas of the design process and critically comment on their history, current state of the art and what could be done differently. The evolution of many of these has been to digitize their original analogue versions of themselves without exploring new opportunities afforded to industry. Even worse the experimentation of technological advances often lays outside of the core meta and reserved for recent graduates, seen as a side activity.

Not only have I challenged all these concepts but successfully started a new Ltd company during the time off the back of these concepts. While bringing all the concepts together into practice we have successfully started a branch off consultancy providing generative designs with massive advantages over our cousins traditionally creating similar designs.

One of the most exciting parts of the process is now that it is in place, we have secured a grant to work with researchers to unlock more advance numerical analyse methods directly into the infrastructure of the new project. Unfortunately, not in time for this thesis to be submitted. However, the 8-year long journey will continue to advance and gain speed as more clients are discovering the advantages this new ideology affords them.

From chapters 1-14 I review the state of the art of various new digital technologies in Civil Engineering, as I sought to explore different subjects for inspiration for a more drastic impact to site works than increasing material efficiency. In chapters 15-25, it's discussed how we not only theorised what the biggest impact would be. but put it into practice, by starting a company and implementing the innovation live in industry. Chapter 26, we take a moment to explore what the future might look like with an extremely novel chapter (less practical for immediate industry implementation.) where we explore a complete digital workspace environment and leave behind all the traditions and workflows which we adhere to, in the pursuit of a completely new way of working.

Lit Review

Figure 2: Charlieverse avatar closeup teaser

Chapter 1: Evolution of Calculations in Civil Engineering

1.1 Introduction

Calculations have always been fundamental to civil engineering, ensuring structural integrity, safety, and optimization of resources. This chapter critically reviews the evolution of calculation methods, highlighting the technological shifts that have significantly impacted engineering practices.

1.2 Historical Development of Calculation Methods

Historically, civil engineering calculations relied heavily on manual methods. Engineers meticulously executed calculations by hand, a practice demanding extensive knowledge of engineering principles and significant mathematical skill. Each calculation was thoughtfully derived, reflecting the engineer's personal diligence and craftsmanship (Garrison, 1999). These manual processes, though precise, were time-intensive and prone to human error, limiting the complexity and speed of design iterations.

In the early to mid-20th century, slide rules emerged as an essential computational aid, drastically reducing the time required for complex computations. Slide rules allowed engineers to perform rapid calculations involving logarithms and trigonometric functions, increasing the feasibility of more intricate structural analyses (Sandström, 2013). While significantly enhancing efficiency, slide rules still required considerable operator skill and were limited by precision constraints inherent in their design.

Mechanical calculators emerged shortly thereafter, introducing unprecedented computational efficiency. These devices could handle complex arithmetic with greater speed and accuracy compared to manual or slide rule calculations (Williams, 2002). Although a considerable advancement, mechanical calculators were bulky, expensive, and limited in managing extremely complex calculations typical in large-scale engineering projects.

The advent of mainframe computers represented a revolutionary leap. Engineers could now perform intricate simulations and analyses previously impossible or prohibitively time-consuming. Mainframes facilitated numerical methods such as Finite Element Analysis (FEA), drastically transforming the complexity and accuracy of structural designs (Ceruzzi, 2003). Despite their revolutionary capabilities, these systems required significant investment, dedicated facilities, and specialized operational knowledge.

1.3 The Digital Revolution in Engineering Calculations

Electronic calculators introduced in the latter half of the 20th century provided convenient, portable computational power, rapidly overtaking mechanical calculators in practical use. These handheld devices enabled engineers to conduct instant and precise calculations onsite or in design offices, significantly enhancing productivity and facilitating rapid iterations during the design process (Atkinson, 2000).

The arrival of personal computers revolutionized engineering calculations, bringing powerful analytical tools directly into design offices. Software applications like Excel, MathCAD, and dedicated structural analysis programs became integral, enabling complex numerical simulations and structural optimizations at an unprecedented scale and speed. Personal computing dramatically reduced calculation times, enhanced precision, and allowed greater iterative exploration of design alternatives (Turban et al., 2008).

1.4 Persistence of Manual Methods in the Digital Age

Despite significant digital advancements, manual calculations persist in civil engineering practice due to several factors. Engineers continue using hand calculations for validation, simplicity in small-scale tasks, and personal confidence in their intuitive understanding of fundamental engineering principles. These manual checks serve as critical safeguards, verifying digital outputs and ensuring practical reasonableness of computational results (Mtenga & Spainhour, 2000).

Integrating digital and manual calculation methods creates workflow complexities and inefficiencies. Challenges include the risk of human error in translating results between manual and digital formats, inconsistent standards of practice across different projects or teams, and difficulty in automating processes for standardization (Oden et al., 2003). These challenges highlight the importance of moving towards integrated and standardized digital calculation frameworks.

1.5 The Need for Object-Oriented Computational Paradigms

Object-oriented calculation methods represent a significant departure from traditional linear calculation processes, encapsulating data and computational methods within modular objects. This encapsulation allows engineers to manipulate and interact dynamically with structural elements, greatly enhancing computational adaptability and scalability across diverse engineering projects (Munassar & Govardhan, 2011).

Adopting object-oriented approaches provides substantial advantages, including enhanced flexibility for iterative design processes, improved accuracy through modularity, and ease of updating or adjusting individual elements within broader computational frameworks. This approach also supports collaborative workflows, allowing multiple engineers to concurrently manipulate discrete structural components without disrupting overall integrity or coherence (Booch et al., 2007).

Although advantageous, object-oriented computational paradigms face significant implementation barriers. Resistance to changing established practices, incompatibility with legacy systems, and knowledge gaps within the engineering community present substantial hurdles. Addressing these barriers will require strategic educational initiatives, management-driven advocacy, and gradual integration strategies to ensure smooth transitions (Fowler, 2002).

1.6 Conclusion

The historical evolution from manual craftsmanship through mechanical aids and mainframe computing to digital and object-oriented methods illustrates a clear trajectory towards increasingly sophisticated and efficient calculation methodologies. Addressing implementation challenges and moving decisively towards modern computational paradigms will enable the civil engineering field to fully leverage current technological potentials, ensuring innovation, efficiency, and enhanced accuracy in future structural designs.

Implementing object-oriented calculations requires a seamless integration with existing workflows. Engineers must navigate the transition from traditional methods to more object-oriented styles without disrupting established practices. This integration demands a careful balance between preserving the efficiency of current workflows and embracing the transformative potential of new computational paradigms. The successful adoption of object-oriented calculations necessitates a concerted effort in training and education within the civil engineering community. Engineers must familiarize themselves with new programming paradigms and tools that facilitate object-oriented approaches. Bridging the knowledge gap is crucial for unlocking the full potential of this computational shift. We will attempt to change the landscape of consultancy and designing to turn these computational methods into the advantage they should be.

In retracing the trajectory of calculations in civil engineering, from the meticulous handcrafted methods of the past to the sophisticated digital tools of today, a nuanced narrative emerges. The coexistence of manual and digital calculation methods, coupled with the potential for more object-oriented styles, signifies a juncture where tradition meets innovation. The persistence of manual calculations is not a regression but rather a testament to the enduring principles of the discipline. The trust placed in hand calculations coexists with the transformative power of digital tools, each contributing to the rich tapestry of civil engineering practices. As the industry navigates this intersection, embracing both tradition and innovation becomes imperative for holistic progress. The exploration of more object-oriented styles in calculations serves as a clarion call for the evolution of computational methodologies in civil engineering. By embracing a paradigm shift toward modular, adaptable, and dynamic approaches, engineers could revolutionize the way structures are conceived, analysed, and optimized.

In the chapters that follow, we delve deeper into the implications of this coexistence of tradition and innovation, exploring avenues for seamless integration, addressing challenges, and envisioning a future where computational methodologies in civil engineering transcend current limitations. (Oden, Belytschko, Babuška, & Hughes, 2003)

Chapter 2: The Role of Documentation in Risk Mitigation

2.1 Introduction

Documentation in civil engineering plays a critical role in risk mitigation, ensuring project safety, compliance, and accountability. This chapter reviews the historical evolution and current practices of documentation, addressing its impact on risk management and project delivery.

2.2 Historical Context of Documentation

Historically, documentation practices in civil engineering were informal, relying largely on the tacit knowledge and skills of experienced craftsmen and builders. These informal practices often resulted in inconsistencies, limited traceability, and significant risks in complex engineering projects (Johnson & Blake, 2005). The need for formal documentation became increasingly evident as the complexity of engineering projects grew.

The 1975 Bragg Report significantly influenced modern documentation practices. This landmark document highlighted the importance of systematic, standardized documentation processes to enhance safety, accountability, and regulatory compliance (Bragg, 1975). Following this report, structured documentation became integral to engineering standards, transforming how civil engineering projects were managed and executed.

2.3 Modern Practices in Documentation for Risk Mitigation

Modern documentation processes in civil engineering involve structured procedures and rigorous approval protocols designed to ensure thoroughness, accuracy, and compliance with safety standards. Documentation now includes detailed records of design decisions, calculations, material specifications, and risk assessments. These records are essential for regulatory compliance, legal accountability, and professional indemnity insurance coverage (Smith & Johnson, 2014).

Legal and regulatory frameworks have increasingly mandated comprehensive documentation practices, emphasizing accountability across all project phases. Proper documentation serves as evidence of due diligence, helping to protect engineers and project stakeholders from liability claims and litigation (Mason & Cooke, 2012). Consequently, thorough documentation has become an indispensable tool for managing project risks and ensuring long-term project integrity.

2.4 Balancing Thoroughness and Agility in Documentation

Despite its advantages, thorough documentation practices can sometimes introduce delays and inefficiencies, particularly in fast-paced or dynamic construction environments. Manual documentation processes can be slow, cumbersome, and susceptible to errors, potentially impeding rapid decision-making and timely responses to unforeseen project challenges (Davies, 2010).

Emerging digital technologies offer opportunities to streamline documentation practices, enhancing both agility and accuracy. Digital platforms and automated documentation tools allow for real-time collaboration, instant updating, and comprehensive data tracking, significantly reducing the time required for documentation processes (Foster & Jackson, 2018). Adopting digital solutions can help balance the need for rigorous documentation with the demand for operational agility, ultimately improving project outcomes and risk management effectiveness.

2.5 Conclusion

The evolution of documentation practices has significantly advanced the management of risks in civil engineering. While structured documentation has improved accountability and compliance, embracing modern digital solutions can further enhance documentation efficiency and responsiveness. Successfully balancing meticulous documentation with project agility will remain essential for effective risk management in civil engineering.

Chapter 3: Evolution of Technical Drawings and Communication

3.1 Introduction

Technical drawings have always been vital in civil engineering, serving as the primary communication medium between engineers, contractors, and clients. This chapter explores the historical evolution of technical drawings, highlighting advancements from manual drafting techniques to contemporary digital approaches and their implications on project communication and efficiency.

3.2 Manual Drafting Practices

Traditionally, technical drawings were painstakingly crafted by hand, requiring skilled draftsmen who meticulously created precise and detailed representations. These manual drawings emphasized clarity and precision, yet they were highly labor-intensive and susceptible to human errors. Changes or revisions necessitated considerable effort, making iterations and updates costly and slow (Cuff, 1992).

The manual distribution of drawings via mail or courier presented additional challenges, including delays and risks of damage or loss. This slow communication process often led to significant project delays and misunderstandings, particularly in large or geographically dispersed projects (Bachman, 2003).

3.3 Transition to Digital Design and CAD Systems

The introduction of Computer-Aided Design (CAD) systems in the late 20th century dramatically transformed the landscape of technical drawing. CAD technologies allowed engineers to produce accurate, detailed, and easily modifiable digital drawings, significantly enhancing productivity and reducing error margins. The digital format facilitated rapid revisions, collaborative input, and standardized documentation, greatly improving design accuracy and clarity (Eastman et al., 2008).

Digital communication further revolutionized the dissemination of technical drawings. Engineers and project stakeholders could instantly share and access drawings through electronic means, removing geographical barriers and substantially speeding up the approval and implementation processes. This enhanced communication capability significantly improved collaborative decision-making and reduced misunderstandings and rework on construction projects (Sacks et al., 2010).

3.4 Limitations and Unexplored Potential of Current Digital Methods

Despite substantial advancements, current digital methods in civil engineering still face several limitations and unexplored potentials. Compared to other industries, civil engineering has been relatively slow to integrate advanced simulation, artificial intelligence (AI), and real-time analytics into standard drawing and design workflows. The limited adoption of these cutting-edge technologies restricts engineers' ability to leverage full computational potential, dynamic simulation capabilities, and enhanced predictive accuracy in their designs (Succar, 2009).

Emerging technologies such as blockchain for secure documentation and dynamic simulation tools offer significant future opportunities. Blockchain could ensure document authenticity, traceability, and security, providing an immutable record of drawing versions and revisions, enhancing accountability and reducing project risks (Turk & Klinc, 2017). Furthermore, advanced dynamic simulations and visualization tools could enable engineers to better predict structural performance, environmental impacts, and construction processes, thereby further improving project outcomes and efficiencies (Eastman et al., 2008).

3.5 Conclusion

Technical drawings in civil engineering have significantly evolved, transitioning from manual, labor-intensive methods to sophisticated digital solutions. While digital advancements have greatly enhanced productivity, accuracy, and collaboration, substantial opportunities remain to integrate more advanced simulation and secure documentation technologies. Embracing these emerging innovations can lead to even more effective project communication, improved risk management, and superior project outcomes.

Chapter 4: Building Information Modelling (BIM) and Digital Collaboration

4.1 Introduction

Building Information Modelling (BIM) has profoundly impacted civil engineering by transforming the ways in which project data is created, managed, and shared. This chapter explores the development and application of BIM, examining its role in digital collaboration, risk management, and the potential it holds for further innovation in civil engineering practices.

4.2 Emergence and Development of BIM

BIM emerged as a revolutionary approach to building design and management, offering comprehensive digital representations of physical and functional characteristics of construction projects. This digital approach replaced traditional 2D drawings with dynamic 3D models containing detailed information about project elements, materials, and specifications. BIM significantly improved coordination among different disciplines, reduced errors, enhanced design accuracy, and streamlined construction processes (Eastman et al., 2008).

Early BIM implementations focused primarily on visualization and design coordination, allowing stakeholders to virtually explore and resolve design conflicts before physical construction. Over time, BIM evolved to integrate cost estimation, scheduling, and facility management, making it a comprehensive lifecycle tool for civil engineering projects. This progression allowed for better-informed decision-making, improved cost control, and enhanced operational efficiency across projects (Succar, 2009).

4.3 BIM for Digital Collaboration and Risk Management

BIM has significantly enhanced collaboration across project teams, enabling real-time data sharing, simultaneous design modifications, and integrated project management. Digital collaboration platforms using BIM have facilitated clearer communication, reduced misinterpretations, and improved stakeholder engagement throughout project phases. This collaborative environment has also greatly improved risk identification and mitigation, with stakeholders proactively addressing design and construction issues early in the project lifecycle (Azhar, 2011).

Risk management is particularly improved by BIM through its capabilities in detecting and resolving clashes, providing accurate simulations of construction sequences, and enabling predictive analysis of potential project challenges. Additionally, comprehensive data management within BIM ensures that critical project documentation is easily accessible, verifiable, and securely maintained, thereby significantly reducing the likelihood of disputes and claims (Sacks et al., 2010).

4.4 Challenges and Barriers to BIM Adoption

Despite its benefits, BIM adoption in civil engineering has faced several barriers, including high initial investment costs, steep learning curves, resistance to changing traditional practices, and interoperability issues among software systems. Many organizations also struggle with the cultural shift required to fully leverage BIM technologies, particularly regarding collaboration and data sharing practices (Howard & Björk, 2008).

Overcoming these challenges requires a combination of strategic investments, targeted training programs, standardized practices, and industry-wide collaboration initiatives. Ensuring interoperability and adopting open standards can further accelerate BIM adoption, facilitating seamless data exchange and collaboration among diverse stakeholders and software platforms (Succar, 2009).

4.5 Future Trends and Potential of BIM

The future of BIM in civil engineering holds significant potential, particularly with advancements in technologies such as cloud computing, artificial intelligence, virtual reality, and augmented reality. Cloud-based BIM systems can further enhance real-time collaboration, enabling seamless global teamwork and immediate project updates. Integrating artificial intelligence can empower BIM platforms with predictive analytics, automated design optimization, and intelligent project management capabilities (Eastman et al., 2008).

Virtual reality and augmented reality technologies promise to extend BIM's capabilities, providing immersive project visualizations and enhanced interactive environments for training and stakeholder engagement. These technological advancements offer new dimensions for exploring project designs, conducting simulations, and ensuring comprehensive understanding and analysis of construction and operational processes (Succar, 2009).

4.6 Conclusion

BIM has significantly transformed civil engineering practices, improving project collaboration, accuracy, and risk management. While challenges remain, the continued adoption and technological advancement of BIM will further enhance its impact. Embracing future BIM trends and innovations is essential for maintaining competitiveness and achieving superior project outcomes in civil engineering.

Chapter 5: Digital Twins in Civil Engineering

5.1 Introduction

Digital twins represent a transformative technological advancement in civil engineering, providing dynamic digital replicas of physical assets and systems. This chapter explores the concept, applications, and implications of digital twins, emphasizing their potential to enhance project management, maintenance, and decision-making in civil engineering.

5.2 Concept and Development of Digital Twins

The concept of digital twins originated in manufacturing and has rapidly expanded into civil engineering. A digital twin is a comprehensive virtual model that mirrors the characteristics, behaviours, and real-time performance of a physical structure or system. By integrating data from sensors, simulations, and historical records, digital twins offer unprecedented insights into the lifecycle performance and management of engineering assets (Grieves & Vickers, 2017).

Initially used for basic monitoring purposes, digital twins have evolved significantly, incorporating advanced data analytics, predictive modelling, and artificial intelligence. These capabilities enable engineers and stakeholders to predict performance, optimize maintenance strategies, and proactively identify potential problems, substantially improving operational efficiency and extending asset lifecycles (Qi et al., 2018).

5.3 Applications of Digital Twins in Civil Engineering

Digital twins have numerous practical applications across various civil engineering domains. Infrastructure management significantly benefits from digital twins through enhanced condition monitoring, predictive maintenance, and asset management optimization. Real-time monitoring using digital twins allows engineers to quickly identify and address performance anomalies, reducing downtime and extending infrastructure longevity (Tao et al., 2018).

Construction projects also leverage digital twins for improved planning, execution, and monitoring. By simulating construction processes and site logistics, digital twins can identify and mitigate risks, optimize resource allocation, and streamline project timelines. The integration of digital twins with other technologies like BIM enhances visualization, collaborative planning, and informed decision-making throughout the project lifecycle (Jones et al., 2020).

5.4 Benefits and Impact of Digital Twins

The implementation of digital twins provides substantial benefits, including improved accuracy in predictive maintenance, reduced lifecycle costs, enhanced safety, and increased reliability. Real-time data analytics allow engineers to make informed decisions rapidly, minimizing operational disruptions and improving overall system resilience (Qi et al., 2018).

Digital twins facilitate better stakeholder communication and collaboration by providing visual and intuitive representations of complex data and systems. Stakeholders can easily understand asset conditions, potential risks, and operational statuses, fostering transparency, informed decision-making, and proactive management practices (Grieves & Vickers, 2017).

5.5 Challenges and Future Opportunities

Despite their significant potential, digital twins face various implementation challenges, including high initial setup costs, complexity of data integration, and requirements for robust cybersecurity measures. Ensuring data accuracy and managing vast amounts of information also present considerable difficulties, necessitating sophisticated data management and analytics capabilities (Tao et al., 2018).

Future opportunities for digital twins lie in their integration with emerging technologies such as Internet of Things (IoT), advanced sensor technologies, and machine learning. These advancements will further enhance predictive accuracy, real-time responsiveness, and operational automation capabilities. Continued innovation in these areas promises to expand digital twin applications, providing even more sophisticated tools for asset management, risk assessment, and decision support in civil engineering (Jones et al., 2020).

5.6 Conclusion

Digital twins represent a significant advancement in civil engineering, providing powerful tools for asset management, risk mitigation, and operational optimization. Despite implementation challenges, continued development and integration with emerging technologies promise substantial future benefits. Embracing digital twin technologies will enhance project performance, safety, and sustainability, positioning civil engineering projects for greater success.

Chapter 6: Generative Design in Temporary Works

6.1 Introduction

Generative design represents a paradigm shift in engineering and architecture, enabling the automated creation of design options based on specified parameters and constraints. In the context of temporary works in civil engineering, generative design offers significant potential to improve efficiency, innovation, and safety. This chapter explores the principles, applications, and implications of generative design, with a focus on its transformative potential in the temporary works sector.

6.2 Principles of Generative Design

Generative design uses algorithms and computational processes to explore a wide range of possible design solutions. Unlike traditional methods where engineers manually develop and refine a few options, generative design allows the computer to generate and evaluate thousands of permutations based on user-defined goals and constraints, such as load capacities, material limits, or spatial restrictions (Kolarevic, 2003).

These systems typically use evolutionary algorithms or rule-based logic to iterate through design possibilities, evaluating each one against performance criteria. The process continues until optimal or near-optimal solutions are identified, offering engineers novel and efficient configurations that might not emerge through traditional design processes (Leach, 2009).

6.3 Application to Temporary Works Design

In temporary works, which are often time-constrained and cost-sensitive, generative design provides a compelling advantage. By automating the design exploration process, engineers can rapidly generate scaffold layouts, shoring schemes, or excavation supports that meet site-specific requirements while optimizing for material efficiency, stability, and ease of assembly.

Generative design can integrate with site constraints, such as available footprint, access paths, or interaction with permanent works. These models enable dynamic reconfiguration when parameters change—such as load adjustments or sequencing revisions—making temporary works more adaptable and responsive to real-world conditions (Shea et al., 2005).

6.4 Benefits and Innovation Potential

The key benefits of generative design in temporary works include reduced design time, enhanced material efficiency, and the discovery of innovative solutions that deviate from conventional approaches. By evaluating thousands of options, generative design uncovers configurations that balance structural performance with constructability and cost (Turrin et al., 2011).

This method also supports early-stage decision-making by enabling engineers to visualize trade-offs between competing objectives—such as speed versus material use—through performance-based metrics. As a result, teams can make informed design choices grounded in data rather than intuition alone, fostering a more transparent and justifiable design process.

6.5 Challenges and Practical Considerations

Despite its promise, the adoption of generative design in temporary works faces several challenges. Engineers must invest time to properly define constraints and objectives, and the computational models must accurately reflect physical behaviour. In addition, generative tools must interface effectively with standard engineering analysis software and BIM platforms to ensure compatibility with established workflows (Broughton & Lindley, 2019).

Another critical barrier is cultural: many temporary works designs are driven by experience and intuition. Shifting to an automated design paradigm may face resistance unless supported by clear demonstration of benefits, adequate training, and assurance of regulatory compliance. Addressing these concerns will be key to realizing the full potential of generative methods in practice.

6.6 Conclusion

Generative design offers an exciting opportunity to transform temporary works in civil engineering. By automating the design exploration process and evaluating vast arrays of possibilities, this method can yield efficient, innovative, and tailored solutions. Overcoming technical and cultural challenges will be essential to fully integrating generative design into standard practice and unlocking its value across the project lifecycle.

Chapter 7: Opportunities for Innovation in Temporary Works

7.1 Introduction

Temporary works in civil engineering have traditionally been viewed as peripheral to permanent construction, often managed with minimal innovation or digital integration. However, emerging technologies and shifting industry expectations present substantial opportunities to transform temporary works into a more strategic and efficient discipline. This chapter explores how innovation can be fostered in temporary works through the adoption of digital tools, new workflows, and a cultural shift in how temporary structures are valued.

7.2 Current Limitations and Underutilisation

Despite their importance to project safety and sequencing, temporary works are often under-prioritized in engineering innovation. Many design processes remain manual or based on standard templates, resulting in suboptimal solutions, inefficient material use, and poor adaptability to site-specific constraints. The lack of digital integration, particularly in early design stages, contributes to time delays, coordination issues, and documentation inefficiencies (Bennet et al., 2014).

Temporary works are frequently designed under tight time constraints, leading to decisions based on past experience rather than data-driven optimization. This reactive approach limits creativity and hinders the application of advanced analysis tools, generative workflows, or simulation-based risk assessments that are becoming standard in permanent works.

7.3 Drivers for Innovation

Several factors are driving the need to modernize temporary works. Increasing project complexity, tighter regulatory oversight, and rising expectations for safety and sustainability all demand more rigorous and adaptable solutions. The availability of powerful computational tools, cloud-based collaboration platforms, and real-time site data from sensors creates fertile ground for innovation.

Cost pressures and sustainability goals also encourage engineers to reduce waste and improve the reusability of temporary structures. Digital modeling and simulation can support these goals by enabling smarter planning, scenario testing, and material tracking, ensuring that temporary works are not only safe and effective but also economically and environmentally responsible.

7.4 Digital and Computational Tools

The adoption of digital tools, including Building Information Modelling (BIM), finite element analysis (FEA), and generative design platforms, offers practical ways to improve temporary works. BIM facilitates better integration with permanent works, clearer documentation, and improved clash detection. FEA tools can be used to validate designs more rigorously, particularly in complex geometries or critical load conditions.

Generative design and algorithmic modeling allow engineers to explore a broader solution space, optimize layouts, and adapt designs in real time. By embedding constraints and performance metrics into the design process, engineers can generate and assess multiple options quickly, reducing reliance on intuition or standard solutions (Shea et al., 2005).

7.5 Cultural and Organisational Change

To unlock the full potential of innovation, a cultural shift is required in how temporary works are perceived and prioritized. Organizations must view temporary works not as ancillary, but as integral to the success of a project. Encouraging digital upskilling, fostering collaboration between temporary and permanent works teams, and embedding innovation into project delivery frameworks are critical steps.

Leadership support is essential to overcome inertia and risk aversion. Piloting new technologies on smaller projects, sharing success stories, and engaging with regulatory bodies early in the process can help build confidence and momentum. Ultimately, organizations that embrace innovation in temporary works can gain competitive advantages in safety, speed, and cost-effectiveness.

7.6 Conclusion

Temporary works present a significant opportunity for innovation within civil engineering. By embracing digital tools, rethinking workflows, and fostering a culture of experimentation and continuous improvement, the industry can transform temporary structures from logistical necessities into strategic assets. The journey toward innovation in temporary works will require both technological investment and cultural change, but the potential benefits in efficiency, safety, and sustainability make it a critical frontier for development.

Chapter 8: Augmented Reality and Virtual Prototyping in Civil Engineering

8.1 Introduction

Augmented Reality (AR) and Virtual Reality (VR) technologies are increasingly influencing the architecture, engineering, and construction (AEC) industries. In civil engineering, these technologies present unique opportunities to enhance design understanding, improve collaboration, and reduce on-site errors through immersive visualization. This chapter explores the roles of AR and VR in temporary works and broader civil engineering applications, outlining their benefits, current limitations, and future potential.

8.2 Concepts and Technologies

AR overlays digital information onto the physical environment, enhancing the real world with contextual data through devices such as smartphones, tablets, or AR glasses. VR, by contrast, immerses users in a fully digital environment, allowing them to explore virtual models independent of physical constraints. Both technologies leverage 3D models, often derived from Building Information Modelling (BIM), to create interactive experiences that improve spatial awareness and design clarity (Whyte, 2003).

In the context of temporary works, AR can be used to project scaffold layouts, excavation shoring systems, or access platforms directly onto the construction site. This enables engineers and site operatives to visualize proposed installations at full scale before implementation, improving alignment, reducing miscommunication, and assisting with constructability reviews. VR, meanwhile, offers immersive design reviews and safety walk-throughs, allowing stakeholders to assess risk and accessibility before construction begins (Meža et al., 2015).

8.3 Applications in Temporary Works

Temporary works often involve tight tolerances, constrained spaces, and rapid design iterations. AR/VR tools can significantly improve these workflows by enabling real-time assessment of temporary structures in their intended contexts. For example, overlaying a scaffold model on-site using AR can help determine clearances, clash points, or required modifications, thus reducing rework and enhancing safety (Chi et al., 2013).

VR simulations are particularly useful in training scenarios. Site personnel can experience complex installation sequences, practice safety procedures, or rehearse emergency evacuations in a risk-free virtual environment. These simulations improve preparedness and reduce reliance on costly or disruptive on-site trials.

8.4 Benefits and Impact

AR and VR technologies contribute to improved decision-making by enabling all stakeholders, including non-technical participants, to intuitively understand spatial arrangements and design intentions. This reduces cognitive load compared to interpreting 2D drawings or abstract data, leading to better design alignment and stakeholder buy-in (Dunston & Wang, 2005).

In terms of safety, AR/VR can support proactive hazard identification, better site logistics planning, and clearer communication of method statements. As temporary works are often modified on-the-fly, having an immersive and responsive visualization method greatly aids in managing rapid changes without compromising safety or quality.

8.5 Technical and Practical Limitations
Despite their potential, AR and VR adoption in civil engineering faces several barriers. Technical challenges include hardware limitations such as field-of-view, battery life, and outdoor visibility. Software compatibility with existing design tools, especially non-standard formats or custom scripts used in temporary works, can hinder seamless integration.

From a practical standpoint, successful use of AR/VR requires accurate and well-structured 3D models, which may not always be available for temporary works. Additionally, cultural resistance and limited digital training can prevent broader adoption among site personnel and smaller contractors.

8.6 Future Outlook
As AR and VR technologies mature, their integration with real-time data, such as sensor feedback or construction progress tracking, will unlock even greater value. Future systems may include augmented field instructions, AI-driven design recommendations, and automated clash detection directly through headsets. These innovations will further improve the agility, safety, and efficiency of temporary works planning and execution.

Moreover, as device costs decrease and interfaces become more intuitive, widespread adoption is expected. Early engagement and upskilling of engineering teams will be key to fully capitalizing on these immersive technologies in temporary works and beyond.

8.7 Conclusion
AR and VR technologies offer transformative potential in civil engineering, particularly in enhancing visualization, communication, and safety in temporary works. While technical and cultural challenges remain, ongoing advancements and growing industry interest suggest that immersive tools will become an integral part of the digital engineering toolkit in the years to come.

Figure 3: Author in full body motion capture suit at Richter reception

While we have not initially actively explored this avenue, exploring virtual reality and better methods of interfacing with digital environments is of huge interest to me, we have invested in the hardware to view a virtual environment in VR combined with full motion tracking of a user’s body, once we have developed more content for the service we talk about in the ending chapters, we will be exploring these more exotic options more freely with the time afforded by the running of the content developed.

Chapter 9: Generative and Parametric Design in Civil Engineering

9.1 Introduction

Generative and parametric design approaches are reshaping how engineers and designers approach problem-solving in civil engineering. These methodologies leverage computational logic to produce adaptive, optimized, and often novel solutions based on defined constraints and inputs. This chapter explores the principles, tools, and implications of generative and parametric design in the context of civil engineering, with particular attention to temporary works.

9.2 Understanding Generative and Parametric Design

Parametric design involves the use of variable parameters to control and adapt geometric models. This approach allows designers to quickly iterate and adjust models by changing input values, resulting in high flexibility and responsiveness to project requirements (Woodbury, 2010).

Generative design builds upon parametric logic by employing algorithms—often evolutionary or rule-based—to automatically explore a wide range of possible solutions. It can generate thousands of design alternatives that satisfy user-defined goals, such as minimizing material use, maximizing load capacity, or optimizing for buildability. The system evaluates each iteration against performance metrics, identifying optimal or near-optimal configurations (Davis et al., 2011).

9.3 Applications in Civil and Temporary Works

In civil engineering, these design methods are increasingly used for site layout optimization, structural form-finding, and infrastructure planning. In temporary works, where solutions must often be tailored to specific and dynamic site conditions, generative and parametric methods provide rapid adaptability and customization.

For example, parametric tools can be used to model scaffold layouts that adjust automatically to variations in building geometry. Generative algorithms can optimize trench shoring configurations or propping systems for different excavation depths, minimizing material use while ensuring safety and compliance. These methods enable a data-driven approach that goes beyond legacy rules-of-thumb or standard templates.

9.4 Tools and Technologies

A range of tools supports generative and parametric workflows in engineering. Grasshopper, a visual programming language integrated with Rhino 3D, is widely used for its flexibility and integration with analysis plugins. Dynamo, a similar tool for Autodesk Revit, allows for parametric modelling within BIM environments. Other platforms, like Bentley Generative Components and Autodesk's generative design tools, offer domain-specific capabilities.

These tools often integrate with structural analysis engines, environmental simulation tools, and optimization solvers to evaluate design performance in real time. They are increasingly being embedded in multidisciplinary workflows to improve coordination and enable simultaneous evaluation of architectural, structural, and logistical constraints (Shea et al., 2005).

9.5 Benefits and Opportunities

Generative and parametric approaches bring numerous benefits to engineering design. They enable greater exploration of the design space, often uncovering efficient or innovative solutions that may be overlooked using traditional methods. These tools also support rapid prototyping, scenario analysis, and early-stage decision-making—critical features in time-sensitive temporary works design.

Moreover, by embedding engineering logic and best practices directly into the design process, parametric models can act as design intelligence systems, guiding users towards safe and efficient outcomes. They also facilitate repeatability and automation, allowing engineers to develop design templates that can be reused and adapted across projects.

9.6 Challenges and Adoption Barriers

Despite their potential, adoption of generative and parametric design is limited by several factors. A key barrier is the learning curve associated with visual programming and algorithm development. Many engineers are not trained in these tools and may be reluctant to deviate from familiar software or manual approaches.

Integration with existing workflows, particularly in environments that rely heavily on traditional CAD or spreadsheet-based methods, also presents challenges. There is a need for better interoperability, user training, and demonstration of value to encourage broader uptake. Concerns about verification and validation of automatically generated designs must also be addressed to ensure regulatory acceptance.

9.7 Conclusion

Generative and parametric design methods offer a powerful extension to the civil engineer's toolkit, especially in the flexible and fast-paced world of temporary works. By facilitating rapid exploration, optimization, and automation, these approaches can enhance efficiency, creativity, and safety. Widespread adoption will depend on cultural change, skill development, and integration with existing engineering practice, but the long-term benefits are substantial.

Chapter 10: Machine Learning in Temporary Works Design

10.1 Introduction

Machine learning (ML), a subset of artificial intelligence (AI), is increasingly applied across engineering disciplines to enhance prediction, automate decision-making, and uncover patterns in complex datasets. In civil engineering, ML holds untapped potential for transforming how temporary works are designed, optimized, and managed. This chapter explores the current and emerging applications of machine learning in temporary works and outlines its possible contributions to safety, efficiency, and innovation.

10.2 Fundamentals of Machine Learning

Machine learning involves training algorithms to identify patterns and make predictions or classifications based on input data. These algorithms improve their performance over time as they are exposed to more data. In engineering, ML can be used for tasks such as structural health monitoring, failure prediction, load estimation, and construction sequencing (Ghahramani, 2015).

Common ML approaches include supervised learning (where models learn from labelled data), unsupervised learning (for clustering or anomaly detection), and reinforcement learning (for decision-making in dynamic environments). ML models require large volumes of structured or semi-structured data, as well as careful preprocessing and validation to ensure reliability.

10.3 Applications in Temporary Works

In the context of temporary works, ML can support predictive safety analysis by identifying risk patterns based on historical project data. For example, models trained on past incidents can highlight high-risk activities or suggest preventive measures for scaffold erection, excavation support, or crane pad placement.

ML can also assist in estimating temporary works requirements from project drawings or BIM models. Natural language processing (NLP) and image recognition tools can extract relevant design features or constraints from documentation, automatically flagging areas needing temporary support. This has the potential to drastically reduce manual effort and improve accuracy in early design stages.

Time-series forecasting algorithms can be applied to construction schedules and resource planning for temporary works, anticipating when and where equipment, supports, or personnel will be needed. This enables just-in-time delivery and reduced material wastage.

10.4 Integration with Existing Workflows

ML tools can be embedded within existing digital platforms such as BIM, construction management software, and digital twin systems. For instance, ML algorithms could analyse sensor data from temporary structures, predicting load exceedances or fatigue before they become critical. Integrating ML insights into project dashboards helps inform decisions in real time.

Open-source frameworks such as TensorFlow, Scikit-learn, and PyTorch provide accessible starting points for developing custom ML applications. These can be tailored to specific temporary works scenarios and integrated into visual programming tools like Grasshopper or Dynamo for enhanced usability.

10.5 Challenges and Considerations

Despite its promise, implementing ML in temporary works design comes with challenges. Data availability and quality are major hurdles—many engineering firms lack structured datasets or historical records needed to train effective models. Ensuring the interpretability of ML models is also critical, particularly when safety-related decisions are involved.

There is a cultural challenge as well: many engineers are unfamiliar with ML concepts and may be sceptical of relying on data-driven models. Addressing these concerns requires investment in training, clear communication of benefits, and transparency in model performance.

Regulatory and legal frameworks may also lag behind technological capabilities. Design outputs informed by ML must still meet traditional verification standards, which may require new validation protocols.

10.6 Conclusion

Machine learning presents a significant opportunity to enhance temporary works design by automating tasks, improving safety, and uncovering insights from project data. While adoption is still in early stages, the integration of ML with existing digital tools and workflows offers a compelling path forward. Success will depend on data readiness, engineer engagement, and the development of trustworthy and transparent models suited to the demands of civil engineering practice.

Chapter 11: Sustainability and Carbon Reduction through Optioneering

11.1 Introduction

As the construction industry grapples with the pressing need to reduce its environmental impact, temporary works must not be overlooked in sustainability initiatives. Although inherently short-lived, temporary works consume significant resources and generate waste. This chapter explores how optioneering—the practice of evaluating multiple design options—can be leveraged to enhance sustainability and reduce carbon emissions in temporary works.

11.2 Environmental Impact of Temporary Works

Temporary works contribute to material consumption, transport emissions, and on-site energy use. Scaffold structures, shoring systems, and access arrangements are frequently over-designed for simplicity or standardization, resulting in excess steel usage and inefficient logistics. Additionally, the lack of tracking or lifecycle assessment for temporary components obscures their true environmental footprint (Ajayi et al., 2017).

Current practices often prioritize speed or familiarity over sustainability, with limited consideration of environmental metrics in early-stage planning. This disconnect is compounded by fragmented procurement processes, limited reuse strategies, and inadequate integration with sustainability frameworks used for permanent works.

11.3 The Role of Optioneering in Sustainable Design

Optioneering supports sustainability by allowing engineers to systematically evaluate alternative designs based on performance metrics, including embodied carbon, transport distance, reusability, and material efficiency. By embedding these criteria early in the design process, engineers can identify solutions that balance performance with environmental impact (Moncaster & Song, 2012).

Using digital tools, multiple design options can be generated and assessed rapidly. For example, parametric models can be used to compare scaffold configurations based on tube lengths, bay spacings, and anchor densities, with each iteration analyzed for carbon content and material wastage. This allows engineers to make informed trade-offs and justify sustainability decisions quantitatively.

11.4 Tools and Metrics for Carbon Assessment

A range of tools and databases supports carbon quantification in construction. These include embodied carbon calculators (e.g. ICE database), BIM-integrated sustainability plugins, and LCA software such as One Click LCA or Tally. Such tools enable rapid estimation of carbon impacts based on material types, quantities, transport modes, and construction processes.

Incorporating these tools into temporary works design enables the inclusion of carbon metrics alongside traditional engineering criteria. Moreover, visual dashboards or comparative matrices can help communicate sustainability outcomes to stakeholders, fostering accountability and supporting low-carbon procurement decisions.

11.5 Opportunities for Reuse and Circularity

Sustainable temporary works design also involves considering the full lifecycle of components. Standardized components such as scaffold tubes, edge protection systems, or trench boxes can be reused multiple times if properly tracked and maintained. Optioneering can help identify configurations that maximize reuse potential while minimizing custom cutting or damage during installation.

Digital tagging and inventory systems—potentially linked with blockchain or QR-based tracking—could further enhance component lifecycle management. This would support circular economy principles, reduce raw material demand, and lower overall emissions from manufacturing and transport.

11.6 Challenges to Implementation

Barriers to sustainable optioneering include a lack of standardised carbon data for temporary works components, limited integration of sustainability metrics into commercial design tools, and time pressures that discourage exploration of alternatives. Furthermore, engineers may not have training or incentives to prioritise low-carbon solutions, especially in fast-moving project environments.

Cultural change, client education, and policy support will be essential to embed sustainability more deeply in temporary works. Clear guidelines, industry benchmarks, and the inclusion of carbon metrics in project KPIs can help drive broader adoption.

11.7 Conclusion

Optioneering provides a practical pathway to reduce the carbon footprint of temporary works, enabling engineers to consider sustainability alongside safety, cost, and speed. By leveraging digital tools, adopting lifecycle thinking, and embracing reuse strategies, the industry can make meaningful progress toward more sustainable construction practices—even in its most transient elements.

Chapter 12: Finite Element Method Integration with Generative Design

12.1 Introduction

The Finite Element Method (FEM) is a cornerstone of structural engineering analysis, enabling accurate modelling of stress, strain, and deflection under complex loading conditions. As engineering workflows evolve toward greater automation and design exploration, integrating FEM with generative design offers the potential to create highly optimized and verifiable solutions, especially in temporary works. This chapter explores how FEM can complement generative approaches to improve design robustness, performance, and adoption in civil engineering.

12.2 Fundamentals of the Finite Element Method

FEM breaks down complex geometries into discrete elements, solving equilibrium equations at nodes to approximate physical behaviour across a structure. It is widely used to assess load paths, identify stress concentrations, and validate structural adequacy under various conditions (Zienkiewicz et al., 2005).

FEM's accuracy and ability to handle irregular geometries make it especially valuable for checking non-standard or adaptive designs. When used properly, it offers a level of analytical rigour essential for compliance with engineering codes and for ensuring safety in both temporary and permanent works.

12.3 Enhancing Generative Design with FEM

Generative design algorithms are typically driven by geometric and rule-based parameters. While these tools are excellent at producing large volumes of design permutations, they often lack built-in structural validation. By integrating FEM into the generative design loop, each design iteration can be evaluated not only for geometry and constructability but also for mechanical performance.

This enables real-time feedback on deflection limits, stress thresholds, and failure modes, which can be incorporated into the fitness criteria guiding the generative process. As a result, the algorithm converges on solutions that are not only geometrically viable but also structurally sound (Tam et al., 2021).

12.4 Applications in Temporary Works

Temporary works often involve bespoke or irregular geometries constrained by site conditions, making them ideal candidates for generative design combined with FEM. For instance, shoring configurations or formwork systems can be generated based on space constraints, and then immediately analysed for structural performance. This integration streamlines the design workflow by removing the manual back-and-forth between conceptual generation and structural checking.

In scaffold design, where standard bay layouts must adapt to complex façades, integrated FEM tools can verify load capacities, anchorage performance, and global stability in each proposed configuration. This approach enables safer, leaner, and more adaptable solutions tailored to site conditions.

12.5 Tools and Workflow Integration

Modern software platforms support varying degrees of FEM and generative integration. Tools such as Grasshopper (with Karamba3D or Millipede), Autodesk Dynamo (with Robot Structural Analysis), and proprietary plugins within Bentley and Tekla ecosystems allow designers to script iterative processes and automatically assess FEM outputs.

These workflows typically involve defining parametric inputs, generating design alternatives, applying loads and boundary conditions, running FEM analysis, and ranking results based on compliance and performance. Results can be visualised directly within the modelling environment, facilitating rapid refinement and decision-making.

12.6 Challenges and Considerations

Integrating FEM into generative workflows introduces computational complexity, requiring more processing power and careful scripting to avoid unstable or unrealistic results. FEM simulations are also sensitive to boundary condition assumptions, mesh quality, and solver settings, which can introduce inaccuracies if not properly managed.

From a cultural perspective, there may be resistance to trusting automated FEM checks, particularly in safety-critical applications. Ensuring transparency, verification, and documentation of automated results will be essential for regulatory acceptance and industry confidence.

12.7 Conclusion

Combining the power of generative design with the analytical depth of FEM unlocks new possibilities for innovation and safety in temporary works. This integrated approach enables rapid generation of custom, efficient, and structurally validated designs, supporting both creative exploration and engineering rigour. With continued tool development and improved workflows, this synergy is poised to become a standard practice in digital civil engineering design.

Chapter 13: Bridging the Gap Between Researchers and Practitioners in Civil Engineering

13.1 Introduction

A longstanding divide exists between academic research and industry practice in civil engineering. While researchers often focus on innovation, theoretical frameworks, and long-term visions, practitioners are primarily concerned with immediate problem-solving, regulatory compliance, and deliverability. This chapter explores the reasons behind this divide, its consequences, and strategies for fostering greater synergy between these two essential communities.

13.2 Contrasting Objectives and Constraints

Researchers are typically driven by the pursuit of novel knowledge, with an emphasis on publishing, academic recognition, and theoretical exploration. This often leads to work that is innovative but not immediately practical. Conversely, practitioners operate under constraints of time, budget, and risk, which prioritise solutions that are proven, efficient, and compliant with current standards (Courtney, 2001).

The result is a gap in expectations and timelines. Research may propose methods that are computationally intensive or reliant on emerging tools not yet adopted in industry, while practitioners often lack the resources to explore unproven ideas, particularly in risk-averse environments like temporary works.

13.3 Communication Barriers

One major challenge in bridging the gap is the lack of a common language or platform for collaboration. Academic research is frequently published in journals behind paywalls, written in technical language, and focused on controlled conditions that do not translate easily to real-world complexity.

Practitioners, on the other hand, often rely on standards, codes of practice, and trade literature that may not reflect the latest research. This disconnect impedes knowledge transfer and mutual understanding, particularly when research findings are not packaged in a form that is accessible or actionable by engineers in the field.

13.4 Opportunities for Collaboration

Despite these challenges, numerous opportunities exist for aligning research and practice. Industry-academic partnerships, knowledge exchange programmes, and collaborative projects offer platforms for mutual learning. Involving practitioners early in the research process ensures that studies are grounded in real-world needs, while embedding researchers in project teams helps align innovation with practical constraints (Davey et al., 2014).

Joint development of digital tools, such as simulation environments or generative design plugins, provides a practical avenue for knowledge transfer. Practitioners can test and refine tools under field conditions, while researchers collect data and feedback to improve algorithms and theories. This cyclical exchange fosters co-evolution of methods and relevance.

13.5 Bridging Through Education and Upskilling

Education serves as a key bridge between the two communities. Embedding research-led teaching in engineering curricula exposes future practitioners to cutting-edge concepts and tools. At the same time, continuing professional development (CPD) programmes can help current engineers stay abreast of new methods and technologies.

Universities can also support industry with training in emerging technologies like BIM, generative design, or machine learning—areas where research is moving faster than commercial adoption. Providing modular, accessible learning content tailored for practitioners helps overcome the inertia often seen in traditional workflows.

13.6 A Shared Vision for Innovation

For innovation to flourish in civil engineering, both researchers and practitioners must see themselves as part of a shared ecosystem. Researchers bring depth, foresight, and experimentation, while practitioners bring context, constraints, and feedback. By aligning their efforts, the industry can develop solutions that are not only inventive but also implementable and impactful.

This alignment will require new incentives, shared platforms, and long-term relationships that transcend individual projects. Institutions, funding bodies, and professional associations all have a role to play in creating a culture that values collaboration over silos.

13.7 Conclusion

The gap between researchers and practitioners in civil engineering is not insurmountable. With purposeful collaboration, mutual respect, and structures that reward engagement across boundaries, both communities can benefit from each other’s strengths. Bridging this gap is essential for ensuring that research is relevant and that practice continues to evolve in step with emerging knowledge and technologies.

Chapter 14: Conclusion to the Literature Review

14.1 Summary of Key Themes

This literature review has explored a wide range of emerging technologies and methodologies relevant to civil engineering, with particular emphasis on temporary works. It has examined the evolution of calculation methods, documentation practices, design communication, BIM, digital twins, generative design, machine learning, sustainability, finite element integration, and the gap between research and practice. Collectively, these chapters illustrate that while technological capabilities in the industry have grown significantly, their practical application remains sporadic and uneven.

Each chapter has highlighted impressive advancements—tools that promise greater efficiency, accuracy, and sustainability. However, despite their potential, these innovations often fail to transition into widespread use. The barriers are not purely technical; they are also cultural, institutional, and procedural. Many of the tools and methods described are well understood in academic or theoretical settings but have yet to find traction in real-world practice where constraints, risks, and delivery pressures dominate.

14.2 From Academic Advancement to Practical Implementation

A central observation emerging from this review is the disconnect between developing better engineering solutions and delivering better engineering outcomes. Much research focuses on improving the theoretical quality of designs—greater efficiency, deeper analysis, more refined optimisation. Yet, these advances are frequently divorced from the delivery environment in which they must operate. If innovation cannot be implemented quickly, reliably, and affordably in a working design office or on a live construction site, its value is diminished.

This thesis takes a different approach. Rather than contributing yet another layer to the growing body of academic innovation, it questions why so little of what already exists is being used. The focus is not on proving that more accurate, sustainable, or optimal designs are possible, but on identifying why current workflows fail to adopt these improvements—and how that adoption gap can be overcome.

14.3 Reframing the Problem

To make meaningful progress, the goal must shift from simply improving the engineering to improving how engineering is delivered. This requires a re-evaluation of priorities: reducing cognitive and procedural overhead, enabling faster decision-making, simplifying digital toolchains, and embedding intelligence into design processes that can be used by generalists—not just specialists. It means creating tools that do not just work in theory but survive the pressures of real projects, limited time, and fragmented data.

Rather than adding complexity through academic frameworks, the focus should be on stripping away friction from daily design work. This thesis argues that the most impactful innovations are those that change how people work—not just what is possible in ideal conditions. By centring the real-world delivery context, a more grounded and impactful path forward for engineering innovation can emerge.

14.4 Conclusion

There is no shortage of technological capability in civil engineering. What is lacking is the ability to integrate these capabilities into practice in a way that meaningfully changes outcomes. This literature review has surfaced many promising approaches but also underscored the deep challenges in implementation. The chapters that follow move beyond theoretical possibilities and focus instead on applied strategies for transforming how engineers work, think, and deliver value—particularly in the overlooked but critical domain of temporary works.

Main body

Figure 4: Prototype render for Charlieverse Avatar real time modelling and analysis tool

Chapter 15: First Attempt at Introducing a Technology Overhaul

15.1 Context and Motivation

Following the extensive literature review, the practical focus of this thesis emerged: not merely to apply technology for its own sake, but to fundamentally improve how delivery is executed in temporary works design. While much attention in the industry is often given to high-end, complex solutions, it is the routine and repetitive designs that experience the greatest delays and inefficiencies—despite representing the bulk of the work on active construction sites. In other words, the everyday design process itself had become the bottleneck, rather than the mathematical techniques used. This chapter explores how the original goal to "digitise design" evolved into a deeper understanding of workflow and human factors that govern real-world success. The emphasis shifted toward changing how designs are made (Theme 1), focusing on better delivery and process efficiency rather than just improving analytical methods.

At the time, I was employed by Costain, a Tier 1 contractor delivering major national infrastructure projects. Costain permitted me to dedicate a portion of my PhD hours and surplus consultancy profits toward experimental development. Weekends and evenings became the proving ground for early ideas. This arrangement provided a unique opportunity to trial innovations within a live project environment, giving insights that purely academic work might have missed. The initial ambition was simple but broad: explore whether technological enhancements could speed up or improve typical design procedures in temporary works—especially for the high-frequency, medium-risk items now governed by the temporary works code BS5975. These common designs (e.g. working platforms, scaffolds, trench supports) are not technically exotic, but they consume considerable time under traditional processes. The hypothesis was that shortened turnaround times could enable far greater agility on-site (Theme 2), reducing the costly idle time and risk currently accepted as normal. This idea aligns with lean construction principles that emphasize eliminating waiting and other non-value-adding activities (Sacks *et al*., 2010). In essence, rather than developing new complex algorithms for niche cases, the greater potential value lay in revolutionizing the delivery mechanism for everyday designs – a theme that would underpin the subsequent development.

15.2 Realising the Problem Firsthand

My initial attempts at digital innovation within Costain included novel visualization and planning tools: for example, a virtual reality (VR) simulation of a complex diving operation, and a 3D sequencing model for the marine works at Hinkley Point C. The latter was even used in tenders and stakeholder meetings, supported by physical 3D-printed models—an uncommon practice at the time. These tools were *visually* impressive and earned praise for their ingenuity. (Indeed, as discussed in Chapter 8, AR/VR and 4D modelling can enhance understanding of construction sequences.) However, they lacked a measurable return on investment in terms of improving project delivery speed or cost. This sparked an important insight: many tech applications in construction are engaging and innovative, but rarely impactful enough to justify systemic adoption. The experience mirrored a broader industry trend – without a clear, heavy impact on key metrics like time, risk, or cost, new technology remains a nice-to-have or one-off demo rather than a game-changer. I realised that if innovation was to succeed in this context, it needed to have a **significant, quantifiable effect** on project outcomes (e.g. cutting weeks to days, or materially reducing on-site risk), not just provide a new way to visualize information.

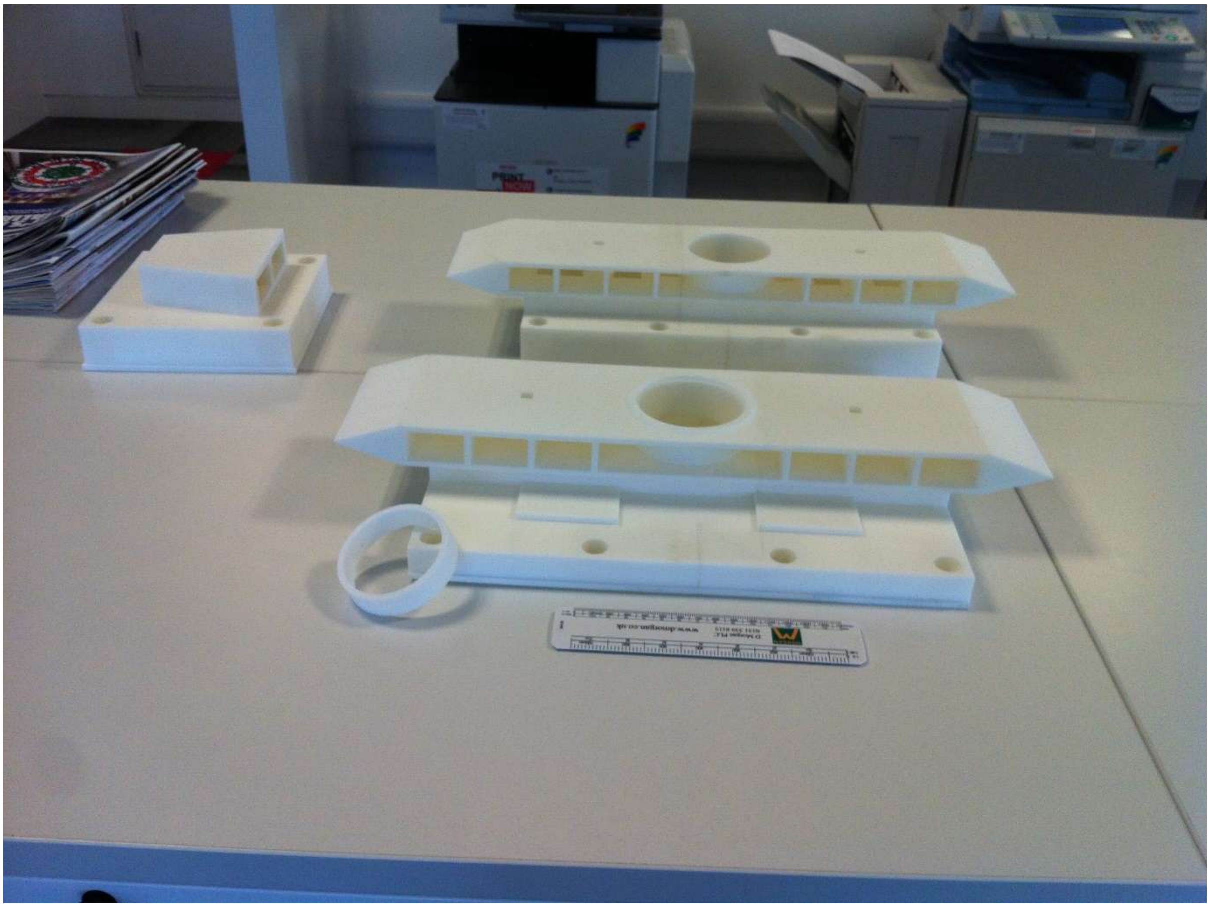


Figure 5: Hinkley point C nuclear station marine water cooling 3D printed scale models

In pursuit of a scalable opportunity, I expanded my research beyond the office. I engaged with site staff and attended industry events to better understand front-line frustrations. The same complaints surfaced repeatedly: slow turnaround on designs, cumbersome approval processes, and a lack of flexibility once work was underway. Eventually, I took a six-month placement as a Temporary Works Supervisor (TWS) at London Paddington as part of the Crossrail project. In this high-pressure role, I had **full exposure to the site-side delivery cycle**: requesting and procuring temporary works designs from engineers, checking those designs, assigning Permits to Load for construction to proceed, liaising with clients on approvals, and physically inspecting the works in the field. This first-hand involvement was invaluable. It revealed the practical consequences of long turnaround times in a way that academic study alone could not. Engineers on site were routinely caught between **urgent site demands and slow design house outputs** – an operational gulf that introduced both safety and schedule risks.

One rainy evening at 7 PM, I found myself facing the very dilemma I had been theorizing about. An excavation needed urgent shoring design approval for work to continue the next morning, but the formal design was still pending from the external engineers. The site team was anxious; we either had to delay critical work (incurring cost and frustration) or improvise a solution without proper sign-off (incurring serious safety and legal risks). Standing in the mud with that untenable choice, it became vividly clear that the traditional process was failing the people on the ground. That moment convinced me: not only could a better system exist — it must exist. This was not an isolated incident but a systemic issue. Delays in design delivery were not just inconveniences; they directly translated into increased risk, as project teams under pressure might take unsafe shortcuts or suffer financial penalties for downtime (Albogamy *et al*., 2014). I recognized that a step-change in real delivery was needed (Theme 3): an approach that could compress the design cycle from weeks to hours, enabling on-site agility without compromising safety or compliance.

15.3 Project Daedalus: A Prototype with a Purpose

Out of these realizations came Project Daedalus, a rapid-procurement design platform intended to produce complete, compliant temporary works packages in minutes rather than weeks. In concept, Daedalus was envisioned as a one-stop, automated design generator: Temporary Works Coordinators (TWCs) or site engineers would be able to input their project-specific parameters and instantly receive a *pre-approved*, validated design package in real time—without compromising quality, compliance, or accountability. For instance, consider the Paddington scenario described above: with Daedalus, the TWS could have logged into a portal, selected the type of support needed, entered the site parameters (excavation dimensions, ground conditions, loading, etc.), and within about 60 seconds obtained an engineered drawing and calculation set ready for approval. The next morning, work could proceed safely because of that package, rather than remaining at a standstill. This use case exemplifies the potential: what traditionally might require days of back-and-forth with an external designer could be delivered on-demand, greatly enhancing responsiveness on site.

To turn this vision into reality, I developed a working prototype of the Daedalus platform. Technically, the prototype was implemented as a lightweight web-based application with a simple user interface and an automation engine behind it. The architecture followed a typical three-tier pattern: a front-end for user input, a back-end processing core for computations and document generation, and a data layer for storing results and user information. Given the limited development resources (essentially a single developer working off-hours), I leveraged familiar and robust tools wherever possible. For example, the back-end calculation engine incorporated pre-validated design formulas and even spreadsheet templates that were already accepted in engineering practice. Rather than coding every calculation from scratch, the system fed user inputs into standard calculation models (such as industry-standard spreadsheets for ground bearing pressure or scaffold load calculations), ensuring that the output mirrored what a competent engineer would manually produce. This approach not only accelerated development but also built trust: by using well-understood design methods (e.g. formulae from BS EN codes and established industry guidance), the results would be recognizable and auditable. Key failure modes for temporary works (uplift, sliding, overturning, structural capacity, etc.) were all encoded in the logic, meaning the tool could automatically check the critical criteria that a human engineer would normally consider.

In parallel, a drawing generation module was created to produce the accompanying technical drawings. Here, too, efficiency was paramount. I prepared parametric drawing templates using Solidworks (and similar CAD tools) with customizable components. The prototype's code could programmatically adjust dimensions, annotations, and layout in these templates based on the user's inputs, thereby outputting a project-specific drawing on the fly. For example, if the user needed a outrigger design for a crane, the tool would draw the plan and cross-section with the correct pad dimensions, spacing, and notes automatically. This was achieved through scripting the CAD software and using a library of pre-drawn components (blocks) that could be inserted and scaled as needed. The combined result was that for each design request, two primary files were generated in real time: a calculation report and a GA (general arrangement) drawing.

Because compliance and traceability were critical, the prototype also integrated a basic data storage system. All user inputs and generated outputs were logged in a small database (using SQL) on the server. This created an audit trail for each design produced – a digital record showing who generated it, when, and what parameters were used. This feature was directly inspired by the need for auditable processes under BS5975 (which emphasizes documentation and accountability). In practice, it meant that if any question arose about a design, we could retrieve the exact input set and outputs for review or rechecking. It also laid the groundwork for iterative improvements, as stored cases could be analysed to see usage patterns or common adjustments.

I first unveiled the Daedalus prototype at Costain's internal engineering forum, with a live demonstration cheekily titled "How to Design in 60 Seconds." In that demo, I showed the audience a real-time generation of a basic design package: within one minute of entering a few key inputs, the system produced a formatted calculation document and an illustrative drawing for a simple scenario. The audience – consisting of engineers and managers – watched the process projected on-screen, and the *completed design output* was passed around for inspection. The reception was overwhelmingly positive. Many could not believe that what they were seeing was not pre-staged; it truly was a working application auto-designing on demand. This strong validation from peers and leadership led to Costain granting me additional time and resources to pursue the project further. For a technology initiative in a conservative industry, this was a crucial early win: it signalled that even seasoned professionals recognized the *potential value* of drastically accelerated design turnarounds. It also reinforced the notion that we were aiming for a step-change in delivery, not just another tech demo.

With the prototype in place, the development process became an iterative design cycle. I adopted a rapid prototyping approach: deploy a basic feature, gather feedback, refine it, and then expand to the next feature. For instance, the initial version of Daedalus focused on one common design type (a simple working platform). Once that workflow was proven, the next iteration added another scenario (a crane outrigger pad design) reusing much of the underlying code. Each cycle involved testing by generating real project examples and sometimes showing them to end-users (trusted TWCs) for feedback. This agile development loop was critical given the limited development bandwidth – it ensured we spent time on the most impactful improvements first. It also meant the system's design was driven by end-user needs from the start, rather than theoretical capabilities. Over a series of iterations, the prototype evolved to be more robust: improving the user interface, handling edge-case inputs more gracefully, and enhancing the quality of the outputs (e.g. clearer drawings, more detailed calcs). In essence, the technology stack and architecture of Daedalus were selected for speed and adaptability. By using a web platform with a database backend and leveraging existing engineering tools (like Excel for calculations and Solidworks for drawings), we created a functional product quickly and set the stage for scaling it up. The experience of building this prototype also taught me how crucial it is to integrate with the familiar practices of engineers (such as their love of Excel printouts) to encourage adoption.

15.4 Understanding the Standard: BS5975

The foundation for this work – and the yardstick for its success – was British Standard BS5975, which governs not only falsework design but the entire *management process* for temporary structures in the UK. BS5975 (latest edition 2019) is essentially the rulebook that clients, contractors, and engineers must follow to ensure temporary works are planned and executed safely. It mandates a highly auditable process, including several key elements:

- Design and checking by qualified individuals: Every temporary works design must be carried out by a competent engineer (designer) and independently checked by another competent person. The roles of designers, checkers, and approvers (often the TWC) are clearly delineated.
- Formal approval protocols: Before implementation, designs must go through proper approval channels, culminating in a Permit to Load signed by the TWC. No load or use of the temporary work should occur without this sign-off.
- Comprehensive documentation: All calculations, drawings, and risk assessments associated with the design must be documented and retained. This documentation is proof that due process was followed and is vital for safety audits or investigations.
- Prescribed minimum turnaround times: In practice, many organizations interpret BS5975 procedures as requiring a *standard minimum turnaround of about two weeks per design* from request to approval. This timeline accounts for design, independent check, revisions, and sign-off steps. While the standard itself may not explicitly impose “two weeks”, it is an accepted industry norm to allocate on the order of 10 working days for even routine temporary works designs to cycle through the process.

This rigorous framework undoubtedly improves safety and accountability (as noted in Chapter 2, thorough documentation and checks mitigate risk – see Davies, 2010). However, it also presents a huge barrier to agility on site, especially for the common minor works like simple scaffolds, excavation supports, or edge protection were waiting two weeks is impractical. The tension between *thoroughness* and *agility* is a known challenge in construction risk management (Foster & Jackson, 2018). In essence, BS5975’s procedures were developed in an era when a slow, careful paper-based process was the only way to ensure nothing was missed. The question I aimed to answer was: could we embed those same checks and documentation in a digital workflow to get the best of both worlds – rigorous compliance with a fraction of the time?

Daedalus was built specifically to address this challenge. The system’s design criteria aligned directly with BS5975 compliance points but sought to compress the timeline dramatically. It aimed to generate, *in an automated and repeatable way, all the following outputs for each design:*

- Verified calculations: A full set of structural calculations covering all relevant failure modes (including uplift, sliding, overturning, bearing capacity, structural member checks, etc.), laid out in a clear format. Each calculation followed industry standards and referenced the appropriate codes or guidelines, so that a checker could easily follow the logic. (In practice, these calculations were automatically documented in an Excel-based report, providing transparency of formulas and allowing further manual checking if desired.)
- Standardized drawings: A general arrangement drawing and any necessary details or sections, produced to a consistent company format. Though simple, these drawings included all essential information (dimensions, notes, loading conditions, references to standards) and adhered to drawing conventions, making them immediately usable for construction or further detailing. Consistency was important – by automating drawing production, we eliminated the variability that comes with different drafters, thus reducing the chance of omissions or miscommunications.
- Populated check/approval documents: All the necessary paperwork for compliance, such as design check certificates, assumptions lists, and risk assessment forms, were automatically filled with the project and design details. For example, a temporary works design brief or a design certificate (documents typically required by BS5975) could be produced with the relevant sections completed (designer name, checker name or ID, design brief description, etc.). The intention was that a human checker would then review the outputs and simply sign the certificate, rather than having to manually transcribe or assemble the information from scratch.

All of this was to be generated in under two minutes from the moment a user submitted the input. Achieving this was ambitious, but the prototype demonstrated it was feasible: by pre-programming all the logic and templates, the marginal time to produce a new design was indeed on the order of seconds. This speed represented an *order-of-magnitude improvement* over the traditional workflow. For perspective, turning a 10-day process into a 2-minute process is roughly a 99% time reduction, which in practice could save not just time but also reduce the opportunity for communication errors and last-minute site improvisations. Such a drastic compression of turnaround time directly targets the "two-week standard" as an area of waste – effectively balancing thoroughness and agility through automation (Foster & Jackson, 2018).

It's important to note that none of the BS5975 requirements were intended to be bypassed. On the contrary, the approach was to *fulfil every requirement in spirit, but via a digital platform.* The system was envisioned as a tool *for* qualified engineers and TWCs, not a replacement of them. For example, the independent check could still occur – a checker could review the auto-generated package just as they would a manually prepared one, but their time spent would be hours instead of days. By automatically providing complete documentation, Daedalus ensured that even though the process was fast, it was fully traceable and auditable. This resonates strongly with suggestions in literature that digital tools can maintain or even enhance compliance while speeding up processes (Foster & Jackson, 2018). The hope was that regulators and safety officers would accept a digital output so long as it could be demonstrated that the same checks and balances were built in.

To summarize the intended impact: a site engineer using Daedalus could get a complete temporary works design package almost immediately, rather than waiting two weeks. In doing so, the platform was not providing "better math" per se but providing much faster delivery of an equivalent outcome. This shift – delivering standard engineering outputs via a digital supply chain – is at the heart of the transformation this thesis advocates. It underscores Theme 1 (changing how designs are made, focusing on delivery) and Theme 2 (shortening turnaround for agility). Early indications were that such responsiveness could significantly reduce on-site risk: if a job can be designed and checked in the same day, there is far less temptation for site crews to proceed without a design or to deviate from planned methods. In effect, improving the speed of design delivery is a form of risk mitigation, ensuring that safety measures keep up with the pace of construction (Albogamy *et al*., 2014).

15.5 Targeting the Real Users: TWC-Centric Design

A critical aspect of developing Daedalus was identifying who the real end-users should be. In the context of BS5975, the key stakeholders in the temporary works process are the Temporary Works Coordinators (TWCs). At Costain, there were over 350 TWCs nationwide, many of them responsible for multiple active sites. A TWC's job, in short, is to ensure compliance with the temporary works procedure: they liaise between site teams and the design engineers, initiate design briefs, ensure checks are done, issue permits, and generally carry a heavy legal responsibility for safety. Crucially, TWCs are under constant pressure to approve works promptly so as not to delay the project – yet they depend entirely on external designers to supply the signed-off designs they need. This can be a frustrating position, as the TWC often has the urgency on their shoulders but not the tools to directly control the pace of design delivery.

My design philosophy for Daedalus, therefore, was user-centric, with the TWC (or site engineer) as the primary user. This was a departure from many engineering software tools which typically target the designer or technical specialist. TWCs, by contrast, are usually generalists: they often have an engineering background but their daily focus is on logistics, safety, scheduling, and coordination, rather than detailed design calculations. Moreover, they are incredibly busy and frequently on the move around a construction site. Thus, the interface for Daedalus was designed with *radical simplicity* in mind, catering to a user who is knowledgeable but not looking to tweak every technical parameter. Some key design decisions included:

- Minimal user input required: Wherever possible, the system would auto-select or auto-populate values. For example, the appropriate wind loading for the design's location was determined automatically from the project's postcode or site coordinates. Behind the scenes, the tool referenced the relevant wind map (per BS EN 1991-1-4) or a lookup table of wind speeds by region, so the user did not have to manually enter or look up this information. This not only saved time but reduced the chance of error or inconsistency in wind assumptions.

- Structured choices for design criteria: Rather than expecting the user to know specific design formulas or criteria, the interface presented simple drop-down menus for key decisions. For instance, the structural category or type of temporary work could be selected from a list (e.g., "Working platform for crane", "Standard trench box", "Tower crane base grillage", etc.), and the form would then adapt to that choice. By selecting an option, all relevant default parameters and checks for that category would be activated. This approach meant that the TWC didn't have to be a specialist in each type of design—the system encapsulated that expertise.
- Auto-filled contextual assumptions: Typical assumptions and minor details were filled in by the system. For example, if the user selected a standard scaffold platform design, the tool might automatically assume a certain live load (unless specified otherwise) based on regulatory standards, or it might fill in a generic statement for ground conditions if detailed geotech data was not provided. The rationale was that nothing critical was left blank; even if the user left some fields empty, the system would apply reasonable conservative assumptions to proceed with the design. These assumptions were of course documented in the output (so that a checker or the user could see them and adjust if needed), but the key was the user didn't face a wall of empty input boxes.

All interface menus and dialogs were thus crafted to reduce the number of decisions the user had to make, not increase them. The guiding question was always: *"Can we have the computer decide this (or look it up) instead of the human?"* By streamlining the inputs, we not only made the tool faster to use, but also more reliable – fewer manual entries meant fewer opportunities to input a wrong value. Importantly, simplifying the user experience did not mean over-simplifying the engineering; rather, the complex computations happened in the background, and only their results or necessary high-level inputs were exposed to the user.

Outputs from the system were provided in two formats: PDF documents for immediate use and editable Excel sheets for transparency and minor tailoring. The PDF versions of the calculation report and drawing were intended as the final deliverables that could be issued on site or emailed to stakeholders. The Excel version of the calculations, however, was a strategic inclusion. By giving engineers the actual spreadsheet with formulas and live calculations, we tapped into a familiar mode of working. If a user wanted to examine a specific calculation closer or adjust a parameter manually, they could do so in the spreadsheet and see the effect (albeit with the caveat that any manual change would then be outside the automated QA process). This dual-format output greatly improved trust in the system: engineers often expressed comfort knowing they could "look under the hood" via Excel if they desired. It also acknowledged the reality that some minor project-specific tweaks (like a slightly different safety factor or an added note) might be easier done manually on a one-off basis; providing the source calculation sheet allowed that flexibility without needing a whole new software feature. In essence, the Excel output acted as both a deliverable and a transparency mechanism.

To facilitate deployment within Costain, the Daedalus prototype was hosted on the company intranet. This meant the application was accessible through a standard web browser on any company computer or device, but it was secured behind the corporate firewall (no external internet needed). This choice eased many potential IT and cybersecurity hurdles: by appearing as an internal web service, it required no special installation on user machines and leveraged Costain's existing network security protocols. I coordinated with the IT department to ensure the hosting met all compliance requirements, particularly because design data (some of which might be sensitive project information) was being stored. User access was controlled via login accounts – I issued credentials to a handful of key users to pilot the system in the field. Each account had a profile on the system, which allowed tracking of usage and, if needed, could be tied to the individual's role (though at the prototype stage we did not yet implement a full permission hierarchy by competency, as would come later at Richter).

Once live on the intranet, Daedalus quickly became a talking point among the pilot group. In field meetings or site walk-arounds, I found that demonstrating the tool live was the most effective way to convey its impact. My "party trick," as colleagues called it, was to take out my smartphone during a discussion about an upcoming temporary work and, within the span of the meeting, generate a preliminary design. The fact that this was possible – creating a design on a mobile device in real-time – was something few had seen before. It usually prompted a flurry of questions: *Is that actually doing the calculations now? Has this been checked? Can I try it?* Such reactions underscored both the excitement and the cautious curiosity that such a new approach engendered. The mobile accessibility (thanks to the responsive web design of the interface) was particularly noteworthy: it meant a TWC could conceivably do design paperwork from the field or at home after hours, rather than being tied to a desk with specialist software.

The feedback from the initial TWC users was encouraging. They loved the idea of self-service design generation, and even those who were not part of the formal trial were eager to get access. This grassroots enthusiasm was a strong signal that we had correctly identified the pain point and the target user. By focusing on the TWCs' needs, we had created a tool that naturally fit into their workflow. In doing so, we were essentially empowering generalists with specialist capabilities, but packaging those capabilities in an accessible way. This approach was fundamentally different from simply building a more advanced analysis program for engineers – it was about delivering useful outcomes to the people who needed them, when they needed them. In retrospect, this user-centred design was a key factor in the concept's later success and is an important theme of the thesis: technology innovation must start with a clear understanding of the end-user and the operational context, not the technology for its own sake.

15.6 Roadblocks and Corporate Friction

For all the excitement in the field, it wasn't long before we encountered institutional roadblocks. The same attributes that made Daedalus attractive to end-users (speed, autonomy, bypassing traditional bottlenecks) also made some stakeholders uneasy. In particular, internal compliance and engineering governance teams at Costain began to raise concerns. Senior management appreciated the innovation in principle – after all, the project had just been celebrated at an internal forum – but they also had to consider corporate liability and strict adherence to BS5975. The core concern boiled down to this: *Could giving direct design-generating access to site staff inadvertently lead to a breach of the required independent check and approval process?*

From a compliance perspective, the scenario of a TWC obtaining a design in seconds and immediately using it raised several questions. BS5975 requires that a qualified engineer designs the temporary work and a separate qualified engineer checks it. If the TWC is not a designated designer, what exactly is the status of a design coming out of the software? Who is the “Designer of Record” – is it the software’s creator (myself), the company, or the individual clicking the button? These were gray areas that had not been encountered before. There was a fear that users might bypass QA unintentionally: for instance, a TWC under pressure might accept the automated output as “good to go” without ensuring a formal checker had reviewed it. Another worry was the misuse of designs in inappropriate contexts. The tool, at that prototype stage, had a limited scope (only certain design types and ranges were encoded). Management cautioned that if a user tried to apply an auto-generated design to a scenario outside its intended scope, the results could be unsafe. For example, generating a working platform design for a certain soil type and then using it on a much weaker soil would be dangerous – such misuse could happen if the system’s limitations were not fully understood by users.

As a result of these concerns, access to Daedalus was soon restricted. Instead of rolling it out widely to TWCs as originally envisioned, Costain’s management decided that only the internal *temporary works design team* (i.e. the professional engineers in the central design office) would have direct access. The idea was that these engineers could use the tool as a productivity aid to produce designs faster, but then they would still follow the normal procedure of independently checking and formally issuing the documents. In practice, this turned Daedalus into an internal engine for accelerating work in the design office, rather than a self-service platform for site. From a safety/compliance standpoint, this was the most comfortable position for the organization – it kept the familiar workflow intact (designers produce, checkers check, TWC approves) while using the tool behind the scenes to speed up the designer’s job. However, from an innovation adoption standpoint, this was *frustrating*. It significantly reduced the transformative potential of the tool, essentially fitting it back into the existing two-week process (albeit maybe saving the design office some hours of effort).

This episode illustrated the cultural and procedural resistance that often accompanies innovation in conservative industries. It wasn’t enough to prove the technology worked; we also had to convince stakeholders that it could be trusted within the regulatory framework and that *people’s roles would remain respected*. In hindsight, the pushback from Costain’s management was understandable: no large contractor wants to be the first to take a risk on a radically new process that might have unknown failure modes, especially in safety-critical work. They needed assurance on questions of liability (who signs the drawings?), quality (how do we know the software is right?), and control (who decides when a design is truly “done”?). We attempted to address these by documenting the verification of the calculations and clarifying that all designs were based on published methods, but organizational momentum was not on our side. The company’s Temporary Works governance had been built over decades around human expertise and hierarchical approval, and it was unrealistic to overturn that in one swoop.

Importantly, throughout this period, the TWCs themselves remained supportive of the project, even when they were sidelined from directly using it. Many TWCs expressed disappointment that they could no longer access Daedalus, and they voiced this in internal forums. In a way, this reaction further validated that the pain point was real – the end-users *wanted* the solution, and the barrier was the system, not the demand. Some TWCs would still request the design office to use Daedalus for their jobs ("Can you run it through that 60-second tool?" became a common ask), effectively trying to reap the benefits indirectly. This groundswell of user advocacy became a useful lever in later discussions: it showed senior management that operational staff were hungry for innovation that solved their day-to-day headaches. Nonetheless, within Costain at that time, we had to operate within the compromise – Daedalus as an internal tool for engineers, not as a direct on-site utility.

The experience yielded a valuable lesson about innovation strategy: introducing a new technology in a large organization requires as much effort in change management and stakeholder alignment as it does in technical development. We encountered the classic paradox of disruptive innovation – the people who would benefit most (in this case, site management) had little authority to approve it, while those with authority (top management) were not the ones personally feeling the daily pain and thus were more risk-averse. While this thesis primarily focuses on the technical and process aspects, it became clear that organizational culture and policy can be the ultimate gatekeepers of change. This realization influenced how I would approach the next phase of development, particularly the move to a different organizational environment that might be more receptive to a radical approach.

In summary, the roadblocks at Costain were not due to technical failure – the prototype worked and had user demand – but due to structural and cultural challenges. Far from discouraging me completely, this partial setback reinforced the need to carefully bridge the gap between technology and governance. It underlined that any future version of the platform must explicitly build in compliance controls (for example, user permission levels, design scope limits, automatic logging of who "approves" the output) to satisfy stakeholders that proper checks and balances are still in place. These lessons would be carried forward as the project evolved beyond this first attempt.

15.7 Lessons and Legacy

This first version of Daedalus was neither perfect nor complete. It was very much a prototype, with limitations in the range of designs it could handle and lacking the full polish or robustness one would want for a production system. Yet, it marked a turning point in my understanding of how to effect change in engineering practice. The experience yielded several key lessons that would shape all subsequent development:

- Technology alone is not the solution – practical assistance is. This means that simply introducing a clever new software or algorithm isn't enough; what matters is whether it *directly helps* people do their jobs better. In the early days, I was enamoured with cutting-edge tech like VR simulations and advanced analysis, but those proved to be solutions looking for a problem. Daedalus succeeded in concept because it was rooted in a genuine need – it provided practical assistance (rapid designs) to those who were struggling with slow processes. In essence, the value of innovation in this context is measured by *real-world utility*, not technical novelty.

- **Real impact comes from reducing site friction, not just increasing theoretical optimization.** Traditional engineering R&D often focuses on optimizing designs (e.g., lighter materials, more precise calculations). However, an insight from this project is that **eliminating process inefficiencies can yield far greater benefits** than marginal gains in design efficiency. Reducing a 2-week delay to 2 minutes is far more transformative than, say, refining a calculation to save 5% material. By removing friction (delays, hand-offs, paperwork) in the delivery process, we reduce the risk of miscommunication and allow projects to adapt quickly to changing needs. This realization echoes lean thinking as well as my early reflections that spending excessive time on ultra-fine optimization can be counterproductive (recall the Introduction: a new FE method that saves a bit of material is of little use if it slows the project and "brings us closer to the edge of failure"). The goal should be *optimal workflows*, not just optimal calculations.
- **Interfaces must serve generalists under pressure, not just technical specialists.** A sophisticated tool that only a highly trained engineer can use is of limited value if the bottleneck is actually at the site coordination level. Daedalus taught me that making advanced engineering *accessible* to the end-user (in this case the TWC or site manager) is crucial. This involves not just a friendly UI but also designing the whole system around how and when those users need information. For example, TWCs often make decisions on the fly – thus a mobile-capable, quick interface was key. By contrast, a complex interface requiring extensive training would have failed to gain adoption. This lesson reinforced the importance of **user experience design in engineering software**, an area sometimes neglected in favour of raw functionality. Simplicity, clarity, and speed are features too, and for the target user they often trump depth of capability.

Despite the internal hurdles, the project did gain notable **recognition and momentum** within Costain. I was selected to present the work to the Costain non-executive board as one of five standout PhD research initiatives in the company. This was a validating moment – it signalled that at the highest levels there was interest in the idea of digitally overhauling our design process. The presentation was well-received; the board members saw the alignment with industry trends towards digitization and were intrigued by the potential competitive advantage if design turnarounds could be slashed dramatically. For a while, it seemed like Daedalus might evolve within Costain's structure, possibly with more formal support or a dedicated budget.

Figure 6: Top PhD's selected to present to Costain's Executive board

However, corporate fortunes shifted. A management reorganization later that year resulted in my project being placed under a new chain of command. The champion who had understood and sponsored my work moved to a different role, and the incoming management had other priorities. Around the same time, it became clear to me that fully **realizing the vision would require an environment with a greater appetite for disruptive change**. Costain, as a large execution-focused contractor, had understandably tight constraints on experimentation in live projects. I faced a choice: try to continue pushing this innovation within the confines of an organization that was cautious and slowing down the effort or seek a setting that was inherently more aligned with technological innovation in engineering.

I chose the latter, deciding to leave Costain on good terms and take the concept to a new home. Opportunity knocked in the form of Richter – a specialist temporary works consultancy known for its engineering expertise and, crucially, interested in innovation. I was offered a role at Richter where I could focus on technology development with fewer bureaucratic impediments. The move was both daunting and exhilarating: I was essentially betting my career on the belief that this platform idea was worth pursuing to its full potential.

Before moving on, it's worth reflecting on the **legacy of this first attempt**. Project Daedalus, in its prototype form, demonstrated a fundamentally new approach to delivering engineering designs. It was a *working answer* to a real operational bottleneck, not just a theoretical concept on paper. It showed that temporary works design could indeed be transformed by reframing the problem – focusing on workflow speed and integration – rather than by simply digitising the existing steps in isolation. Many colleagues who saw or used it were convinced that they had glimpsed the future of how designs might be done. In that sense, even though the project at Costain did not immediately lead to a company-wide deployment, it succeeded in changing mindsets. It proved internally that such a rapid turnaround **was possible**, thus raising expectations of what "good" looks like.

Furthermore, the lessons learned (technical, human, and organizational) formed a guiding blueprint for the next iteration. The importance of integrating compliance, the need for management buy-in, the power of user-centric design – all these would inform how I approached development at Richter and beyond. In a broader industry context, the Daedalus pilot contributed to the conversation about construction innovation: it was cited in internal discussions as an example of trying to productize engineering, and it fed into industry forums (via presentations) about the art of the possible.

In conclusion, the legacy of Chapter 15's efforts is a foundation of insight and proof-of-concept that propelled the journey forward. Sometimes, the first attempt at overhauling technology in a traditional field does not immediately stick, but it cracks the door open. Here, that crack was wide enough to illuminate the path ahead.

15.8 Conclusion

This chapter has captured the messy, iterative birth of a new kind of design automation within a traditional civil engineering environment. Project Daedalus was not an abstract proposal or a theoretical exercise – it was a working prototype born directly from on-site challenges. It demonstrated that by reimagining the process (not necessarily inventing new structural theory), one could achieve staggering improvements in delivery time and efficiency. In doing so, it exemplified the principle that changing *how* designs are made can be more impactful than merely improving the calculations themselves (Theme 1). The ability to turn around designs almost instantly suggested a future where construction sites could be far more agile and responsive (Theme 2), adjusting to changes or needs in real-time rather than being held up by paperwork. Moreover, Daedalus hinted at a genuine step-change in real project delivery (Theme 3) – it wasn't just another tech demo to marvel at and shelve, but a functional tool that, with refinement, could integrate into everyday practice and reshape it.

Of course, this first implementation also highlighted the non-technical barriers that any such step-change must overcome standards compliance, corporate risk aversion, and the necessity of blending human oversight with automation. The experience underscored that innovation in engineering is as much about people and process as about algorithms and code. The positive reception by end-users and the simultaneous cautious approach by management provided a balanced perspective: the idea had merit, but to thrive it would need the right ecosystem and perhaps a different business model to support it.

The next chapters continue this journey, charting the evolution of the concept from this initial prototype into a scalable, commercially viable service. Chapter 16 will describe the "Current State of the Art of Automation Service" as the project entered a new phase at Richter, with full corporate backing and an expanded vision. There, we will see how the lessons from Daedalus's pilot informed the architecture of a more robust platform – including features like user competency controls, a broader suite of design modules, and deeper integration of checking and approval workflows. In moving forward, the essence of Chapter 15's lesson remains ever-present: true innovation in civil engineering design comes not from isolated technical advances, but from weaving those advances into the fabric of how engineers and sites operate daily. The first attempt at a technology overhaul has shown the promise and revealed the pitfalls; the stage is set to build upon that foundation and truly transform temporary works design practice.

Chapter 16: Current State of the Art of Automation Service

16.1 Introduction

This chapter describes the transition from a research prototype to a live, operational digital design platform. The objective was to establish a scalable, fully autonomous service capable of delivering temporary-works designs on demand. Unlike earlier grant-funded experiments, this system was designed for continuous commercial use, with built-in profitability and self-sustainability. In this phase, the focus shifted from proof-of-concept to a productized engineering service. The platform had to reliably serve clients at scale, support on-going innovation, and integrate seamlessly into routine workflows. In effect, it needed to act as a permanent business asset rather than a time-limited project.

16.2 Concept Evolution

With focused project leadership and organizational support, the automation initiative accelerated. The development team partnered with a specialist temporary-works consultancy (Richter), forming Richter Technologies Ltd. to commercialize the platform. This change freed the project from earlier distractions and mandated that it operates as a viable business solution. In practice, the traditional hourly-billing consultancy model was abandoned. Instead of revenue growing linearly with staff hours, each design deliverable was offered at a fixed cost. This productized approach decoupled income from labour time and encouraged investment in automation. As Bryden Wood (2025) observes, design automation embeds expert logic and enables mass-customization while ensuring consistent performance. In this model, each new automated design module effectively multiplies the system's productivity without proportionate increases in cost. In other words, the platform's productive capacity could scale exponentially: every additional automated routine adds value, allowing rapid reinvestment in new features.

DESIGNATION	HOURLY RATE (excl. VAT)
Group Managing Director	£190.00
Group Technical Director	£165.00
Director/Technical Director	£165.00
Associate Director	£135.00
Associate	£125.00
Principal Engineer	£115.00
Senior Chartered Engineer	£105.00
Senior Engineer	£97.00
Grade 1 Design Engineer	£87.00
Grade 2 Design Engineer	£77.00
Graduate Engineer	£67.00
Undergraduate Engineer	£55.00
BIM Modeller	£87.00
Principal Technician	£87.00
Senior AutoCAD Technician	£77.00
AutoCAD Technician	£67.00
Apprentice Technician / Engineer	£45.00
Project Manager	£97.00
Admin/Commercial	£65.00
Commercial Management/QS	£95.00

Figure 7: Richters hourly rates for Engineering levels

16.3 Web-Based Interface and Access Control

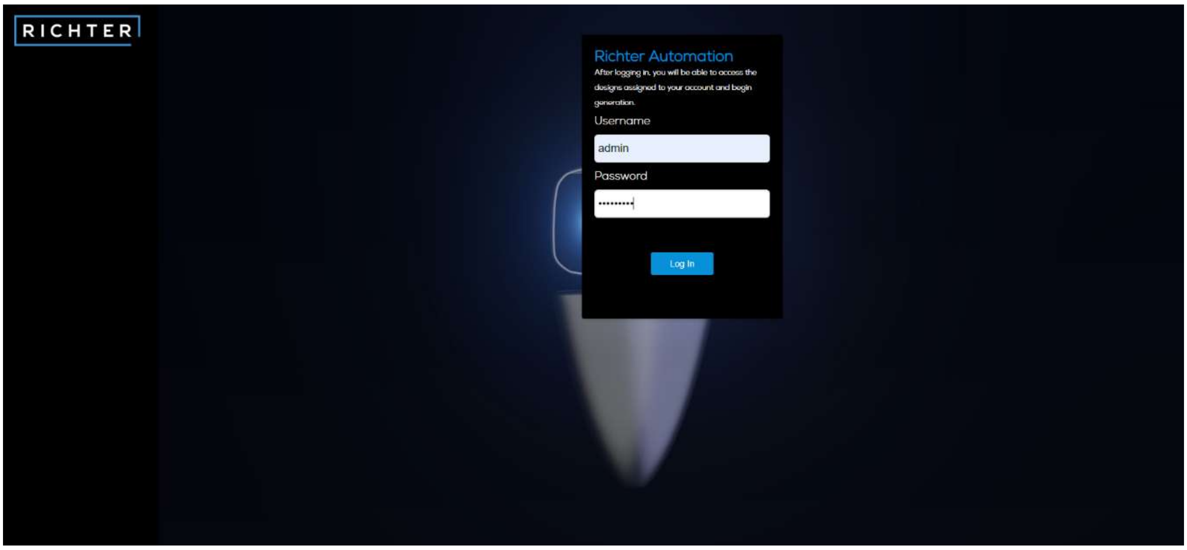


Figure 8: Automated design platforms login page

The automation service was delivered through a secure web-based portal hosted on the company intranet. This cloud-like architecture allowed engineers to access the platform from any device (desktop, tablet, or phone) without the traditional delays of software installation or licensing. By leveraging existing IT security infrastructure, the service remained protected behind corporate firewalls. This design choice aligns with modern practices in engineering IT: cloud-based CAD and BIM tools are known to centralize data and facilitate uniform access, greatly improving coordination (Downer, 2025). For example, features such as postcode-based wind load defaults and dropdown menus for soil type were implemented in the user interface to streamline data entry and reduce errors.

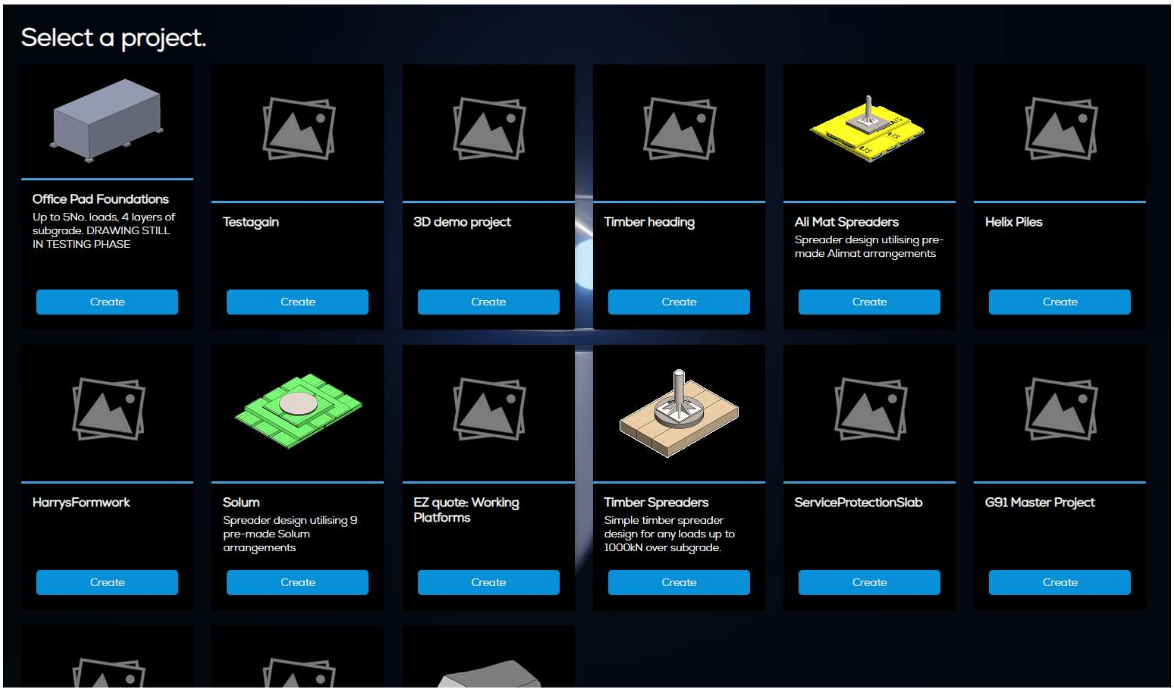


Figure 9: Automated design platform module selection

To manage quality and training, each engineer had a user account tied to a competency profile. Borrowing concepts from the nuclear sector's SQEP (Suitably Qualified and Experienced Personnel) model, users were only granted access to modules for which they had been certified. New users were approved by management before getting access to the tools. This enforced traceability and governance: complex design functions were restricted to experienced engineers, while trainees or less experienced coordinators had limited rights. In practice, this competency matrix ensured that only qualified personnel could run certain calculations or generate specific outputs, balancing flexibility with safety.

16.4 Project Processing Workflow

Once a design request was submitted via the web form, the input parameters were recorded in a relational (SQL) database. An automated backend engine (internally code-named "Charlie") then orchestrated the workflow. Charlie executed the full pipeline automatically: it performed all required structural calculations, generated custom CAD drawings, compiled the project documentation, and logged every output and user interaction. By treating each design as a discrete, version-controlled job, the system achieved end-to-end traceability and auditability. Engineers could review the complete history of any design, trigger recalculations with updated inputs, or regenerate documents on demand. This automated pipeline is analogous to a software continuous-integration process: every step's output is reproducible and recorded. Industry experience suggests that such automation dramatically cuts errors and delays. For example, Allplan (2023) reports that automating drawing production "minimizes the potential for errors" and results in "reduced risk of delays" in construction workflows. In our service, logging and history features meant that a project could be reopened months later, modified if needed, and processed instantaneously without loss of context. This capability to iterate rapidly is in line with modern computational design principles; as Bryden Wood (2025) notes, intelligent automation "allows us to iterate more quickly" and make evidence-based decisions.

16.5 Design Revisions and Iteration Tools

A key design requirement was the ability to modify an existing design without re-entering all data. To support this, the platform included a comprehensive "History" tool. Every past submission was listed chronologically, and any previous job could be reopened for editing. When a user reopened a project, the original input form was pre-populated with the stored values. The engineer could then adjust any parameters (for example, change a span length or load condition) and simply re-run the automation. This greatly reduced repetitive data entry and enabled fast optioneering. In effect, the system provided version-control of design data: engineers could experiment with alternatives on top of a baseline. This iterative approach mirrors lean design principles of minimizing waste and improving throughput (Tzortzopoulos and Formoso, 1999) and makes the design process more agile. By eliminating manual re-keying, the platform accelerated each design cycle and improved user adoption of the tool.

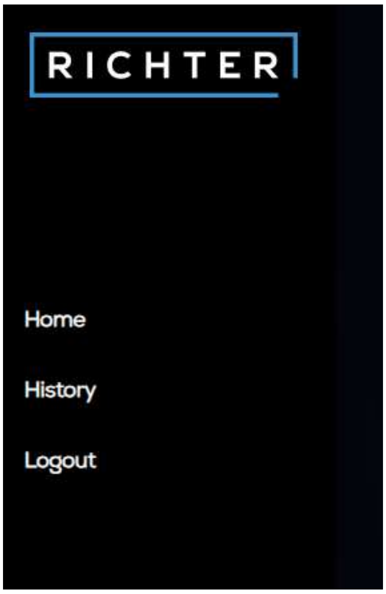


Figure 10: Adding History and editing features for rapid iterations

16.6 Output Package

16.6.1 Calculations

The final outputs were delivered in a format familiar to the industry. Detailed calculation reports were generated as Excel files, following standard engineering conventions with labelled equations, references, and step-by-step logic. Although machine-produced, the documents deliberately mirrored what a human engineer would produce, to build trust and facilitate peer review. For example, working platform designs using the Temporary Works forum method (TWf) could span over 20 pages of calculations due to detailed intermediate steps and checks. In each report, key assumptions and calculation steps were explicitly shown. This transparency helps ensure the results are auditable. In the future, the service aims to offer more concise summary reports (like those produced in bespoke design projects) for routine designs, balancing brevity with technical detail.

16.6.2 Drawings

Custom CAD drawings were automatically produced alongside the calculations. These drawings conformed to BS 5975 (the UK code for temporary works) and used parametric blocks that scale with the computed design. The parametric approach means that changes in input immediately propagate to the drawing geometry, maintaining consistency. By integrating the design data directly into CAD, the system eliminated the usual gap between engineer and draftsman. Industry observers note that model-driven temporary works design leads to faster approvals and fewer clashes compared to isolated 2D drafting. In our case, each output drawing was tailored to the computed section and loads, with titles and labels filled automatically. This tight coupling of calculation and drawing ensured that the visual plan always matched the structural logic. Moreover, because the blocks are intelligent, engineers could quickly adjust details on the CAD model if needed, further shortening the design cycle.

16.6.3 Documentation and Cover Pages

Each project's deliverables were bundled into a single download package (ZIP file) containing all documents. In addition to the calculation and drawing files, the package included necessary management documentation: a project-specific risk assessment, a list of design limitations and assumptions, and electronic signature pages for the designer and checker. These cover pages documented who prepared and reviewed the design, providing formal traceability. By automatically assembling this complete dossier, the platform ensured that no procedural documentation was omitted. Packaging all files together also made it straightforward to attach the design to client or contractor correspondence.

16.6.4 Sustainability Metrics

An innovative aspect of the platform was its multi-method design and sustainability optioneering. The system could run several different calculation methods in parallel on the same input. For instance, a working-platform module might simultaneously apply the TWf method, BRE470, Eurocode 7 Annex D, CIRIA guidelines, and a simplified hand-calculation. The user could then compare the outcomes (material quantities, loads, geometry) side by side. This real-time comparison highlights which design is most efficient or economical. From a sustainability perspective, it empowers engineers to choose the lower-carbon option. Recent industry commentary emphasizes that modern modular scaffolding and formwork systems (often using high-strength, lightweight materials) achieve significant carbon savings compared to traditional setups. Moreover, designing components for reuse (a circular-economy approach) “minimizes waste and reduces the carbon footprint” of temporary works. By providing a form of live benchmarking, the platform encouraged selection of the least-material, lowest-impact solution among the alternatives. An experimental “sustainability score” was included to give users a quick indicator of each option’s resource efficiency. In practice, having instantaneous feedback on design alternatives helps drive material optimization and aligns with best practices in green construction.

16.7 Observations and Cultural Dynamics

The real-world deployment revealed interesting patterns in adoption. Engineering teams led by younger or more commercially agile managers embraced the automation service enthusiastically; they recognized the time savings and were open to adjusting their workflows. In contrast, more traditional offices showed inertia and scepticism at first, even after the service had been refined based on user feedback. To manage this, the rollout strategy focused on supporting the highest-uptake teams rather than attempting a broad mandate. Concentrating on early adopters allowed the platform to reach self-sustaining usage levels and demonstrate value internally. Success proved contagious: once one office realized that designs could be delivered in hours instead of weeks, others took notice. For example, a promotional video demonstrating the platform’s capabilities received over 10,000 views within the industry – an unusually high engagement for temporary-works content. These dynamics reflect Rogers’ diffusion of innovation: by helping a critical mass of innovators and early adopters, the service gained momentum. Over time, this approach-built confidence and justified further investment in the platform.

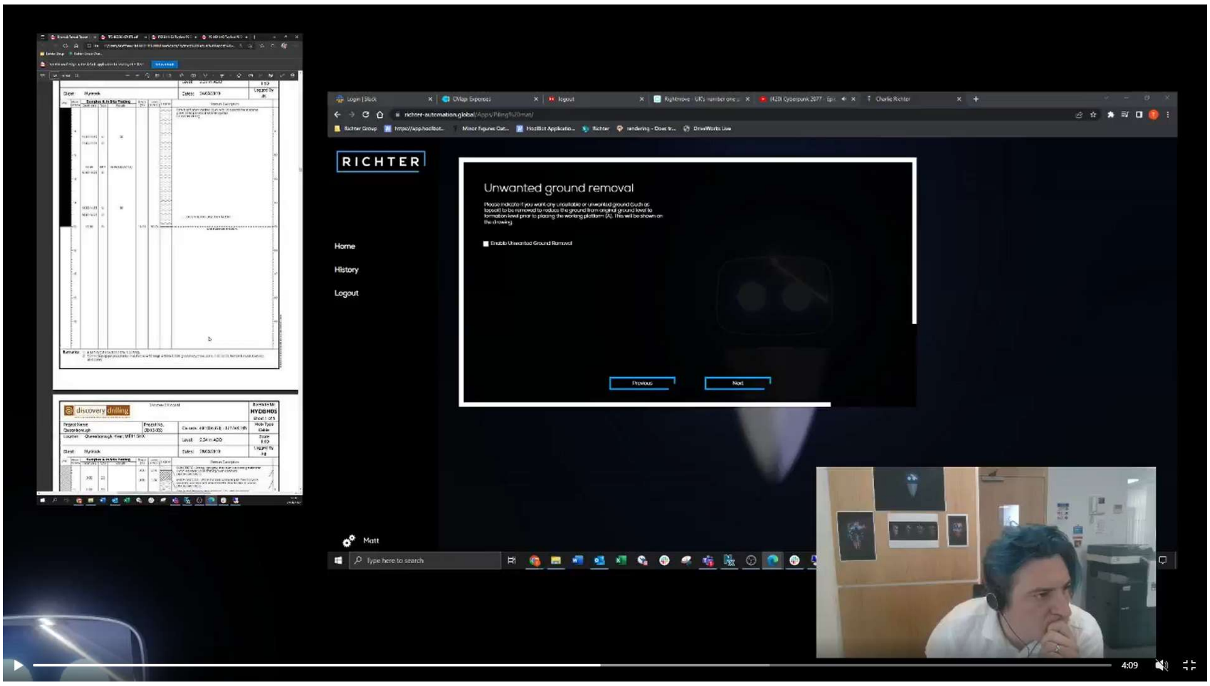


Figure 11: "The 8 minute run" Screen shot from proof of concept video

16.8 Competitive Advantage and Unique Value Proposition

The automation platform proved to be far more than a mere efficiency tool; it fundamentally changed the delivery model for temporary works. Even though many firms already use partial shortcuts (custom Excel sheets or CAD templates), the traditional design process remained fragmented and time-consuming. Typically, a scheme would require an engineer to do hand calculations, a draftsman to draw the plan, and then a check/approval cycle – often spanning one to two weeks. In contrast, our platform compressed all stages into an integrated workflow. Engineering calculations, drawing generation, and documentation were all executed by a single automated routine once the inputs were provided. Because the system encodes the decision rules of expert designers, the outputs are highly consistent from one job to the next. Bryden Wood (2025) highlights that such rule-based automation "locks in aspects of asset performance and design compliance, while achieving genuine mass customisation". In practice, this means the platform can deliver outputs equivalent to senior engineers' work without compromising on standards or traceability. Industry experience backs up the quality gains: automated design tools not only speed up the process but also yield fewer errors. Allplan (2023) observes that intelligent automation "not only enhances efficiency and productivity" but also "significantly reduces error margins". Thus the unique value proposition of the service lies in total workflow automation – not just saving time in one task, but transforming the entire design sequence into one repeatable process. The consistency and speed of the platform have become its defining advantages over conventional methods.

16.9 Conclusion

This chapter has documented the live deployment of a digital automation service for temporary works design. Far from a prototype, the platform is now an everyday engineering tool, validating the thesis's premise that practical impact must drive innovation in civil engineering workflows. By delivering a fully operational system rather than a theoretical concept, this work demonstrates that automated design can deliver substantial gains in efficiency, safety, and sustainability. In practice, delivering design packages in hours rather than weeks greatly enhances on-site agility: projects can adapt to last-minute changes with minimal delay. This rapid turnaround directly reduces schedule risk and cost overruns, improving overall project outcomes (Downer, 2025). Moreover, by codifying best practice into software, the platform ensures repeatability and reliability that manual processes often lack. In summary, the success of this automation service underscores the importance of prioritizing real-world deployment, integration, and measurable benefits in engineering research. Rapid digital design not only accelerates workflows but also supports better decision-making and lower environmental impact, aligning with broader industry goals.

Chapter 17: Charlie Richter and the Combination of All Concepts

Figure 12: Rolling out Charlie merchandise after the combined concept became popular and increased efficiency effectively

17.1 Intro

The Charlie Richter platform embodies the integration of all digital concepts discussed in earlier chapters. It combines automated calculations, parametric drawing, digital documentation, optioneering, and sustainability analysis into a single, coherent workflow. In practice, Charlie accelerates temporary works design dramatically: in one case it delivered a complete working platform design package in just three hours – a ~99% reduction compared to the typical two-week turnaround. This chapter describes how Charlie Richter unifies these technologies, the technical architecture that makes it possible, and the practical outcomes in efficiency, cost, and risk management. It also examines real case studies and organizational factors that shaped its deployment.

17.2 Overcoming Resistance with a Mascot

Charlie Richter began its life as a friendly robotic mascot to ease the cultural barriers to automation. In a traditionally conservative industry, engineers often exhibit a "fight-or-flight" reaction to new tools, fearing loss of control or jobs. To counteract this, the development team introduced *Charlie* – a non-threatening robot character (inspired by Coca-Cola's polar bear campaign) that personifies the automated service. This branding helped reframe automation as approachable and reliable, rather than as a threat. By rallying users around Charlie, the firm was able to celebrate early adopters and discuss the system's work by saying "*Charlie does the work while we wait*," which built familiarity and trust. Merchandise and branding based on the mascot were offered to project teams and clients, fostering positive engagement without revealing proprietary technology.

Psychologically, the mascot's effect can be understood considering change management theory: framing a new technology as a friendly "teammate" rather than a replacement reduces resistance

(Kotter 1996). In practice this proved essential. Early users reported that Charlie made the idea of robot-generated designs seem **less alien**, and word-of-mouth among field engineers increased uptake. As a result, even risk-averse teams began referring routine designs to Charlie voluntarily. This cultural shift was critical: without user confidence, even the best technology cannot be adopted (McKinsey 2020).

17.3 A New Business Model: Decoupling Value from Hours

Traditionally, consultancy revenue in civil engineering is tied to hours worked by graded staff. Growth thus depends on hiring more people. Charlie Richter replaces this linear model with a **content-driven model**. Each automated design is sold at the same price as a human-generated one, but the *production cost* is fixed rather than hourly. In effect, Charlie **captures value as it learns**: every new automated module or case increases the platform's value without proportionally increasing effort. The result is exponential scalability – as more designs are added, Charlie's capacity to produce designs grows without commensurate increases in staff cost. Within months, the platform generated enough margin to support two full-time engineers, funded by reinvested revenue.

This paradigm shift mirrors the gains predicted for digital transformation more broadly: companies that focus on fixing real pain points and leverage technology strategically have been found to achieve **double-digit productivity gains and multi-percent cost reductions** (McKinsey 2020). In our case, Charlie has already delivered on this promise. By automating routine tasks, it *removed time as a bottleneck*. Designs can now be produced on demand without overtime, and the saved time is reallocated to innovation (for example, developing new modules or refining algorithms). In short, Charlie turns engineering expertise into a **perpetually growing asset**, rather than a per-project expense.

17.4 Technical Architecture and Workflow

Beneath the mascot and business model lies a sophisticated technical infrastructure that integrates earlier innovations. Charlie's calculation engine is the core of the platform. Initially, each design calculation was prototyped in Microsoft Excel to leverage engineer familiarity and enable rapid development. Custom Excel workbooks contained modular design equations (optimised by real-world trial), with Visual Basic scripts for convergence and variant toggles. These interactive spreadsheets allowed multiple methods to be embedded simultaneously (for example, the industry-standard TWf method alongside CIRIA guidance, BRE470 and Eurocode 7 methods), enabling early *optioneering* in a familiar interface.

Once a design recipe was validated in Excel, the logic was transcribed into production code (in a compiled language such as C# or Python) and deployed on a web server. The web interface provides a simple form for the user (now assumed to be a competent engineer with design knowledge) to enter site parameters: loads, ground conditions, span lengths, etc. Upon submission, the server runs the appropriate calculation modules, performs simultaneous method comparisons, and returns results in real time. This hybrid approach – Excel for prototyping and calculation validation, code for deployment – ensured mathematical rigour and version control while keeping the process efficient.

On the drawing side, Charlie uses a **parametric 3D CAD API** to generate full design drawings automatically. The platform embeds a commercial CAD engine and drives it via script: once the calculations determine member sizes and geometry, the server instructs the CAD tool to place beams, supports, loads, dimensions, and annotations. Every detail on the final PDF is derived from the model – there are no static templates. The advantage is consistency and flexibility: drawings automatically adapt to new design variations, and all symbols/notes adhere to standards. This eliminates manual drafting work and ensures that the drawing always matches the calculation.

Each design submission also triggers automatic documentation generation (calculations report, check certificate, and risk assessment), using Word/PDF templates populated with results and checks. The interface then allows an engineer to review and digitally sign these outputs. Although initial ideas considered fully automated sign-off, legal review mandated keeping a human verifier (per BS 5975 procedures). In future versions, a partial automation ("light check" after many repetitions of identical designs) is envisioned, but as of now no design goes unsigned.

Finally, one of Charlie's unique technical features is optimize-and-compare analysis. For cases like working platforms, the system computes multiple design methods in parallel (e.g. CIRIA and TWf approach) and reports all solutions. This provides engineers with immediate optioneering: they see the leanest design side-by-side with the most conservative one. In concrete terms, in a Thames Valley clay working-platform case the CIRIA method produced a slab ~57% shallower than the traditional method. Charlie captured both results, calculated the embodied carbon difference, and generated a sustainability report with the CO_2 savings.

17.5 Case Studies: Rapid Turnaround and Efficiency

The practical benefits of Charlie are best illustrated by real-world case studies. Three representative examples demonstrate the rapid turnaround, cost savings, and risk reduction the platform enables:

- Last-Minute Working Platform (Emergency Design) – A construction site suddenly needed a piling-platform design on short notice. The client's usual design source had dropped out. Charlie generated a full design package (calculations, drawings, checks, certificates) *in just 3 hours* after quote acceptance. (Notably, the calculation itself completed in about 8 minutes – the rest was process and review.) This turnaround was a ~99% reduction from the standard two-week schedule, preventing a costly site delay. The client was "blown away" by the speed, and subsequently used Charlie for multiple similar schemes. The efficiency also meant unusually high profitability for that task, as one engineer could handle work that used to occupy an entire team.
- Rail-Closure Bridge Lift (Time-Critical Spanning) – Another case involved a bridge deck segment that needed removal under a short rail possession. The contractor realized at the eleventh hour that their crane's outriggers required a certified design to satisfy Network Rail standards. Charlie produced the required outrigger pad design within 24 hours, well inside the possession window. Because of this rapid support, the lift proceeded as planned. When the deck unexpectedly fractured during the lift, the client again called Charlie; the platform generated an emergency support scheme for a temporary crane overnight, allowing the replacement lift

to occur the next day. In both instances, Charlie's speed directly prevented an indefinite shutdown of a critical rail link.

- Major Contractor Adoption (Scaled Use) – A large contractor (Costain) was introduced to the Charlie system and immediately recognized its value. They especially noted the integrated sustainability reports and cost analyses, which aligned with their ESG goals. After a pilot, the contractor began using Charlie for multiple concurrent sites, praising not only the speed but also the traceability and consistency of output. For example, when one project had suffered frequent temporary works failures, Charlie was engaged to redesign the access platforms, outriggers, and work routes across the site. By the next morning the client had complete safe designs for all these components – effectively stabilizing the site and "halting improvised and rushed solutions". As a result, that contractor has since funnelled most routine temporary works tasks through Charlie, achieving cost savings and avoiding further incidents.

In addition to these in-house cases, industry examples confirm the platform's impact. For instance, Bentley Systems' OpenSite+ generative AI tool has demonstrated design acceleration up to 10× faster than traditional methods (Valois 2025) – automating grading and layout tasks that formerly took days. Like Charlie, OpenSite+ automates repetitive engineering tasks and embeds sustainability (e.g. reducing earthwork to cut fuel use). These parallels underscore that Charlie's results (deliverables in hours, not weeks) are consistent with broader trends in digital civil engineering (Valois 2025; OpenAsset 2025).

17.6 Risk Management and Quality Assurance

Charlie's automated outputs have also streamlined risk management. All designs are accompanied by standard checklists and certificates that comply with BS 5975 (temporary works) requirements. Initially, there was interest in having Charlie auto-sign certificates with its "digital signature," but legal review determined that human sign-off was still required to meet the standard. Consequently, each generated design is reviewed and signed by a qualified engineer (designer, checker, approver) as per regulation. The platform does, however, keep an audit trail of changes: if a particular design were used many times without modifications, a "light check" shortcut was considered. In practice, Charlie's rapid evolution means no design has repeated unchanged enough to use that shortcut (the system continuously improves itself with each use).

Importantly, Charlie also reduces design risk by eliminating human error in routine calculations and by preserving institutional knowledge in code. Instead of manual drafting or spreadsheet copying (which can introduce mistakes), each design follows the same coded logic every time. This standardization has had measurable effects. In one risk case involving repeated site failures, Charlie was able to deliver over 90% of a full site-wide temporary works package overnight, giving the client a fresh, safe starting point. That rapid, reliable response averted potential injuries and compliance violations. In general, by accelerating low-risk designs, Charlie allows human engineers to focus on high-risk, unique tasks – improving overall safety. In short, automating common designs with verification logic built-in has demonstrably lowered both schedule and safety risk on projects.

17.7 Sustainability and Carbon Reduction

Charlie embeds sustainability analysis into every design. As described earlier (Chapter 11 and 24), the platform's optioneering runs multiple design methods in parallel. The Sustainability Report feature automatically calculates embodied carbon (CO_2e) for each option. In practice, this yields large savings. For example, in the Thames Valley case, the platform compared a traditional method (TWf) to an optimized CIRIA method for a working platform over clay. The CIRIA-based design required a 0.38 m aggregate depth versus 0.65 m for the conservative method – a 57% reduction in depth. This cut material volume by ~25% and saved about 2.8 tonnes CO_2e per platform. The client documented this saving and offset it, avoiding £300–£450 of carbon liability per site. Notably, the carbon savings alone often funded the entire design cost – turning sustainability from a cost centre into a profit centre for clients.

Because these calculations are automatic, the Sustainability Report became a unique selling point. Clients began using it to support bids, fulfil ESG reporting requirements, and negotiate green financing. Public bodies and corporations on carbon budgets preferred Charlie for low-carbon temporary works designs. In effect, Charlie reframes engineering as value-creating: it turns design comparisons directly into carbon and cost justification, aligning day-to-day engineering with strategic environmental goals. In an era of mandated net-zero commitments, this capability gives Charlie users a competitive advantage (OpenAsset 2025).

17.8 Organizational Impact and Industry Recognition

Despite its technical strengths, Charlie's adoption has varied across teams. Offices with younger, innovation-minded leadership embraced the tool quickly, while more traditional teams were initially skeptical. Over time, however, success bred acceptance. Teams that tried Charlie reported substantial efficiency gains ("unlocking huge profitable efficiency"), which in turn encouraged more usage. Management gradually agreed that Charlie would be the first point of call for all compatible designs, rather than an optional tool. In other words, Charlie turned from an experimental service into *business as usual* for routine tasks.

Industry recognition has also validated Charlie's approach. In 2023, the system won a Digital Construction Excellence award (Construction News), with judges noting that the in-house design automation tool "demonstrated improvements and benefits provided to clients" and a "high degree of innovation". The team also secured Innovate UK funding to further advance the platform, collaborating with university researchers to integrate more advanced analyses (e.g. finite element solvers) into Charlie. These accolades have bolstered client confidence and signalled to the wider industry that fully integrated digital workflows can deliver real-world impact.

Figure 13: Winning the 2023 construction news, Digital Construction Excellence

17.9 Future Directions

Charlie Richter has evolved from a pilot project into a platform poised for expansion. Future work includes integrating full finite element analysis into the calculation engine, deploying mixed-reality interfaces for onsite visualization, and extending the library of automated modules (scaffolding, façade retention, excavation support, etc.). Research into AI-assisted risk forecasting and automated code compliance is also underway. Importantly, the platform's proven market traction and self-sustaining revenue model mean that innovation will continue to be customer-driven. New modules are prioritized not just by technical interest, but by client demand and profitability. In this way, Charlie will keep advancing "infinite possibilities" at the intersection of theory and practice.

17.10 Conclusion

The Charlie Richter platform demonstrates that combining automation, digitisation, and innovative business thinking can transform an established engineering domain. Technically, it integrates advanced calculation routines, parametric modelling, data-driven optioneering, and sustainability accounting into a seamless workflow. Practically, it delivers outcomes that would be impossible with manual methods: design package turnarounds in hours, significant cost savings, and reduced material waste. Culturally, it reframes engineers' roles as supervisors of smart tools, preserving their expertise while freeing time from routine tasks.

Charlie Richter's success – from case studies to industry awards – confirms the original thesis vision: that practical innovation in the delivery of civil engineering is achievable at scale. By productising design knowledge and aligning incentives with client value (rather than hours), the platform achieves more than digitisation: it creates a new paradigm for how temporary works are conceived and delivered. In the process, it has raised the bar for efficiency, sustainability, and safety in the specialist construction sector.

Chapter 18: Current Limitations and Ongoing Challenges

18.1 Introduction

Despite the successes of Charlie and related automation tools, significant obstacles remain before widespread digital transformation can be realized. In practice, established engineering practices and human factors create barriers to adoption. Studies of technology acceptance in construction underscore that new systems improve quality and efficiency only when users can trust and integrate them – otherwise "stakeholders… may exhibit some resistance to operational use". Influential models (e.g. TAM, TPB, UTAUT) show that perceived usefulness, ease of use, social norms and facilitating conditions are key determinants of acceptance. In this chapter we examine the technical, regulatory, cultural and economic limits that currently constrain Charlie's impact, and we consider how they point to future improvements. Each category of barrier – from hard computational limits to human scepticism – highlights areas where targeted change management and innovation can close the gap between proof-of-concept and robust deployment.

18.2 Technical Gaps in Workflow Coverage

Charlie excels at automating well-structured, repetitive tasks, but complex or novel engineering problems still defy full automation. Advanced temporary works design (such as bespoke bridge falsework, demolition sequences or scaffold removals under variable site conditions) involves highly context-specific inputs and counterintuitive interactions that are difficult to encode in a rigid algorithm. In effect, the system lacks large, representative datasets or clear rules for such scenarios. Modern approaches like machine learning often struggle in structural engineering: trained models tend to "capture data associations rather than causal relationships," and their "black-box" nature can undermine trust. Inadequate training data exacerbate this: if the ML model's training set does not capture the full diversity of real-world cases, even an "accurate" model will fail in deployment. In practice this means the system currently handles only standardized or semi-standardized designs. Any truly adaptive, generative approach still needs significant human oversight. As one recent study notes, the inability of ML models to generalize beyond their training data and the lack of transparency ("feature importance") are fundamental deployment challenges in structural engineering.

In short, highly creative or unfamiliar design tasks remain beyond our automated workflows. These gaps are not unique to Charlie – they reflect a general reality that data-driven design tools require extensive training data and validation before replacing expert judgment. Addressing this will likely involve hybrid approaches (e.g. physics-guided AI, modular rule-based engines) and careful data collection strategies to gradually expand the system's coverage.

18.3 Computational Bottlenecks

Even when a task is in scope, computational costs and technical latency introduce friction. For example, detailed finite-element analyses may still take minutes or hours to run, far longer than an engineer would tolerate in a fast-paced meeting. Similarly, any reliance on external servers or services (CAD APIs, cloud compute, or Excel interfaces) can stall under heavy load or software updates. These delays break the seamless user experience that is essential for live design collaboration. In practice, this means that some Charlie modules cannot be used interactively without patience – a major drawback for on-site use. Such bottlenecks are a common challenge in digitization: complex simulations and cloud calls often introduce nontrivial latency. Minimizing these delays (for example by caching common cases, precomputing lookup tables, or using edge computing) will be essential to making real-time automation viable.

18.4 Legal and Ethical Barriers

Beyond pure technology, regulation and professional ethics constrain how far automation can go. In the UK and similar jurisdictions, engineering designs must ultimately be signed off by a competent human engineer. BS5975 and HSE guidance explicitly require human-certified design certificates and independent checks. In other words, even a correct design generated by Charlie cannot bypass the requirement that a qualified engineer review and approve it. Attempts to automate that final check risk violating statutory duties and professional liability rules. Similarly, Construction (Design and Management) regulations impose accountability on named individuals (Designer, TWC) for safe design, which today cannot be outsourced entirely to software. As one industry analyst warns, while AI can streamline design, "no matter how sophisticated [it] may be, human oversight remains crucial," since engineers will ultimately be held accountable for safety. Relatedly, intellectual property and data-privacy concerns also arise if proprietary design rules or site data are fed into third-party services.

In summary, Charlie operates within a framework where professional accountability and legal responsibility cannot be automated away. Any workflow must preserve traceability, documentation and sign-off steps. While these requirements do not prevent the use of automation, they do limit the claim of "fully automatic design." Instead, we must build tools that assist engineers, with clear audit trails so that a human can be confident in the outcome.

18.5 Cultural Resistance and Change Management

Arguably the greatest limitation lies in people and culture. Many experienced engineers and managers remain sceptical of radical automation. In practice, staff may view tools like Charlie as "black boxes" that deskill the profession or may simply mistrust an unfamiliar system. Research in technology adoption consistently finds that resistance can stem from fear, lack of perceived benefit, or social norms. Indeed, a recent study of U.S. workers showed that fear of job loss to automation significantly worsens productivity and well-being. In engineering, this "automation anxiety" may reduce willingness to change habits. Trieste and Turchetti (2024) note that *scepticism* – the "distrust or disbelief toward… proposed technology" – is one of the most common attitudes toward innovation and can "brake technical change" unless carefully managed.

Overcoming this cultural inertia requires deliberate change management. Industry case studies emphasize that early adopters and champions are critical: when respected engineers pilot the tool and share success stories, colleagues are more likely to follow. Conversely, projects that push too fast without buy-in tend to stall. Change-management literature on BIM and construction digitization shows that transparent communication and training are vital. For example, Ottaviani et al. (2025) report that *"Change management plays a pivotal role in overcoming resistance"* to new engineering workflows, recommending comprehensive training, leadership commitment, and user involvement. Large consulting firms with entrenched processes may require effort: cultural inertia in such organisations is well documented. In summary, no matter how capable the tool, "people – not software – ultimately drive engineering change." Charlie's diffusion will depend as much on addressing these human factors as on its technical merits.

18.6 UX and Human Factors

Closely related to cultural resistance are usability and explainability challenges. Even enthusiastic users will turn away if the interface is clunky or opaque. Current prototypes of Charlie include many cascading menus and inputs, which can overwhelm users when handling uncommon design scenarios. Engineers have noted frustration when a minor design failure yields no clear explanation, or when the system does not justify its suggestions. This "black box" problem extends from the underlying AI: as Zaker Esteghamati *et al.* (2024) warn, users tend to distrust ML models when they cannot see how inputs map to outputs. In practice, lack of transparency can cause even correct solutions to be questioned or disregarded.

Improving this requires careful UX design. Today's platforms should be augmented with on-demand explanations: for instance, "why was this parameter chosen?" or "how sensitive is the design to this input?" Interactive visuals, just-in-time tips, or even conversational agents could help translate the tool's logic. Ultimately, the goal is to make the automation feel like a partner rather than an oracle. Achieving this will likely involve ongoing user research and iterative interface improvements.

18.7 Economic and Operational Scaling Risks

Finally, the business and support model face challenges as usage grows. Currently, Charlie's compute costs (cloud servers, solver licenses) and maintenance overhead are manageable at pilot scale. But rapid expansion could strain budgets and bandwidth. For example, commercial CAD APIs and high-performance computing services charge per-use, so heavy demand might increase costs nonlinearly. Similarly, supporting many simultaneous users would require staff to handle helpdesk tickets and module updates. Without robust engineering change control, multiple developers iterating independently could cause version conflicts or inconsistent behaviour across projects.

These scaling issues are common in tech adoption: a system that works as a small pilot may reveal hidden costs at larger scale. The challenge will be to grow without losing flexibility – for instance by securing enterprise agreements, automating testing and deployment pipelines, and carefully monitoring usage.

18.8 Focus on Practical Assistance, Not Ambition

One of the most important realizations of this project is that modest, well-targeted tools win trust faster than grand visions of full automation. Early in the thesis we tried to replicate an entire engineer's design process; that proved too ambitious. In practice, the biggest gains came from small, practical helpers: a mat calculator that generates drawings in minutes, a section-sizing tool that engineers use daily, a quick PDF export to eliminate tedious formatting. These focused tools solved real pain points without requiring users to overhaul their methods.

This approach echoes lessons from other industries: continuous, incremental innovation often succeeds where radical overhaul does not. In engineering practice, taking a “bite-sized” approach – automating one familiar task at a time – builds confidence and delivers immediate value. It also aligns with lean and human-centred design principles (e.g. involving end-users in the development loop). In summary, the cultural and technical lessons of Charlie suggest that *practicality beats novelty*: tools that integrate smoothly into existing workflows and demonstrate clear benefits will ultimately drive adoption, even more than any single breakthrough algorithm.

18.9 Summary

Charlie’s journey so far illustrates a key truth: the remaining barriers are as much social and procedural as they are technical. On the technical side, the system must expand its scope (through better data, modular algorithms and explainable AI) to cover more complex scenarios. Regulatory limits underscore the need for transparent QA and human-in-the-loop safeguards. Cultural resistance reminds us that effective change management – training, leadership engagement, peer advocacy – is required to build trust. And practical experience shows that focusing on immediate user needs (rather than futuristic novelty) gains traction. Each limitation thus points the way to the next improvement: tighter integration, smarter interfaces, clearer accountability, and gradual rollout strategies. The following chapter will outline a roadmap to address these challenges and guide Charlie’s evolution toward a mature, widely accepted platform.

Chapter 19: Roadmap and Ongoing Development

19.1 Goals

The trajectory established by earlier chapters (especially the challenges in Chapter 18) is now addressed through a staged roadmap of continued innovation. Building on the current deployment of the Charlie platform, the project will pursue an iterative, timescale-based development plan. In the short term (next 1–2 years), efforts will consolidate core functionality and address immediate user needs. In the medium term (3–4 years), the focus will expand to new capabilities and broader integration. In the long term (5+ years), the aim is fully operational maturity and industry adoption. Throughout, the plan emphasizes the team's internal priorities: developing high value features in-house, collaborating with equipment manufacturers, and leveraging continuous feedback loops. This approach follows a structured innovation framework – akin to technology readiness levels (TRLs) and diffusion/adoption theory – to ensure each phase builds on the last (Mankins, 1995; Rogers, 2003).

19.1.1 Short-term goals (0–2 years)

In the immediate future, the project will capitalize on recently secured funding and early successes to strengthen the platform's foundation. A recently awarded research grant (early 2024) will be used to develop an advanced numerical analysis module for crane mat and working-platform design, addressing one of the most frequent user requests. This brings the platform to the threshold of *TRL 6–7* (prototype demonstration in relevant environments) (Mankins, 1995). At the same time, new user features will be released quickly – for example, a simple 3D layout tool and coordinate-based planning interface will be introduced to improve spatial design; this was already prototyped in "coordinate layout" experiments. Bundled design packages (e.g. site mobilization kits combining multiple related designs at a discount) are also planned to improve value for time-sensitive projects. These additions will be delivered on a weekly/quarterly cadence, as described in the agile development model, allowing rapid iteration based on real user feedback. Importantly, development will remain *in-house* to preserve control and agility; for instance, a team has begun exploring a virtual-reality (VR) training interface for site engineers, prototyping a VR "look-around" of proposed scaffolds. By keeping these efforts internal, the team can raise the technological maturity of VR systems without the delays of outsourcing.

At the same time, adoption strategy efforts will begin. The pricing model will deliberately stay at parity with traditional design fees, lowering barriers to trial and avoiding "justification" hurdles (reflecting diffusion-of-innovation principles: Rogers, 2003). Early adopters – typically younger engineers and forward-thinking offices – will be engaged through training sessions and demonstrations. A structured post-implementation review process will capture performance metrics (turnaround time, error rates, user satisfaction) for every new feature. These metrics will inform refinements and serve as the basis for continued funding. In effect, the project will "crawl-walk" toward higher readiness, leveraging short-term wins (e.g. >99% reduction in mat design turnaround) to build confidence internally and with pilot customers. This aligns with TRL assessments: each release will be measured against clear criteria (prototype demo, validation in lab, etc.) to chart progress (Mankins, 1995).

19.1.2 Medium-term goals (3–4 years)

Building on the solid base of early successes, the roadmap then expands in scope and technical depth. In this phase, the project will broaden its engineering automation and partnerships. Development will shift to more advanced computational methods: for example, finite-element analysis will be integrated into new modules (such as complex shoring or scaffolding bay designs) to replace factor-based approximations. Generative optimisation algorithms may be introduced for structural layout, raising the TRL further toward 8 (system prototype tested in relevant environment) (Mankins, 1995). The in-house VR interface, initiated earlier, will mature into a deployable tool for client presentations or design review, allowing engineers to "walk through" a temporary structure before construction. Importantly, collaboration with manufacturers will accelerate in this period. Partner firms that supply standard temporary works products (e.g. interlocking crane mats, scaffold components) will share specification data and design rules. For example, working with a scaffold company could allow automated generation of shop drawings based on their proprietary connector types. These collaborations will both improve model accuracy and help the product fit real industry practice. (This open-innovation approach has parallels in engineering: sharing technical standards accelerates adoption of new tools (Chesbrough, 2003) and reduces resistance.)

On the adoption front, the project will target the "early majority" of users. Training materials – potentially including VR-based tutorials – will be developed so that engineers can learn new features with minimal handholding. A feedback loop with clients and partner sites will ensure real needs are met, reflecting an evidence-based approach to diffusion. Internally, every use of the system will feed data into monitoring frameworks: we will apply concepts from change management and technology acceptance research (e.g. measuring perceived usefulness and ease-of-use) to refine interfaces (Davis, 1989; Venkatesh et al., 2003). Post-implementation evaluation will consider both quantitative KPIs (e.g. time saved, reuse rates) and qualitative impacts (user trust, organizational change). By mid-term, the aim is to have the platform adopted as the "default" solution for many standard tasks within the company, effectively reaching TRL 8–9 (system proven in operational environment) in those areas.

19.1.3 Long-term goals (5+ years)

In the long run, the roadmap aspires to full technology maturity and broader industry transformation. The platform's architecture – now enriched with advanced analysis, expanded design categories, and VR/AR interfaces – will continue evolving through continuous R&D. Long-term plans include extending to entire classes of temporary structures (e.g. complete scaffold systems, modular formwork, or complex shoring) so that what began as individual calculators becomes an *integrated engineering toolkit*. At this stage, internal learnings will be codified into standard methodologies, and any remaining manual steps will be minimized. The project will also consider commercial scale-up: if the platform's performance exceeds the in-house use case, it could spin off as an external service.

By this horizon, the project will have cycled through all key phases of the technology life cycle: from basic research (TRL 1–3) through system prototyping (TRL 7–8) to full deployment (TRL 9). Adoption strategies will have expanded beyond the original organization: experiences from Rogers' diffusion theory suggest that by this time even late adopters should be engaged through demonstrations of proven success (Rogers, 2003). A formal post-implementation audit will be conducted, evaluating long-term outcomes such as safety improvements, carbon/efficiency gains (stemming from optioneering), and return on investment. Lessons learned will feed back into the research agenda (e.g. exploration of next-generation ideas like augmented reality site-monitoring or AI-driven design assistants).

In summary, the roadmap integrates the project's *internal insights* with structured innovation principles. Short-term focus on rapid feature delivery and VR prototyping lays the groundwork. Mid-term expansion through advanced analysis and partnerships builds technical depth. Long-term ambition is broad industry integration and continuous innovation. Throughout, the approach is guided by formal frameworks: the platform's maturity will be tracked via TRL-inspired metrics (Mankins, 1995) and adoption will be managed using diffusion and change-management strategies (Rogers, 2003). This ensures a coherent progression from initial prototypes to an industry-standard solution. By aligning practical development goals with academic models of technology evolution, the roadmap creates a clear, credible path for ongoing development of the Charlie platform.

Chapter 20: Business Model and Operational Strategy

20.1 Introduction

The Charlie platform was developed not just as a design tool but as a novel business model. Unlike conventional engineering consultancies, which tie revenue to billable hours and staff headcount, the Charlie platform operates as a productized service with fixed-price deliverables. This fundamentally shifts value creation: as Sawhney (2024) observes, product-based firms can achieve much higher margins and revenue per employee than traditional service firms. In this chapter we compare the Charlie platform model to the classic UK consultancy model, emphasizing automation, scale and resilience. We show that by decoupling revenue from labour, reinvesting returns into continuous improvement, and embracing outcome-based delivery, the platform creates sustainable competitive advantage (Sawhney 2024).

20.2 Traditional Consultancy vs Platform Paradigm

Traditional UK consultancies have historically billed clients on a time-and-materials basis. Engineers charge by the hour (often tiered by seniority) and total revenue is strictly linear in staff hours. In this "pipe" model, growth requires proportionally more engineers. Profit margins are relatively low because every additional project demands more overhead and human resources. This "butts in seats" approach was once the norm: as Tank (2022) notes, *"engineering firms are effectively the opposite of SaaS"*, where more staff simply means more billable hours. By contrast, the Charlie platform treats each design as a standardized product. Clients pay a fixed fee per deliverable (for example, a scaffold design or mat design) regardless of how much time the engineers would have spent. This breaks the direct link between headcount and revenue, enabling the company to scale profitably without hiring in lockstep with demand (Sawhney 2024).

- Time-based billing: Traditional firms tie fees directly to hours. More revenue requires more staff time and higher overhead.
- Productized pricing: The platform charges per design or service module, not by time. Each new module is sold repeatedly at the same price, so revenue grows by reuse.
- Fixed staff: Richter Technologies (the Charlie platform's parent) operates with only two full-time staff, funded entirely by platform earnings. There is no need for a large sales or delivery team.

This shift to a "platform" approach has several benefits. For example, Sawhney (2024) reports that professional services firms that move toward product-like models see dramatically higher growth margins: product companies often command valuations 4–6× greater than project-based firms. In practice, the Charlie platform sets prices comparable to manual designs to ease customer uptake, but delivers them in minutes instead of days. The result is a much higher gross margin per project, once the automation development cost is covered. In effect, each completed design funds the creation of new modules and features, in a self-reinforcing cycle of growth.

20.3 Automation, Scale and Rapid Delivery

The core value of the platform model comes from automation and scalability. Every design type (module) is encoded into the system's calculation and drawing engine, so that it can run automatically. Instead of tying design cost to an engineer's diary, the system uses computing power. Tank (2022) emphasizes that generative design tools let firms *"complete repetitive, manual tasks and analyses in hours rather than days or weeks – and do it more profitably"*. For example, an engineering firm using Charlie reported compressing a five-day design process into a single day via automation. Similar cases abound repetitive calculations (outrigger designs, falsework calculations, etc.) that used to require 3–8 hours of engineer time now run to completion in seconds.

This rapid delivery builds client trust and enables far faster turnaround on urgent projects. Because the platform outputs complete calculations and drawings automatically, each sale requires virtually no incremental labour. In effect, the platform becomes a revenue engine: every additional purchase directly contributes to fixed-cost recovery and new development. Over time, the average cost per design plummets. Whereas a traditional design might cost a client £1200 in staff time, the platform issues it almost instantly (minutes), so the consultancy's effective cost is orders of magnitude lower while keeping price parity. The profit from each sale is then reinvested to build more modules, rather than paying additional staff or sales commissions.

Key advantages of this automated, scalable engine are:

- Virtually unlimited throughput: The platform's capacity increases with new software modules, not with new hires. Each module allows additional designs at near-zero marginal cost.
- Speed and quality: Calculations that took days are now done in minutes, dramatically shortening project schedules. Clients gain immediate answers and options that would never be feasible manually (Tank 2022).
- Margin expansion: Once a module is developed, every repeat use yields almost pure margin. Over time the system's content library grows, compounding return on the original development effort (Sawhney 2024).
- Predictable delivery: Fixed per-design pricing removes billing uncertainty. Clients appreciate knowing their costs upfront, which accelerates purchase decisions.

20.4 Pricing and Revenue Structure

The Charlie platform employs a per-unit fixed pricing strategy, in stark contrast to hourly billing. Designs are sold at rates comparable to traditional consultancy (so clients see no immediate saving), but the work is done by the software. For example, a scaffold or mat design might cost around £1200 – the same fee a human engineer would charge – yet Charlie generates it in minutes not days. Because development effort is "banked" in the software, each sale beyond that development incurs almost zero extra cost.

This pricing strategy has three core financial impacts:

- **Barrier-free adoption:** By matching industry pricing norms, there is minimal client resistance. No special approvals are needed for these purchases, speeding uptake.
- **High incremental profit:** After covering the initial investment, each design sold goes straight to profit (aside from server costs). This contrasts with traditional firms where every project requires new labour cost.
- **Self-funding growth:** Revenue from completed designs is channelled back into R&D. As more designs are processed, a larger share of profit is reinvested into expanding and refining the platform, driving continuous improvement.

In effect, the platform reinvents the unit economics: revenue is decoupled from labour hours. We note that even as per-design prices remain static, the **profit per design rises** over time. In a traditional model, price-to-staff-time ratio constrains growth. Here, an engineering design costing one hour at £1200 yields the same top-line, but costs only a tiny fraction once automated. As Sawhney (2024) highlights, services-to-products transformations free companies from linear cost structures, since *"product companies enjoy much higher growth margins and revenue per employee*s."

20.5 Reliance on R&D Tax Incentives (and Policy Shifts)

Before this platform era, many UK engineering consultancies bolstered margins through generous government incentives for innovation. The UK R&D Tax Credit scheme historically allowed companies to deduct or credit extra on qualifying development costs, effectively subsidizing R&D and software development. Indeed, smaller consultancies often built their business cases around reclaiming a significant portion of their salaries and expenses via R&D relief. However, recent policy changes have dramatically curtailed this support, reshaping the economics of innovation.

For instance, the SME R&D relief was **sharply reduced in April 2023**. RSM UK reports that the additional deduction fell from 130% to 86%, and the repayable credit rate dropped from 14.5% to 10% of qualifying spend. In practical terms, the effective tax benefit to a typical SME is about one-third lower than before. Moreover, from April 2024 the "old" SME scheme was largely closed except for very R&D-intensive companies; most firms now claim under the newer merged RDEC scheme at 15% of spend (after tax). These reforms were driven by concerns over error and fraud, but the upshot is that **much less R&D support accrues to smaller firms and consultancies**.

Dowsett (2024) underscores that HMRC's changes have *"confirmed [his] worst nightmare"* for SME innovators: smaller companies face a heavier compliance burden and reduced relief, whereas large firms see increased incentives. Practically, many consultancies can no longer count on substantial R&D tax payouts to pad their profits. As a result, a revenue model tied purely to labour hours will see lower after-tax margins than in the past. By contrast, the Charlie platform model is already profitable without such subsidies. Its fixed-cost structure means it never depended on R&D credits to stay viable. This independence makes the platform inherently more resilient to policy shifts: it earns money from actual designs delivered, not from one-off tax rebates.

20.6 Alignment with Future Industry Trends

Looking ahead, the engineering sector is moving toward digital-first, outcome-based delivery – a shift for which the platform model is ideally suited. Industry commentators note that the age of IoT and big data is ushering a "powerful shift" toward services measured by outcomes, not hours (Soltani 2024). In other words, clients increasingly demand turnkey solutions, predictive analytics, and operational efficiency, rather than just completed drawings. According to Soltani (2024), *"over 90% of businesses are investing heavily in digital transformation,"* moving from reactive models to customer-centric, outcome-focused services. This trend is visible in construction and infrastructure too: owners want digitally modelled options, carbon metrics, and near-real-time design updates – exactly what automated platforms can provide.

The Charlie platform is already "outcome-based" by design. It delivers complete, verified packages (calculations, drawings, reports) that directly achieve project goals. No client training is needed, and no change orders are required for additional scope – each purchase yields a finished outcome. The data-rich deliverables (e.g. BIM models, material quantities, carbon estimates) align with client expectations for digital transparency. In contrast, traditional firms often struggle to meet these needs without extensive bespoke effort.

Moreover, because the platform's revenue is linked to outputs, it remains robust even as market conditions change. For example, sudden inflationary pressures or labour shortages hurt hourly consultancies badly (more cost and headcount required per project), whereas the platform can absorb such shocks by adjusting compute resources and deployment. Its slim team and automated core mean it can pivot faster and invest in new technology (AI, cloud) more easily. As Sawhney (2024) suggests, companies built on product or platform models are better positioned for rapid innovation and resilience to disruption. In sum, Richter's platform is inherently aligned with the "engineering firm of the future" — one that measures success in client value and outcomes delivered, not time billed (Tank 2022).

20.7 Precedents and Comparisons

Other sectors provide successful precedents for this transformation. Sawhney (2024) notes that major professional services firms (e.g. Accenture, JPMorgan) are hiring product managers to *"productize"* their offerings. A concrete example is Littler Mendelson – the largest U.S. labour law firm – which developed a digital platform ("CaseSmart") to automate routine legal work. By moving from bespoke hourly billing to a standardized platform, Littler can serve many more cases simultaneously, improve predictability for clients, and achieve higher leverage on its expertise (Sawhney 2024). The Charlie platform mirrors this pattern in engineering: automating the "routine cases" (standard designs) so human experts focus only on novel challenges.

In the software industry, similar shifts have occurred for years. For instance, companies like Adobe and Autodesk famously moved from perpetual licenses to subscription/SaaS models. This changes decoupled revenue growth from product support costs and encouraged continuous innovation. Autodesk's own shift (noted by industry analysts) was motivated by the need for more predictable recurring revenue and broader market reach. Though those examples are software-centric, the principle is the same: *platformization* unlocks scale economies and client stickiness. In civil engineering, early adopters of digital design tools (e.g. cloud-based calculation engines, parametric BIM generators) have likewise begun to sell their technology as platforms or services, signalling that the industry is embracing this model.

20.8 Conclusion

In summary, the Charlie platform's business model stands in sharp contrast to the legacy UK consultancy model. By replacing time-based billing with a productized approach, it harnesses automation and content reuse to drive value. The platform generates faster turnaround, higher margins, and compounding returns – all without linear staff growth. This model is deliberately designed to be self-sustaining reinvestment comes directly from usage revenue, not external funding or tax credits. As government policy tightens around R&D incentives, traditional consultancies face shrinking buffers on innovation spend; the platform, however, remains profitable on a fee-for-outcome basis. Finally, this model is inherently aligned with future expectations – clients and regulators now demand digital, measurable outcomes rather than just hours worked. In this way, Charlie's business strategy is not only innovative but anticipatory, echoing successful transformations seen in law, IT, and productized services. The chapter has shown that in engineering innovation, how work is delivered can be as revolutionary as what is delivered.

Chapter 21: Calculation Development, Processing Workflow and Mathematical Integrity

21.1 Introduction

This chapter describes the design and implementation of the automated calculation engine at the heart of the Charlie platform. We explain how the calculation logic was built from established engineering formulae and guidance (e.g. Eurocodes, BS/EN standards and industry manuals) and how these formulas were encoded into software. Emphasis is placed on the process of prototyping calculations, translating them into code, and ensuring mathematical integrity through verification and validation. We also highlight how this fully automated workflow differs from traditional manual calculations and outline architectural strategies for accuracy, maintainability and standards compliance.

21.2 Engineering Logic and Formula Implementation

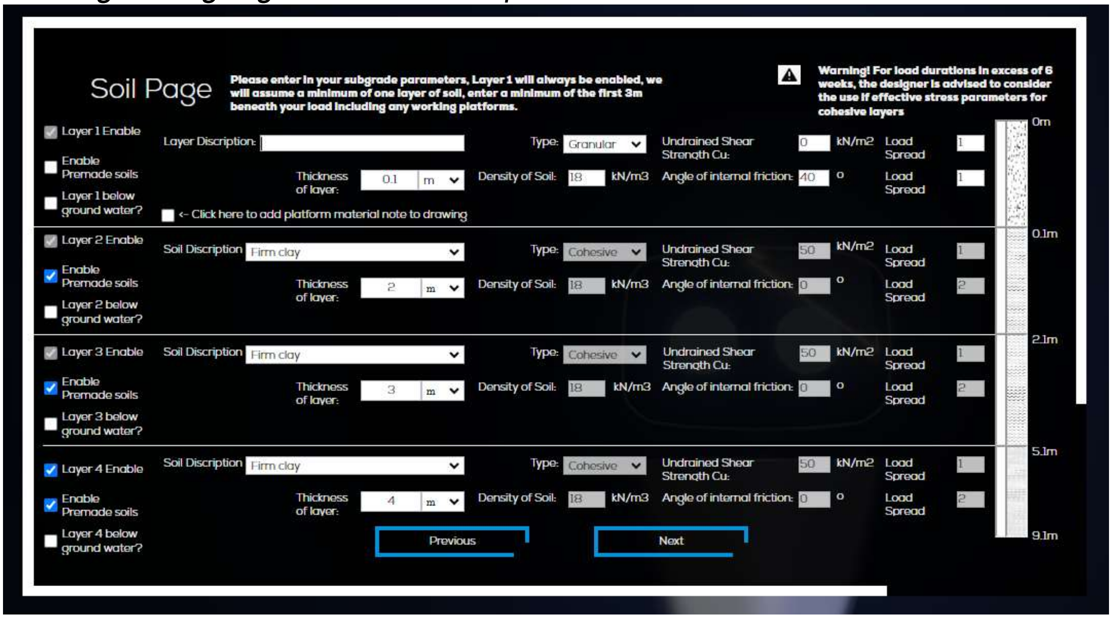


Figure 14: The multiple layer soil input interface

The platform's calculation logic is grounded in published design rules and codified methods. For example, well-known guidelines such as CIRIA Special Publication 123 (1996) and BRE Report 470 (2004) define analytical procedures for working platforms; more recently the UK Temporary Works Forum published TWf2019:02 (2019) as a good-practice design. These references include explicit formulae. For instance, BRE 470 provides an equation for bearing resistance of a temporary platform in cohesive/granular soil types, expressed in terms of subgrade cohesion, bearing capacity factors and platform depth. Such formulae are implemented as code. Where relevant, the platform also uses parameters from Eurocode 7 (EN 1997-1) and other standards to define limit states and partial safety factors. All input parameters (soil strengths, actions, factors of safety) are drawn from these codes or manufacturer data, so the platform's outputs are compliant with established practice. By encoding the expert knowledge of senior engineers into mathematical models, the system ensures each design follows the same rigorous logic every time.

Figure 15: Charlie processing calculations for 4 numerical methods simultaneously

21.3 From Spreadsheets to Software

To develop each calculation, engineers first prototyped the logic in Microsoft Excel. Excel was chosen because of its ubiquity in industry, ready availability of built-in functions, and transparency. In this prototyping phase, worksheets were structured with modular tabs or "calculation units" so that each step of the design could be inspected. VBA macros were sometimes used to support iterative convergence routines or to toggle between design scenarios, turning the static sheet into an interactive testbed. This spreadsheet-based sandbox allowed engineers to experiment with assumptions, visualize force or settlement profiles (e.g. with 3D plots), and verify outputs against hand calculations or known examples. Once a worksheet model was confirmed correct, the logic was rewritten in a software language (typically Python or C#) as part of the backend engine. The production code exactly reproduces the vetted formulae and algorithms from the prototype. All calculation modules are maintained in a version-control system, giving full traceability of changes. In operation, the code executes in real time on the server, taking user inputs from the web form, running all relevant checks, and outputting numeric results instantaneously. This automated workflow eliminates the need for manual data re-entry or step-by-step arithmetic: calculations are always performed consistently and to machine precision once a model is implemented.

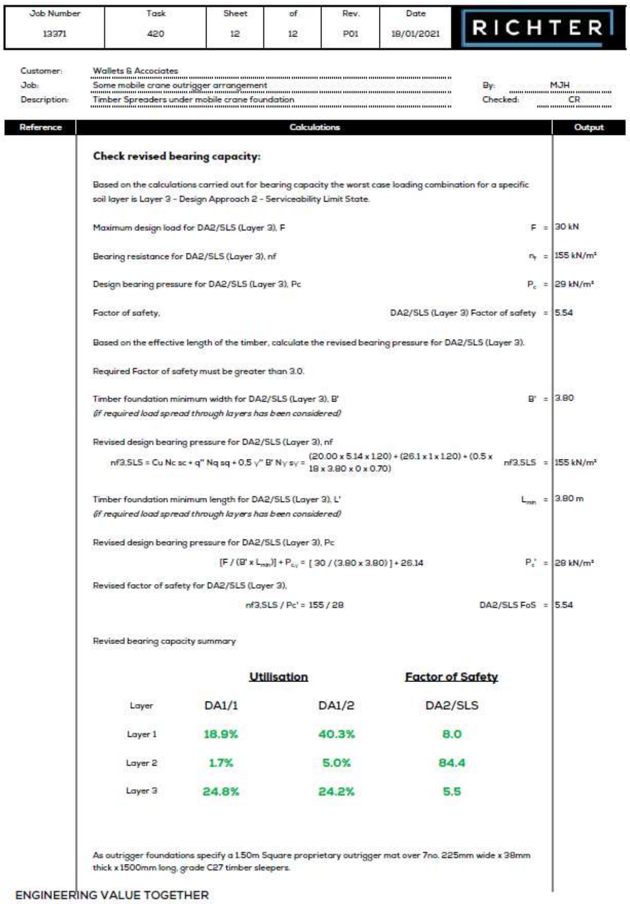
21.4 Validation, Error-Checking and Integrity

Ensuring the integrity of the calculations is critical. Industry best practice separates verification (checking that the math and code correctly implement the design logic) from validation (checking that the assumptions and models correctly represent the physical situation). In practice, each calculation module was rigorously reviewed. First, engineers compare the code's outputs to trusted hand or spreadsheet results under many test cases to verify the math. Range checks and sanity checks are built in (for example, requiring all inputs to fall within allowable engineering limits). Version control means that any change to the code is logged and peer-reviewed before deployment. In the platform's workflow, once a design is run the detailed Excel-style report still shows each calculation step (as per conventional practice) so that users can audit the logic if needed.

In addition, systematic validation is performed by comparing results from the new engine to alternative methods. For critical designs (like working platforms), the platform runs multiple approved methods in parallel (e.g. the TWf method vs. CIRIA vs. any proprietary formula) and highlights any discrepancies for review. Deviations beyond tolerance flag a design for engineering checking. This parallel optioneering approach not only lets users select the most economical solution given site conditions but also serves as a consistency check between independent algorithms. Errors are further controlled by automated unit tests: for example, a code update is considered correct only when it reproduces a suite of benchmark cases within an acceptable error margin. In short, the combination of careful prototyping, code-based checks, and multi-method comparisons provides a high degree of confidence that the engine's calculations are mathematically correct and compliant with engineering intent.

21.5 Difference from Traditional Manual Workflow

The automated process differs fundamentally from the old manual workflow. Traditionally, a temporary works engineer would perform one set of hand calculations or spreadsheets per design scenario, a process that is time-consuming and error prone. In contrast, the platform eliminates much of this human effort. By encoding expert logic, it instantly applies complex formulas (including loops and iterations) that would be tedious by hand. As one study notes, spreadsheets typically contain a very high rate of error, and even simple mistyped data or formula bugs can invalidate an entire design. In our system, user input is validated at entry, and formula errors in the code are extremely unlikely once tests pass. Another advantage is consistency: an automated engine always applies the same set of rules and partial factors (for ultimate and serviceability limit states) from the codes, whereas manual designs may vary depending on who does the calculation. Finally, the platform integrates all steps (input, calculation, checking, drawing, documentation) into a single workflow. Traditional practice fragments these tasks across separate Excel files, CAD templates, and report documents, which introduces coordination delays. Our solution therefore not only speeds up design (reducing typical turn-around from weeks to hours) but also provides a full audit trail of every calculation for quality assurance.



Job Number	Task	Sheet	of	Rev.	Date	RICHTER
13371	420	12	12	P01	18/01/2021	

Customer: Wallets & Accociates
Job: Some mobile crane outrigger arrangement — By: MJH
Description: Timber Spreaders under mobile crane foundation — Checked: CR

Reference	Calculations	Output
	Check revised bearing capacity:	
	Based on the calculations carried out for bearing capacity the worst case loading combination for a specific soil layer is Layer 3 - Design Approach 2 - Serviceability Limit State.	
	Maximum design load for DA2/SLS (Layer 3), F — F =	30 kN
	Bearing resistance for DA2/SLS (Layer 3), nf — n_f =	155 kN/m²
	Design bearing pressure for DA2/SLS (Layer 3), Pc — P_c =	29 kN/m²
	Factor of safety, — DA2/SLS (Layer 3) Factor of safety =	5.54
	Based on the effective length of the timber, calculate the revised bearing pressure for DA2/SLS (Layer 3).	
	Required Factor of safety must be greater than 3.0.	
	Timber foundation minimum width for DA2/SLS (Layer 3), B' *(if required load spread through layers has been considered)* — B' =	3.80
	Revised design bearing pressure for DA2/SLS (Layer 3), nf: nf3,SLS = Cu Nc sc + q'' Nq sq + 0,5 γ'' B' Nγ sγ = (20.00 x 5.14 x 1.20) + (26.1 x 1 x 1.20) + (0.5 x 18 x 3.80 x 0 x 0.70) — nf3,SLS =	155 kN/m²
	Timber foundation minimum length for DA2/SLS (Layer 3), L' *(if required load spread through layers has been considered)* — L_{min} =	3.80 m
	Revised design bearing pressure for DA2/SLS (Layer 3), Pc: $[F / (B' \times L_{min})] + P_{c,\gamma}$ = [30 / (3.80 x 3.80)] + 26.14 — P_c' =	28 kN/m²
	Revised factor of safety for DA2/SLS (Layer 3), nf3,SLS / Pc' = 155 / 28 — DA2/SLS FoS =	5.54

Revised bearing capacity summary

	Utilisation		Factor of Safety
Layer	DA1/1	DA1/2	DA2/SLS
Layer 1	18.9%	40.3%	8.0
Layer 2	1.7%	5.0%	84.4
Layer 3	24.8%	24.2%	5.5

As outrigger foundations specify a 1.50m Square proprietary outrigger mat over 7no. 225mm wide x 38mm thick x 1500mm long, grade C27 timber sleepers.

ENGINEERING VALUE TOGETHER

Figure 16: Example calculation report in same layout as high quality hand calculations

21.6 Architectural Strategies and Lessons Learned

Several architectural strategies were adopted to ensure accuracy, maintainability and compliance. First, the code was written in a modular fashion: each calculation rule or design check lives in its own function or class. This single responsibility approach means changes to one module do not inadvertently break others. It also allows unit-testing each module in isolation. Second, all design parameters and formulae come from documented sources. For example, coefficients and partial factors are hard coded from the relevant Eurocodes or guidance, with a code comment or link to the source. This traceability to standards makes it easier for an engineer to verify that the program is implementing the intended formula correctly. Third, a comprehensive logging system records all inputs and outputs. Every time an engineer runs a design, the system timestamps the case, logs which code version was used, and archives the results. This log enables later review or reproduction of any calculation, satisfying both technical and legal audit requirements.

A key lesson was the importance of user trust. Rather than hiding the engine behind a “black box,” the reports initially mimic traditional Excel output so engineers see familiar layouts and detailed steps. This helped gain user confidence even as the backend was fully coded. Over time, as trust grew, we can phase in more advanced features (e.g. dynamic charts or AI checks) because the engineering community saw the calculations remained correct. Finally, we treated the calculation engine as safety-critical software: changes undergo formal review (by qualified engineers) and we plan to implement automated regression testing in each software release cycle. In summary, by combining sound software engineering practices (version control, code review, automated testing) with adherence to civil engineering standards (Eurocodes, CIRIA, BRE, etc.), the Charlie platform achieves both mathematical rigor and practical maintainability.

21.7 Conclusion

The Charlie calculation engine is the intellectual foundation of the platform. It brings together codified engineering formulas, creative prototyping in spreadsheets, and disciplined software practice to produce designs that are accurate, fast, and auditable. The engine performs calculations far more quickly than traditional methods and, through built-in checks, ensures that designs comply with the same safety and serviceability standards that a chartered engineer would apply manually. In doing so, it represents not just digitization of existing workflows, but a fundamental step-change in how civil engineering calculations is generated and quality-assured. See appendix A, attached is example generated calculations following the TWf method for working platforms, it is presented still in a logical, followable way. However its creation has been adjusted for a more object-oriented approach allowing it to adjust for any input scenario. This goes beyond adjusting a few variables, but being able to switch different relevant features on and off and still present well.

Chapter 22: Drawing Generation, Visual Communication, and Site Integration

22.1 Introduction

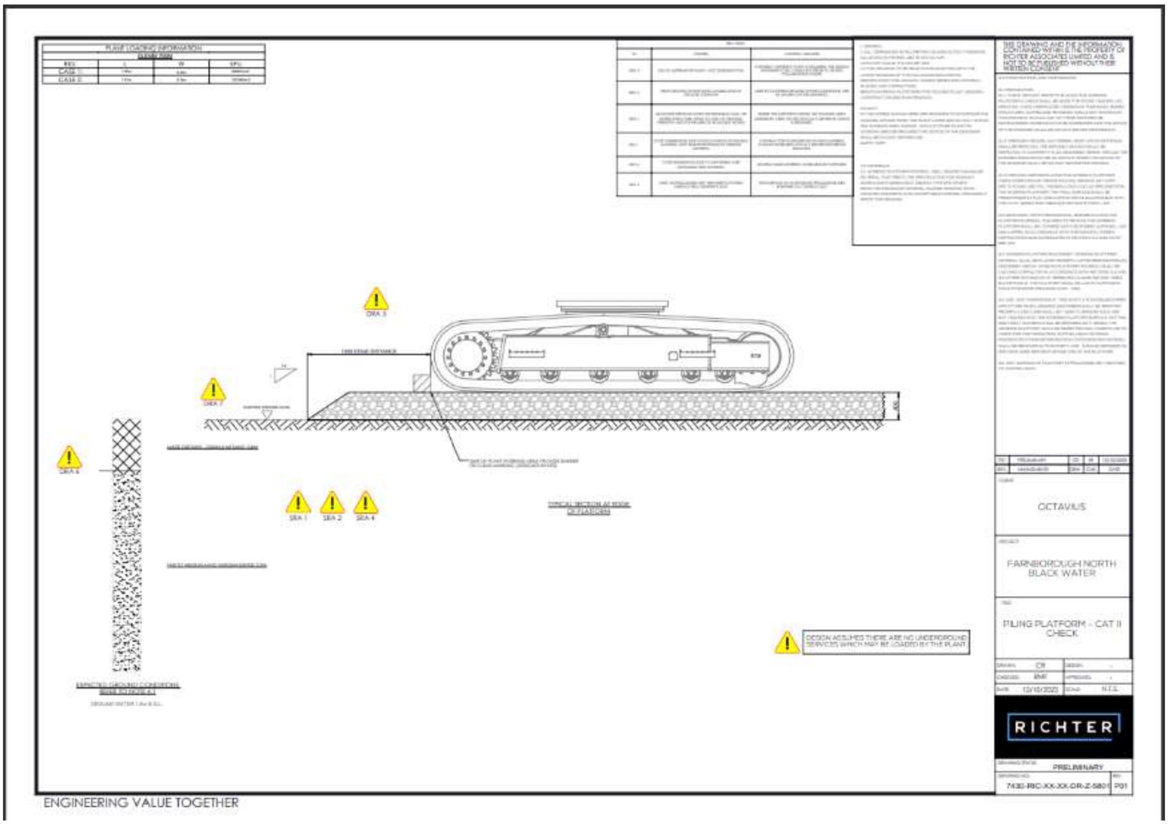


Figure 17: Example Generated drawing output

Drawings serve as the primary medium for communicating design intent and site instructions in civil engineering. They translate the results of engineering calculations into tangible guidance on layouts, dimensions, sequencing, and hazard controls. High-quality drawings are therefore essential: poor-quality or delayed drawings often contain inaccuracies and omissions that lead to errors, rework, and delays (Govender *et al.*, 2022). In practice, manual drafting workflows can introduce inconsistencies across projects and offices, and any lapse in issue of drawings forces on-site staff to improvise. Such improvisation, while sometimes necessary, is inherently risk-laden: as Alhussein *et al.* (2022) note, “improvisation is unavoidable in construction to address ... unforeseen uncertainties,” and frequent reliance on ad hoc planning can compromise safety and compliance. The automated system described here addresses these challenges by linking the digital calculation engine directly to a rules-based drawing generator. The remainder of this chapter describes how drawings are auto-generated from calculation outputs, the novel features built into these drawings, and the benefits of delivering them rapidly to site.

22.2 From Static Drafts to Parametric 3D Models

Traditional drawing generation often relied on static templates: fixed CAD layouts or PDFs where engineers manually inserted results and notes. This approach is time-consuming and error-prone, especially for non-standard designs. In the system presented, we replaced static drafts with a fully parametric drawing engine driven by a commercial CAD platform API. Each design module now creates its drawing from first principles: geometry, dimensions, annotations and title blocks are all drawn programmatically based on the engineer's inputs and the calculated results. For example, pad layouts, scaffold assemblies, or formwork are built as parametric 3D objects, then projected to 2D views with automated dimensioning and labelling.

This parametric approach yields several clear advantages:

Full automation of layouts, dimensions, and annotations, eliminating manual drafting steps and reducing human error (Lin *et al.*, 2022). The CAD API places and resizes every line, label, and symbol, ensuring that the drawing content exactly matches the calculation data.

Consistency across modules and offices. Automated drawing logic enforces uniform standards (fonts, line types, symbology) so that all outputs comply with company and industry conventions (BSI, 2017). In other words, drawings become standardized documents rather than bespoke one-off sketches.

Flexibility and scalability. Because the drawing is defined by rules rather than by fixed templates, it can easily adapt to different configurations or updated code requirements. New components or annotations can be added in software without manual redlining of hundreds of templates.

Parametric drawing generation also greatly improves speed and accuracy. Errors in contract documents are a major source of project delays: over 60% of errors in contract documents have been attributed to drawings. By contrast, a parametric engine can regenerate an entire drawing in seconds after any change in input data. In practice this means even last-minute design revisions produce correct, up-to-date drawings instantly, rather than waiting days for redrafts. In fact, research suggests parametric design can increase drafting efficiency by orders of magnitude – one study found up to a 90% productivity gain when moving from manual to parametric drawing workflows. Similarly, Söderlund *et al.* (2024) emphasize that parametric tools (linked directly to calculation logic) could streamline the otherwise slow, error-prone process of producing and reviewing design drawings.

22.3 Collaborative Case Studies and Supplier-Driven Content

The drawing engine has been successfully applied in collaborative case studies. For example, in partnership with an aluminium pad supplier (Brilliant Ideas Ltd), we developed automated drawings for their modular Alimat pads. The calculation determines the required pad layout based on bearing pressures, and the generator produces plan views showing up to eight interlocking pad configurations, each drawn at the correct scale with loads and capacities annotated. This data-driven approach – using supplier-provided capacity tables – ensures that the drawings always reflect the latest product specifications. Other supplier collaborations have followed: when an equipment vendor shares a component's geometry or load charts, we integrate it into the parametric library so future drawings automatically use the new data.

Such supplier-driven integration is an emerging best practice. By linking manufacturers' data to our CAD engine, we eliminate the need for designers to approximate component behaviour. The system's outputs become semi-custom "catalogue" drawings: the components are pre-validated (by the supplier) and the software simply selects the correct parts and arrangements. This accelerates design work and reduces risk of mismatch between design and what's available on site.

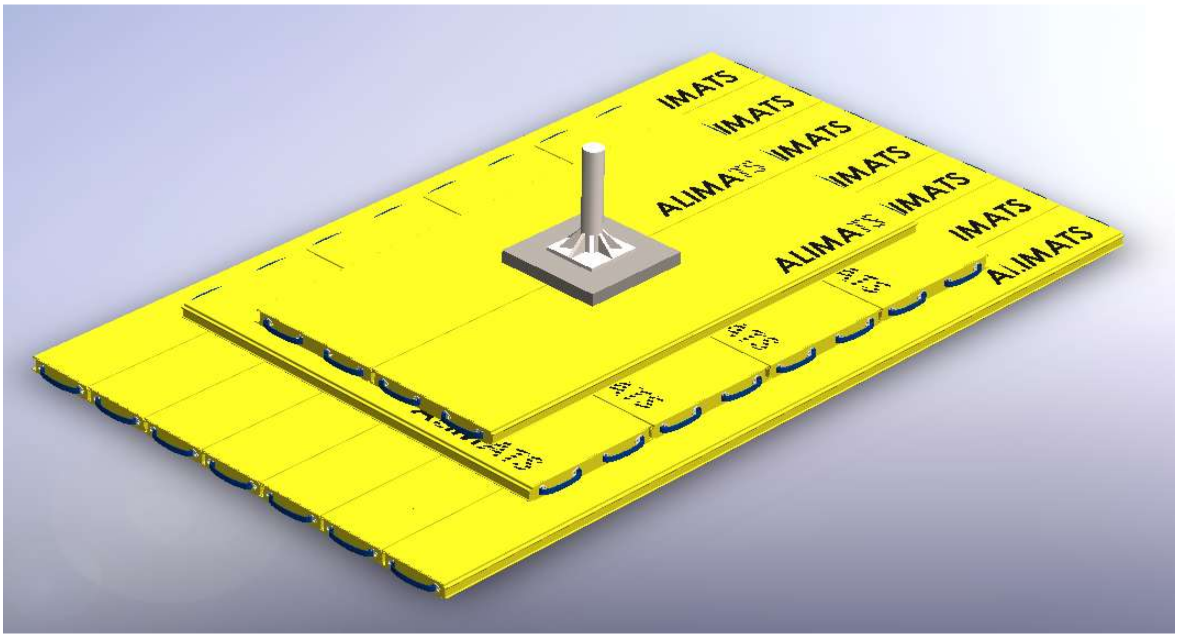


Figure 18: 3D model of generated Alimat outrigger arrangement

22.4 Data-Driven vs Analytical Visualisation
The drawing engine supports two complementary methodologies. For custom-designed items (e.g. timber spreaders or bespoke scaffolds), the drawing is analytical: it dynamically shows bending moment diagrams, deflected shapes, or stress limits corresponding to the calculated loads. Annotations (such as required member sizes, bolt spacings, or reinforcing bar marks) are all generated from the numerical results. In effect, the drawings visualize the analysis, making it clear on site why a certain configuration was chosen.

For standard products (e.g. supplier pads, scaffolding sections), the approach is data-driven: the engine uses lookup tables of capacity or empirical performance rather than computing every detail. For example, the system knows that a given pad design safely supports X tonnes per square meter, so the drawing simply shows enough pads to carry the load, without re-running finite-element calculations. Both approaches converge on the same goal: accurate, simple drawings that clearly communicate capacity and layout. In practice, this dual strategy yields concise, legible outputs. Contractors can see immediately whether a detail is bespoke (analytical) or off-the-shelf (data-driven), and the assurance of correctness is built into either method.

22.5 Customisation and Site Context
Site engineers often request local context on their drawings (e.g. plan overviews or logo branding). While fully automated context views are difficult, the system provides semi-automated tools: users can upload an image (survey plan or site photo) as a background overlay, which the software scales and clips. We also allow optional insertion of client logos or project headers in the title block. These features are driven by the same parametric logic: once a user sets the scaling and position, the overlay is saved as part of the module profile. This customization capability increases on-site clarity (showing building

footprints, access roads, etc.) without sacrificing automation. In essence, drawings remain generated by rules but can be enriched with site-specific graphics in a controlled way.

22.6 Risk and Environmental Annotations

Modern temporary-works drawings must convey safety and environmental information as well as geometry. To support this, the system includes smart risk annotations. For example, if a load exceeds a threshold, the drawing automatically adds a coloured hazard symbol (e.g. tipping hazard or heavy lift icon) with a note. Originally these were simple on/off toggles, but now they are fully configurable. Engineers can choose which hazards to display, edit the text of each warning, or reposition symbols to avoid crowding. This aligns with best practice in design safety: guidance emphasizes that residual risks (from the designer's risk assessment) should be "clearly shown on the design output, e.g. drawings" so that contractors can plan mitigations.

In practice, each drawing includes a summary table (akin to a designer's risk assessment) listing the key hazards, risk levels and mitigations. These Designer Risk Assessment tables are auto-filled from the calculation logic (e.g. identifying "Crushing under pad" or "Trench collapse" if triggered) and formatted per standard practice. The result is an integrated document: the drawings not only show *what* to build, but also *what dangers remain*. Such embedded hazard notation has been shown to improve site safety by making risk information accessible to all stakeholders at the point of use (Brownrigg, 2009). By automating this, the system ensures that no critical warning is omitted or outdated.

22.7 Context-Aware Drawing Notes

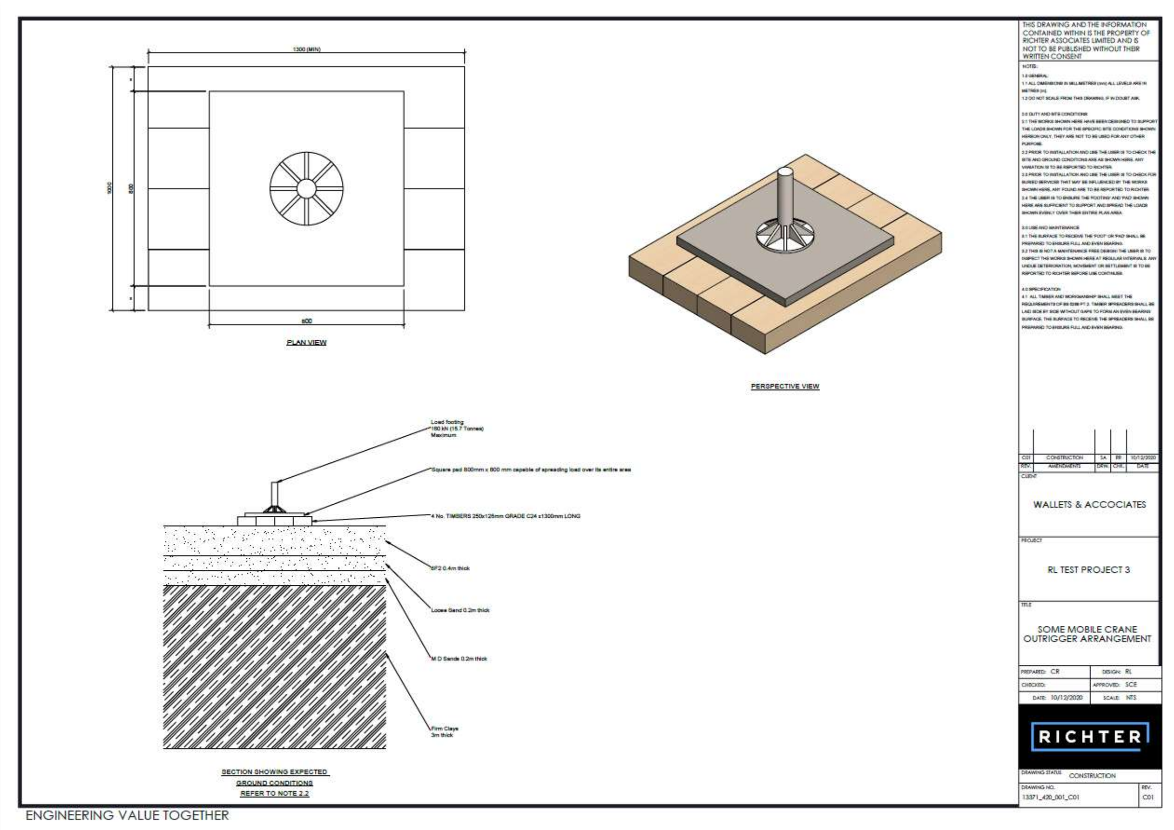


Figure 19: Generated drawing showing customisable ground configuration and mat/timber arrangement

All text notes on the drawings are "smart" fields. Standard clauses (e.g. material specs, method statements) are scripted to pull variables from the engineer's choices and calculation results. For example, a note template might read "Pad size: ${width}×${length} mm, quantity ${n}", with width, length and quantity filled in automatically. Similarly, any triggered warning notes (e.g. "All operatives must wear hard hats") appear only if their condition is met. This context-awareness ensures that notes are always accurate and relevant to that design. It also maintains professionalism: standard text, fonts and formatting are enforced, so the drawings look like a well-edited report even though they were machine-generated.

By contrast, manual drawing processes often involve copying text between documents and risk outdated or mismatched notes. Here, every note is linked to a single source of truth (the calculation and user inputs). If an engineer changes a parameter (say, foundation type), all dependent annotations update instantly. This traceability of information is critical for compliance: if an auditor checks the calculation, they can see exactly how each note on the drawing was derived.

22.8 Drawing Standards and BIM Compatibility

To ensure clarity and consistency, the platform enforces a drawing standards manual. All generated outputs use a uniform title block, layer scheme, symbology and dimension style as prescribed by British Standard BS 8888 (2017) and company policy. (In practice we embedded these rules in the CAD template.) This eliminates common errors like misplaced north arrows or inconsistent line weights. The result is that drawings from any module or office can be understood without re-education.

The system also facilitates digital integration with BIM and document management. Each drawing file is automatically named using concatenated metadata (drawing type, project code, version, etc.) following the BS 1192 naming conventions. Though the service does not yet produce full BIM objects, these naming conventions allow easy uploading of the PDFs to common BIM servers or archives. In the future, the parametric models could be linked directly into 3D coordination tools, but for now the naming and output formats form a stable "bridge" to modern workflows.

22.9 DWG Export and Post-Generation Editing

Every design output includes both a ready-to-issue PDF and a native AutoCAD DWG file. The PDF is immediately portable for site issue, but the DWG can be opened and edited by the engineering team. This hybrid output approach brings flexibility: small local adjustments (e.g. annotating an existing slab or shifting a temporary edge protection line to match site conditions) can be done quickly without redrafting the whole drawing. At the same time, most of the content is already drawn, saving hours of work.

Providing the editable CAD file has eased the transition for engineering users. Instead of a fully "black-box" output, designers see that every element of the drawing was auto-generated – and they can tweak it if needed. Yet this is still far faster than manual drafting. In our deployment, user feedback indicates that the DWG export has enabled at least a 50% reduction in total drafting time, since routine geometry and text are pre-placed by the system.

22.10 Significance and Site Impact

The ability to deliver correct drawings within minutes has powerful practical benefits. In traditional practice, drawing delays force site teams to work from incomplete information or to improvise on the fly. Such improvisation is often a source of accidents and defects (Hamzeh *et al.*, 2018; Alhussein *et al.*, 2022). By contrast, having a complete and clear set of drawings ready immediately reduces uncertainty. Excavations are shored correctly the first time, load paths are visualized, and installers know exactly where critical lifting points are. This can materially improve safety: site crews can identify hazards (like underground utilities or fall zones) on the issued drawings and plan mitigations in advance.

Moreover, rapid drawing issuance shortens project timelines. Interim requests (e.g. a site manager needing a bracing detail tomorrow) can be fulfilled within hours instead of weeks. This “real-time” supply of drawings keeps work flowing without compromise. And because the drawings are machine-checked against standards (e.g. title block content, dimension accuracy), compliance is assured even at high speed. In short, the system’s parametric drawing engine transforms drawings from static, delayed deliverables into dynamic, up-to-date communication tools. In doing so it eliminates much of the risk and inefficiency associated with traditional drafting workflows, helping to ensure that designs are built safely and exactly as intended on site.

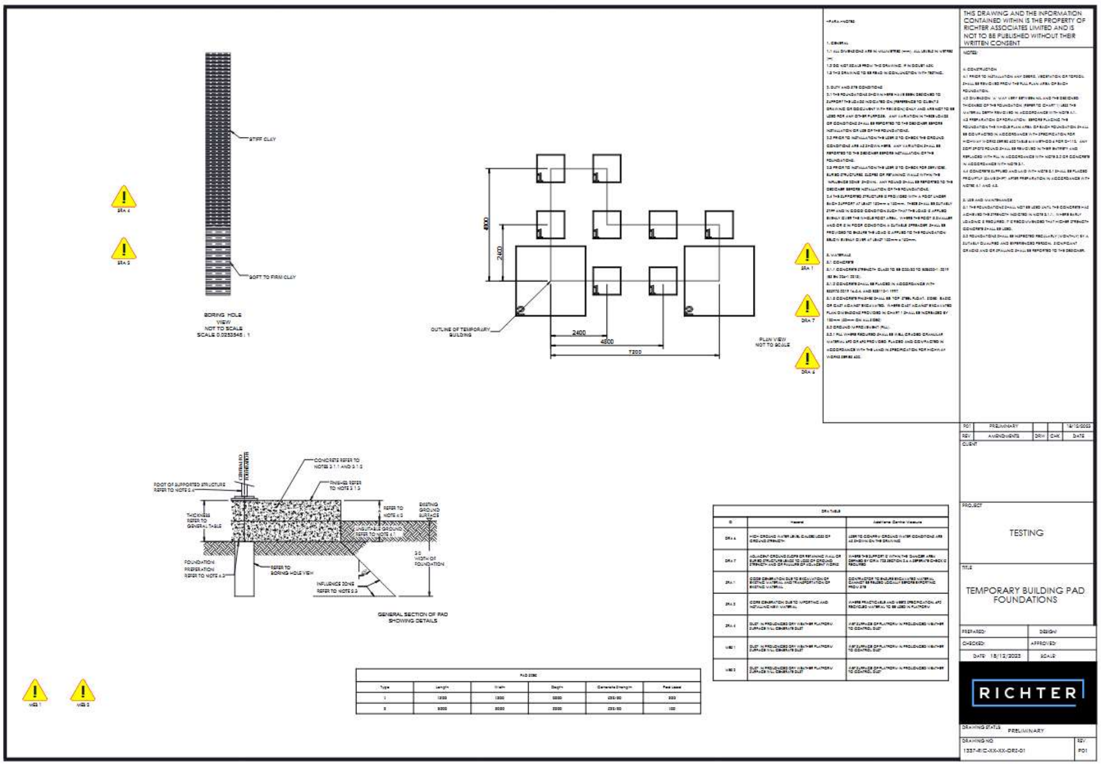


Figure 20: Testing generated drawing for office pad foundations with custom plan view

<u>Chapter 23 Documentation, Certification, and Assurance</u>

23.1 Introduction

Temporary works documentation is the formal bridge between design and assurance. BS 5975:2019 and related HSE guidance require that every temporary works design be supported by a clear design brief, risk assessment, drawings, and an independent check by a suitably qualified engineer, with a signed design-check certificate issued upon approval. In practice, BS 5975 partitions designs into four check categories (CAT 0–CAT 3) based on complexity. CAT0 covers basic, standard solutions, whereas CAT3 applies to complex or innovative designs requiring an independent checker from outside the design organization. These procedures mandate auditable records of assumptions, calculations, and signatory approvals to document that all checks have been performed. In effect, detailed documentation is not merely bureaucratic – it is risk management, providing traceability of decisions and assigning legal responsibility to the designer and checker.

BS 5975:2019 explicitly requires that temporary works documentation include "the design brief, design risk assessment and a designer's method statement where appropriate," followed by "independent checking of the temporary works design" and "the issue of a design/design check certificate, if appropriate". In other words, each package of calculations, drawings, and reports must culminate in a certificate signed by the Temporary Works Designer (TWD) and the Temporary Works Design Checker (TWDC). By design, this ensures that a qualified engineer formally accepts responsibility for the design outputs. The automated platform described herein (often called *Charlie*) embeds these requirements into the workflow. Rather than treating certification as an afterthought, the software generates and populates the certificate during design creation, guaranteeing that no package can be completed without a corresponding approval.

23.2 Core Objectives of Documentation

The documentation system in the platform is engineered around three core objectives:

Risk communication: Clearly record all assumptions, design methods, calculation results, and checks so that potential hazards are understood. In particular, any risks that remain after design must be explicitly annotated (see below). Effective documentation "mitigates design risk" by avoiding hidden assumptions or missing data.

Traceability: Maintain a complete audit trail of inputs, outputs, version changes, and authorizations. Every change to a design input or output is logged, time-stamped, and associated with a user. This fulfills regulatory requirements and protects against miscommunication or disputes.

Enable certification: Assign clear roles (designer, checker, approver) and embed their signatures into the documents. BS5975 mandates that the design team be identifiable and accountable; the automated system ensures that the Design Certificate identifies the TWD, TWDC, and TWC (Temporary Works Co-ordinator) for each design.

Without rigorous documentation, even a technically sound design cannot be certified or defended. Construction projects lose time and money when drawings or calculations are ambiguous or incomplete. Studies note that manual document control failures often lead to errors, rework, and delays. By contrast, an automated documentation process integrates quality control at its core. It transforms documentation from a bureaucratic bottleneck into a value-adding component of the workflow.

23.3 G91 Design Certificate Workflow

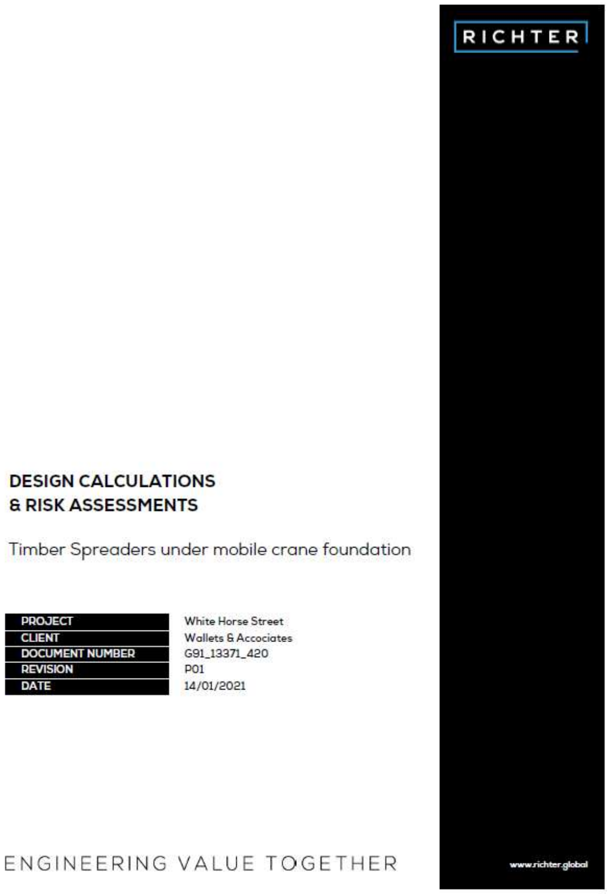
The G91 Design Certificate is central to the platform's documentation output. (G91 is the UK Temporary Works Design Certificate format prescribed under BS5975.) Under BS5975, a check certificate must state the category of check and identify the drawings, specifications and design methods used. In the platform, the G91 certificate is implemented as a modular form that is automatically populated with data from the design. Key features include:

Roles and signatories: The form automatically lists the Design Engineer, Checker, and (if required) the Temporary Works Co-ordinator as approver. Because CAT2/3 checks require separate individuals, the certificate enforces that the TWD and TWDC are not the same user and have appropriate roles.

Input and results log: All design inputs (geometry, loads, material properties, etc.) are referenced in the certificate, along with key calculation results (e.g. factor of safety, computed pad size). These fields are auto-filled from the same database that generated the drawing, preventing double-entry errors. As a result, the certificate "tracks input data, results, and key decisions" without manual transcription.

Manual and automated sections: Some parts of the certificate require manual text (e.g. design notes or project-specific conditions), while others (like numeric check category, calculated values) are auto-populated. The modular design of the G91 form makes it easy to update and standardize. When the industry updates BS5975, the software's G91 template can be revised centrally to comply with new requirements.

These design certificates are generated immediately upon completion of the design. Because the platform enforces that a certificate is part of each output package, the process of certification is not deferred. In a traditional consultancy, certificates might be drafted after final checks, often causing delays. Here, certificate generation is integrated: once the engineer "clicks approve," a signed PDF certificate is produced.



RICHTER

DESIGN CALCULATIONS
& RISK ASSESSMENTS

Timber Spreaders under mobile crane foundation

PROJECT	White Horse Street
CLIENT	Wallets & Accociates
DOCUMENT NUMBER	G91_13371_420
REVISION	P01
DATE	14/01/2021

ENGINEERING VALUE TOGETHER

www.richter.global

Figure 21: Front page of generated certification documentation

23.4 Risk Disclosure and Residual Hazards

A key requirement of temporary works documentation is to communicate *residual risk* – that is, hazards that remain even after the design's mitigation measures. The platform addresses this by extending the G91 certificate and drawing annotations to include safety warnings:

Annotated drawings: Any hazard noted in the design (for example, a steep unshored excavation face or an unusual ground condition) is annotated graphically (e.g. with hazard triangles) on the drawing. These annotations are driven by the calculations (triggering warning symbols when certain thresholds are exceeded).

Risk commentary: The G91 form includes a dedicated section for risk commentary. The system uses standardized language to assign RAG (red/amber/green) risk ratings, explain the meaning of each warning symbol, and describe any hold points or operating restrictions. (Hold points are stages during construction where work must stop until a condition is verified – BS5975 explicitly requires passing such constraints to the contractor.)

Residual risk adjustment: Based on user actions or design choices (e.g. adding additional supports), the system can adjust the residual risk assessment. For example, if the user decides to add extra bracing, the residual risk level on the certificate automatically recalibrates.

User editing: Although default risk notes are provided, the platform allows the engineer to edit or append remarks before finalizing the document. This accommodates project-specific details (site layout, client preferences, unusual conditions) that an automated system might not predict. Importantly, these custom notes are also saved and versioned.

These features ensure compliance with BS5975's emphasis on hazard communication. As one industry guide notes, "risks that cannot be eliminated or mitigated must be passed on to the contractor as 'residual risks', together with the supporting information that describes them", including any hold points. And the contractor "is most interested in the residual risks which should be clearly shown on the design output, e.g. drawings". By embedding residual-risk disclosure into every package, the platform makes sure that nothing is omitted: the design output itself flags all conditions that site personnel must respect.

23.5 Editable and Versioned Outputs

Recognizing that construction is unpredictable, the system produces both finalized and editable versions of each document. Official documents (drawings, certificates, calculations) are issued in locked PDF format for issue control. Simultaneously, editable copies (e.g. the G91 certificate or calculation sheets in Excel) are archived. This hybrid approach offers the best of both worlds:

Flexibility: If the site needs minor clarifications or additions (for instance, adding a company logo or adjusting a note to suit local wording), the engineer or TWC can make these edits in the Excel version without losing the time already invested.

Traceability: Every editable document is version-controlled. The system's database tags each output with a unique design ID and revision number. Any subsequent edits create a new revision in the history, with a log of who made changes when. Thus all versions are archived and retrievable. Automated revision tracking ensures that "all document updates are accurately recorded and easily accessible," so the current design is always identifiable. In practice, this means an engineer can restore an earlier version or compare changes over time if needed.

The platform's version control and audit logs vastly improve transparency. As digital-document experts note, automatic revision tracking and audit trails are critical: they "capture every change made to a document, including who made the change and when," which is invaluable for resolving disputes and demonstrating due diligence.

23.6 Verification, Sign-Off, and Automation Limits

All automated documentation ultimately requires a *verified* sign-off by qualified personnel. In practice, the temporary works designer and checker must sign the certificate to assume responsibility for the design's accuracy. The platform supports this by enabling digital signatures: approved users can apply an electronic signature (or a scanned hand-written signature image) to the certificate PDF. The system enforces that the signer is a licensed engineer with the required competency.

Legally, a professional engineer's signature confirms authenticity and responsibility for the document. As engineering boards state, by signing and sealing a design the engineer "verifies the authenticity of the document, and accepts responsibility for its accuracy and legitimacy". Modern digital signing tools can satisfy these requirements, provided the signature is unique to the engineer and any document changes would invalidate the signature. In other words, the signer effectively places their digital stamp of approval on the design.

Originally, the project explored fully automating the check-and-approval step (for example, allowing "Charlie" to automatically sign off minor designs). However, this ran into legal and insurance concerns: standard Professional Indemnity (PI) policies do not permit designs to be signed off by an unlicensed agent, and regulators insist on a human signatory. Consequently, the platform retained a manual sign-off model. A designated checker must still review and approve outputs before they are released. Nonetheless, the system introduces one path to increased automation: if a particular design type and parameter range has run successfully many times (for example, 60+ designs with no issues), the checker may opt for a "light-check" on future cases, simply confirming inputs rather than redoing all calculations. This progressive trust approach lays the groundwork for eventual rule-based approvals, but with human oversight ensuring compliance in the meantime.

23.7 Document Naming and Archiving

All files generated by the platform follow a consistent, BIM-compatible naming convention. For example, each output file uses the format: [DocumentType]_[ProjectID]_[DesignID]_[Revision] (where DocumentType might be CERTIFICATE, DRAWING, or CALCULATIONS). This standardized naming ensures that each document can be uniquely and quickly identified. Consistent file naming is a recognized best practice in construction document control: it "simplifies document management and prevents confusion". Moreover, it facilitates interoperability with wider project systems (common data environments, BIM portals, or archives) even though full 3D BIM linking is beyond scope.

All versions of documents are archived in a secure database. When a new revision is issued, the old version is not deleted; it remains indexed under the original design ID. Thus at any time, project managers can retrieve a complete history of the design package, with clear records of who issued each revision and when. This satisfies record-keeping obligations and aids later audits or post-construction reviews.

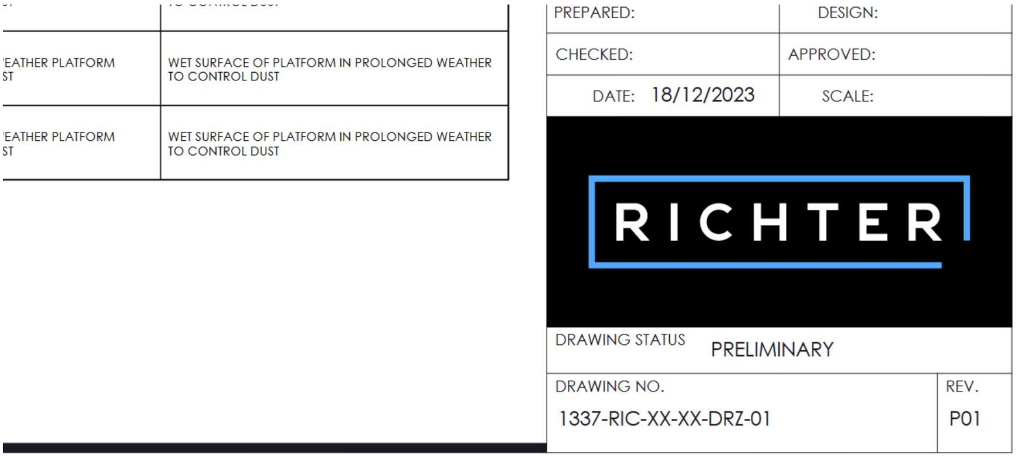


Figure 22: Drawing close up showing BIM documentation number generation

23.8 Professional Liability and Insurance Implications

Automation of documentation does not change the fundamental liability structure: the engineers signing the outputs remain legally and financially accountable. In the event of an error or omission, the design firm's Professional Indemnity insurance would respond in the same way as for a manually produced drawing. In fact, the growing cost of PI insurance in construction reflects concerns about design quality and risk. Industry analysts note that PII premiums have risen sharply due to a high claims history – in some markets, claims have increased by over 100% in recent years. In principle, a robust automated workflow *could* improve the firm's risk profile by reducing manual mistakes. The platform's auditability and consistency provide documentary evidence of rigorous checking, which insurers may view favourably. However, engineers must still exercise judgment and cannot abrogate responsibility to software.

Legally, signing a document (even one largely auto-generated) places the engineer in responsible charge. For example, professional regulations (such as Florida's PE Board rules) specify that an engineer may only sign and seal documents that they "were in responsible charge of preparing". Whether on paper or in a digital form, the signature is intended to be unique, verifiable, and to invalidate the document if altered. Accordingly, the platform ensures the signed certificate clearly identifies the engineer's license or registration number, satisfying those requirements.

In summary, automation shifts some liability away from clerical tasks (eliminating transcription errors) and toward oversight (ensuring the inputs are correct). But from an insurance standpoint, the coverage is essentially the same. Any output – manual or automated – that bears an engineer's signature is their professional responsibility. By integrating certification into the toolchain, the platform helps engineers meet their duty of care, but it does not eliminate that duty.

23.9 Cultural Reception and Practical Impact

Introducing automated documentation into a traditionally conservative environment required careful change management. Many engineers are accustomed to hand-crafted reports and have strong preferences about formatting. To ease the transition, the platform offers familiar elements in an automated guise: pre-filled certificate forms, context-sensitive risk notes, and editable exports for those who want to add a personal touch. This combination of structure and flexibility has proven effective.

In urgent, high-pressure situations – the very scenarios BS5975's two-week turnaround calls out as problematic – users have reported that the platform enables issuing documents on the same day rather than waiting weeks. Early field trials showed that up to 90% of repetitive tasks (calculations, filling in standard sections of reports, drafting drawings) can be automated, allowing human reviewers to focus on "high-risk" decisions like load cases or atypical ground conditions. Industry experience confirms that poor document control often causes project delays and disputes; by comparison, automated workflows have sharply reduced such delays on test projects.

Overall, the cultural reception has been positive but cautious. Engineers appreciate the consistency and time savings, but still view the final certificate as a significant item. By explicitly requiring the engineer to review and finalize each document, the system aligns with professional expectations. The platform thus bridges traditional and digital practices: it provides the speed and traceability of software while maintaining the final sign-off rituals of engineering practice. In doing so, it demonstrates that automation can enhance, rather than endanger, accountability and quality.

23.10 Conclusion

In Charlie, documentation is not an afterthought – it is an integral design product. The platform generates complete, checked design packages, including drawings, calculations, and a fully populated design certificate, in a single workflow. By automating the generation of BS5975-compliant certificates, embedding residual risk disclosures, and maintaining thorough audit trails, the system transforms documentation from a bottleneck into a value-adding component. The result is a modern, defensible approach: designs are delivered faster and with greater transparency, while meeting all professional and insurance requirements. In short, automating documentation has converted an onerous constraint of temporary works into an opportunity for efficiency and assurance. Find in appendix B a full G91 check certificate generated by the system ready for issue.

Chapter 24: Sustainability Report

24.1 Introduction

Sustainability is now a central criterion in civil engineering design as nations legislate for deep carbon cuts. The UK, for example, has committed to net-zero by 2050 with interim carbon budgets requiring ~78% cuts by 2037. Such targets, along with frameworks like BSI PAS 2080 (the UK standard for carbon management in infrastructure), oblige designers to demonstrate lifecycle emissions reduction. In practice, clients and funders increasingly demand proof of embodied carbon savings before and during construction. To meet this need, the Charlie automated design platform embeds a Sustainability Report feature that converts design optioneering into quantified carbon reductions. Rather than treating sustainability as an afterthought, Charlie integrates embodied-carbon calculations into every design pass so that low-carbon solutions emerge organically from the same algorithms that ensure structural adequacy. In effect, the system turns each alternative design into a data point in carbon space, enabling engineers to make immediate decisions based on numerical CO_2 savings.

24.2 Industry Context and Carbon Accounting

Best-practice infrastructure guidance now requires full life-cycle carbon accounting. Standards such as PAS 2080 and RICS's Whole Life Carbon Assessment mandate that projects consider emissions across all life-cycle stages. In simplified terms, environmental assessment is divided into: A1–A5 (material production, transport and on-site construction), B1–B5 (use, maintenance and operation) and C1–C4 (end-of-life and disposal). For temporary works, the relevant stage is A5 (site construction). The UK Temporary Works Forum (TWf) explicitly notes that temporary structures – though short-lived – often produce significant carbon. In heavy civils or refurbishment projects the majority of embodied carbon may come from site works and temporary works. Furthermore, BS EN 15978 (the building sustainability standard) treats all materials not incorporated into the final asset as waste in A5. In practice, this means *temporary works emissions normally fall in A5w (waste)* and cannot be ignored. TWF guidance observes that temporary works usually exceed the typical 5% cut-off criterion of PAS 2080, so they must be included in any compliant carbon inventory. Put simply, current frameworks demand that designers treat temporary works carbon on par with permanent structures: by quantifying A1–A5 embodied carbon and linking it to procurement and operational plans.

24.3 Automated Carbon-Optioneering Method

The Charlie platform leverages its parametric engine to evaluate multiple design alternatives simultaneously, making sustainability a built-in outcome. Each project's inputs (loads, spans, geometry, materials, site context, etc.) are fed into parallel calculation routines. For a given temporary works element (e.g. a working platform pad or scaffold), the system runs two or more code-based methods – for instance a conservative design method and an optimized guide (such as a CIRIA guideline). Each method yields a complete design solution: one typically deeper or more material-intensive, the other shallower and more efficient. By comparing the two, the platform identifies a *"most-efficient"* versus a *"fallback"* option. For example, in one case over Thames Valley clay the CIRIA method produced a pad ~0.38 m deep versus 0.65 m by the more conservative procedure – a 57% reduction in depth. Because the geometry and loads are identical, this difference is purely due to design logic.

To translate these differences into carbon, Charlie multiplies the material quantities from each design by embodied-carbon coefficients (e.g. $kgCO_2e$ per m^3 of concrete or per tonne of steel). Authoritative sources such as the University of Bath *Inventory of Carbon and Energy (ICE)* database supply the necessary factors. For example, if the optimized pad uses half as much concrete, the corresponding CO_2e would be roughly half. In practice, Charlie reports both absolute and percentage carbon savings. In the Thames Valley example, the 57% reduction in depth (and ~25% reduction in volume) yielded roughly 2.8 tCO_2e saved per platform. By framing design optioneering in this way, carbon becomes a quantified design metric rather than a soft goal. Similar parametric approaches in the literature have demonstrated the ability to assess hundreds of design permutations for embodied carbon in a single run; Charlie applies this principle to temporary works.

24.4 Life-Cycle CO_2e Calculations

The platform's carbon module performs a simple cradle-to-grave calculation for each design. It uses embodied CO_2e factors for common materials (concrete, reinforcement steel, fill material, geotextile, etc.) drawn from public databases and literature. For instance:

- Concrete (crushed aggregate) – *x* kg CO_2e per m^3 (ICE values)
- Recycled aggregate – *y* kg CO_2e per m^3 (industry standards)
- Geotextile – *z* kg CO_2e per m^2 (manufacturer data)
- Steel (reinforcement or tubes) – *w* kg CO_2e per tonne (UN Steel LCA)

Each design's bill of materials is multiplied by these factors and summed to give a total embodied CO_2e. The tool then computes the difference between alternative designs and expresses it as total CO_2e saved. It also converts this saving into equivalent carbon offsets (tonnes CO_2e) or cost savings, assuming a market offset price. These outputs support reporting: for example, a working platform design may show "–2.8 tCO_2e, equivalent to 70 tree-months of sequestration" or "£350 carbon credits avoided". All figures can be normalized (e.g. per unit area or per m^3 of structure) to facilitate comparison. The result is an auditable, numerical sustainability report grounded in standard LCA practice: total embodied carbon and whole-life CO_2e are fully tabulated and explained, aligning with PAS 2080's requirement for transparency at each life-cycle stage.

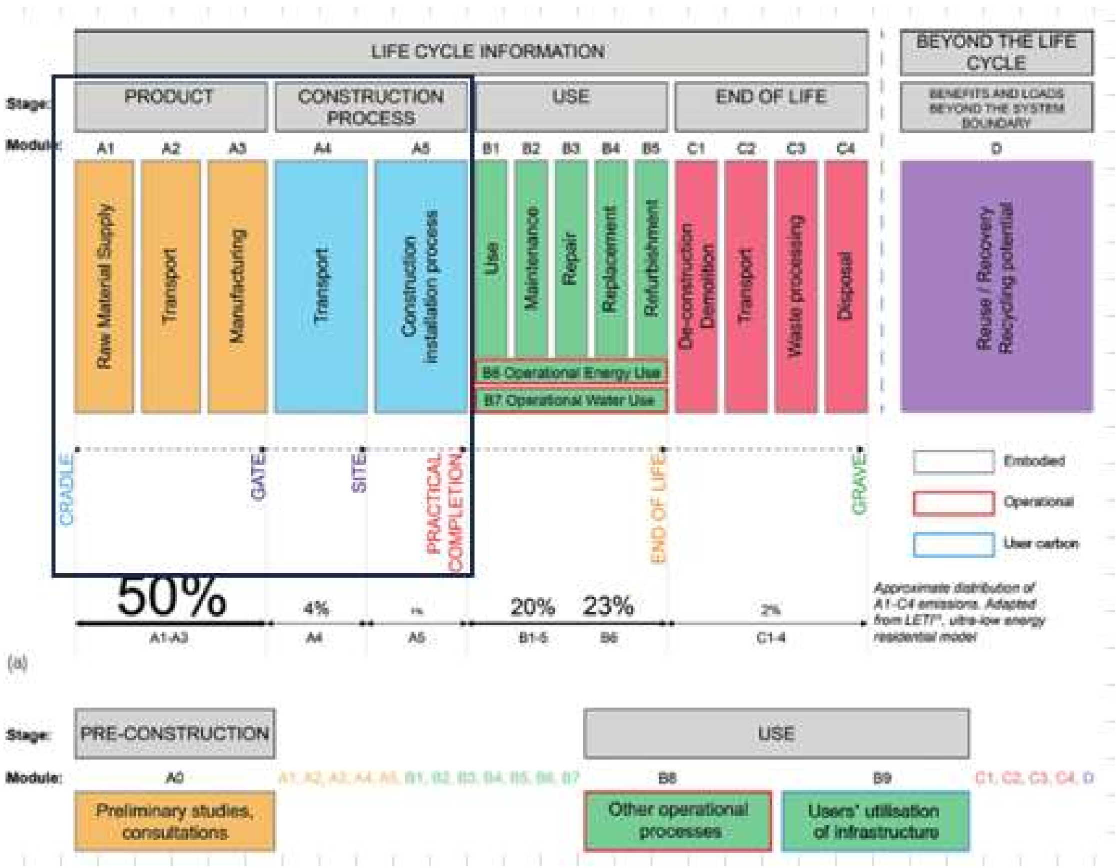


Figure 23: Institute of Structural Engineers sustainability life cycle diagram highlighted for the section we have control over

24.5 Integration with the Design Platform

Crucially, these carbon calculations are not a separate after-sales service but integrated into Charlie's core workflow. Users enter project parameters once (e.g. building footprint, loads, site conditions, material choices). These feed the parametric design logic and also feed directly into the sustainability module. Any change to inputs or assumptions automatically propagates to the carbon outputs. For example, if the engineer specifies a high-strength concrete variant, the system updates the pad dimensions via the structural checks and simultaneously uses the new concrete's ICE factor for carbon. Likewise, optional inputs – such as specifying a recycled vs. virgin aggregate – adjust both the structural design (through modified material properties) and the associated carbon factor. In effect, **every parametric input in the platform inherently carries a carbon attribute**. This ensures that sustainability is embedded at the code level: low-carbon alternatives emerge from the same logic that generates drawings and calculations. The result is a single, cohesive design model with carbon transparency built in, rather than a manual add-on step.

24.6 Sustainability Reporting and Decision Support

Once the designs and carbon metrics are generated, the platform produces a formatted Sustainability Report for each project. This report includes comparative tables, charts and explanatory text. Key sections highlight:

- **Design variants and assumptions:** listing each method's geometry and quantities.

- Carbon outcomes: total CO_2e for each variant, absolute and percentage savings, and normalized metrics (e.g. $kgCO_2e$ per m^2 of structure).
- Financial impact: estimated cost of carbon offset avoided.
- Summary conclusion: statement of carbon reduction (e.g. "Site X saves 2.8 tCO_2e (57%) vs baseline").

For example, a report might show that one scaffold configuration uses 25% less steel and 2 t fewer embodied CO_2e, which translates to "X $kgCO_2e$ saved per m^2 of decking". By quantifying the benefits precisely, the report gives engineers and clients clear justification for selecting the greener design. This level of detail turns sustainability into an actionable decision metric: teams can compare "Design A vs B" side-by-side not just on cost and schedule, but on carbon cost per square metre. Embedding this report in the same user interface means decisions can be made on the spot – rather than awaiting a separate LCA study – dramatically accelerating environmental decision-making. The platform even supports "what-if" scenarios: engineers can tweak a parameter (such as plate thickness or material grade) and instantly regenerate carbon outputs. In practice, clients have found these reports invaluable for bid support, ESG disclosures, and carbon-credit negotiations. Providing precise carbon savings as part of the deliverable aligns with PAS 2080's emphasis on early action and whole-life value.

24.7 Practical Impact on Design and Operations

By automating sustainability analysis, Charlie shifts low-carbon design from a manual, time-consuming effort to an integral part of routine workflow. What once took days of off-line calculation can now be evaluated in minutes. This speed enables faster iteration: engineers can test multiple structural and carbon scenarios before finalizing a scheme. In turn, project teams can make informed trade-offs immediately (e.g. accepting a slightly higher material cost to gain a large carbon saving). The business value is clear: firms that adopt PAS 2080 practices report reduced costs and competitive advantage in carbon-conscious markets. For many clients, Charlie's Sustainability Report became a unique selling point – one major contractor noted it "underwrites both speed of delivery and net-zero readiness." In projects with strict ESG targets, Charlie designs were preferred over manual ones purely on the strength of their quantified carbon savings. In summary, by embedding sustainability at the heart of its algorithms, the platform empowers engineers to make low-carbon choices quickly and confidently. It demonstrates that reducing embodied carbon is not just a compliance exercise but a built-in outcome of better design delivery.

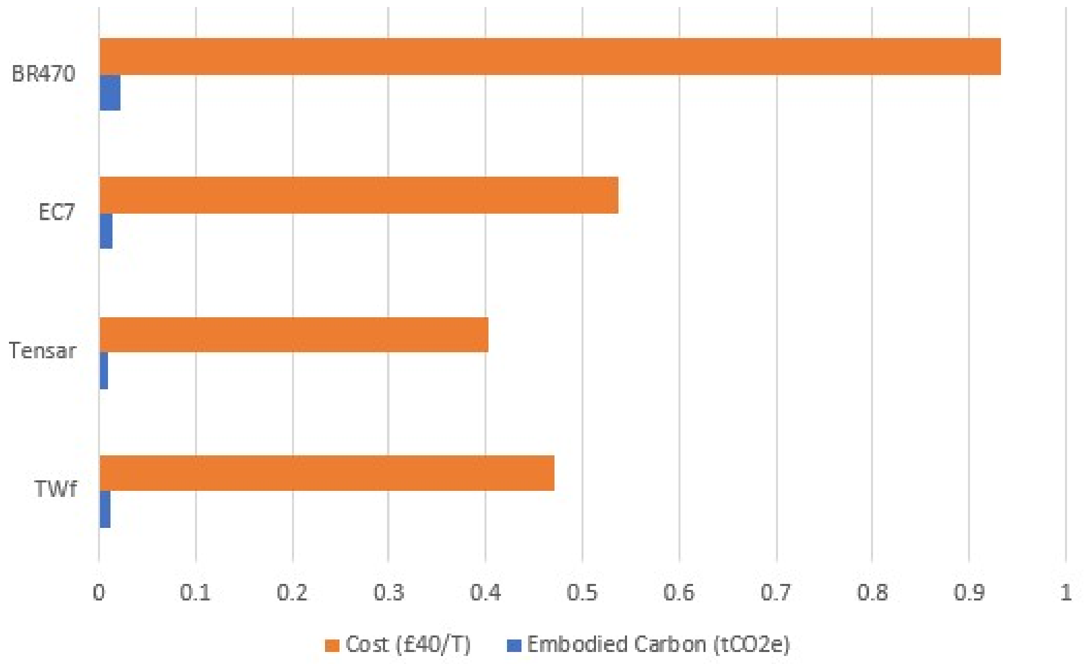


Figure 24: Excert of sustainability generated document showing the differences in saved carbon per m2 between different numerical method results

24.8 Conclusion

The Sustainability Report feature in Charlie exemplifies how practical engineering innovation can align technical rigor with environmental stewardship. By combining robust numerical design methods with transparent lifecycle CO_2e tracking, the platform delivers net-zero-ready logic at speed and scale. Carbon calculations are not a bolt-on analysis but a natural byproduct of the automated design process. This approach meets the letter of modern frameworks – allocating emissions to A1–A5 modules and following PAS 2080 guidance – while also meeting industry demand for efficiency and clarity. In effect, Charlie redefines “sustainability” from an ambiguous goal into a quantifiable design objective. Engineers can now justify every choice not only on strength and cost, but on carbon. As a result, the profession’s contribution to a low-carbon future is built into every calculation, illustrating that practical delivery-focused tools can drive more impact than theory alone. Find in Appendix C an example of the sustainability report generated for working platforms as part of a package from the platform.

Chapter 25: Beyond the Thesis — Reflections, Conclusions, and Future Work

25.1 Introduction.

This thesis represents a nine-year, part-time journey culminating in a disruptive automated design platform ("Charlie") for temporary works engineering. In closing, we reflect on that journey, its outcomes, and the vision ahead. The work has bridged technical research and real-world practice, creating not just a theoretical construct but a live service that reframes civil engineering design. In doing so, the project has generated lessons at the intersection of technology, business model innovation, and engineering culture. This chapter synthesises those insights and looks forward to how the platform and its underlying philosophies can shape future work.

25.2 Summary of Contributions.

The core contributions of this thesis are manifold and practical in nature. They include:

- Automated Design Platform (Charlie). We developed and deployed a fully operational, web-based automation engine that can generate complete temporary-works designs (calculations, drawings, risk assessments, certificates) at scale. The system has processed hundreds of real jobs under legal/commercial conditions, demonstrating that on-demand civil engineering deliverables are viable in practice.

- New Consultancy Model. Rather than billing time, the project pioneered a *productized* engineering service: fixed-cost designs delivered with near-instant turnaround. This challenges the traditional linear "hours in = revenue" model. By standardising and automating expertise, the platform shifts consultancy from custom billable projects to repeatable content-based delivery. In effect, we built a self-sustaining design service that funds itself from operational use rather than grant funding.

- End-to-End Automation. The thesis shows that all aspects of the design package can be automated. Calculations are computed instantly, drawings are generated parametrically, risk and method statements and certification texts are templated and filled automatically. Embedding this end-to-end automation proved that routine, repetitive tasks can be removed entirely, freeing engineers to focus on higher-level judgment. The result is a system that "ensures improved efficiency, quality, and consistency" in its outputs.

- Embedded Sustainability. Sustainability considerations were built in from the start rather than bolted on afterwards. The platform includes rapid optioneering and lifecycle CO_2e reporting, allowing users to compare design methods and material choices in real time. By designing for reuse (e.g. modular, reusable formwork) and tracking embodied carbon, the system aligns with circular-economy principles. Industry experience suggests that designing components for reuse "minimises waste and reduces the carbon footprint", and our work operationalises that insight within the automation. Notably, all these sustainability features incur *no extra client cost* beyond the normal fixed price – demonstrating that environmental responsibility and commercial efficiency can coincide.

- Engineer-Centric Design. Importantly, Charlie was designed to *support* engineers rather than replace them. It leverages human oversight (e.g. initial input choices, final checks) while automating routine detail. This respects professional judgment and distributes expert time to where it's most needed. By lowering manual workload, the platform has made complex designs accessible in contexts where they might otherwise be bypassed.

These innovations are not merely theoretical. Unlike most doctoral research, every contribution here was proven in revenue-generating operation. In short, the thesis extends beyond papers into a live business innovation.

25.3 Rethinking Civil Engineering Practice

A key philosophical insight is that civil engineering rarely needs *more* complex equations – it needs *better ways of working*. Traditional design often bottlenecks on process, coordination, and billing model rather than on lacking analysis capability. Our work reframes these problems through three central ideologies:

- From Time to Value. Engineering services have historically been sold by the hour. Charlie flips this assumption: design content is the product. This shift aligns with broader trends in productized consulting and software engineering. By treating design deliverables as fixed-price products, the model incentivizes efficiency gains (once automated, additional designs cost virtually nothing) rather than revenue through inertia.

- Integrated Digital Workflows. We showed that aligning all stakeholders on a digital platform reduces friction and error. In practice, shared information environments (BIM/CDE) and parametric models "allow seamless collaboration and clearer communication, leading to faster approvals, fewer clashes, and improved compliance". Charlie embodies this by using standardized data inputs and outputs, meaning that engineers, safety teams, and clients all see the same up-to-date model. This breaks the old, siloed workflow and proves that a better process can be more impactful than marginally improved calculations.

- Sustainability as a Baseline. Rather than an optional feature, low-carbon design is a default expectation. Integrating carbon metrics and reuse strategies into the design logic ensures that every solution is environmentally conscious by default. This flips the usual engineering mindset – clients are no longer asked to pay extra for sustainability. Instead, the platform makes the greener choice the effortless one. This reflects the industry narrative that modern temporary works innovation should serve both safety and climate goals.

These ideologies – productized delivery, unified digital processes, and built-in sustainability – collectively challenge the limits of the traditional consultancy model. The success of the platform suggests that many design challenges are solved not by new formulas but by removing manual friction. This aligns with recent findings that AI and automation in engineering boost consistency and let specialists focus on creativity.

25.4 Platform Impact and Performance

The real-world performance of Charlie underscores its promise to eventually exceed human-generated design content in both quality and consistency, at equal or lower cost. To date the system has generated designs in minutes that would take humans days, achieving turnaround reductions from roughly two weeks to under a day in typical cases. In urgent scenarios it delivered *up to 99% time savings*. These efficiency gains translate to cost savings: AI-driven project management, for example, "streamlines processes, leading to cost reductions and faster project completion times". At the same time, automation catches errors and enforces standards. Practitioners note that AI-augmented design "delivers fast-turnaround, highly detailed, quality results while maintaining the best value for money". In effect, the platform produces outputs at least as good as (and often more consistent than) manual work – but at far lower marginal cost per design.

Empirical evidence of the platform's impact is clear. In live deployments it has not only reduced time and labor but also enabled better decision-making (e.g. choosing more material-efficient schemes once designs can be compared instantly). It has generated enough revenue to sustain a dedicated technical team, proving viability. These facts demonstrate operational proof: Charlie is not just a concept, but a service that already outperforms traditional delivery on speed, reliability, and cost. Crucially, by automating routine tasks, the service also reduces human error. As Waddington (2023) observes, standardized AI workflows ensure high consistency across projects – something very difficult for even the best engineering teams to achieve manually. As industry reviews conclude, AI in civil engineering is "transforming the field… improving efficiency, safety, and sustainability". Charlie delivers on all these fronts.

25.5 Future Work and Roadmap

The platform is now poised for its next phase of evolution. Key feature developments under active planning include:

- Automated Bill of Quantities (BoQ): Linking the parametric model directly to quantity take-off will allow instantaneous cost and materials estimates. By extracting volumes and item counts automatically, the system will close the loop between design and procurement.
- Multi-Language Drawing Output: Generating drawings in multiple languages will serve global teams. The same design data can be used to produce, for example, English and Arabic plans simultaneously, improving cross-border collaboration.
- 3D/VR Construction Sequencing: Integrating virtual/augmented reality will let clients and site teams "visualize and implement design" virtually. For instance, an automatic generation of staged 4D animations will help teams walk through assembly sequences and identify clashes before breaking ground, further reducing errors and change orders.
- RAMS (Risk Assessment and Method Statement) Automation: The next release will auto-generate RAMS documentation from the same inputs. Given that RAMS are fundamental to

health and safety policy on site, encoding this into the workflow will eliminate yet another manual deliverable.

- Advanced Structural Integration (FEA and Beyond): Work is underway to embed real-time finite-element and numerical analysis into the engine. This will allow the platform to automatically handle whole new categories of temporary works (e.g. bespoke shoring or non-standard scaffold systems) by performing full 3D stress checks during generation. As Kumar and Devi (2025) note, AI-driven simulation can model complex structures under varied conditions, "improving design accuracy and safety". By coupling our parametric generator with FEA solvers, the system can output designs that would previously have required manual software passes, all fully auditable.

This roadmap is backed by both grant funding (e.g. Innovate UK) and rising commercial demand. The goal is that in the next 1–2 years, Charlie will expand its scope of covered design types and further reduce the need for human editing. Each new feature is chosen to scale the platform's impact without scaling cost. For example, once VR integration is built, every project – from small piling works to large scaffold jobs – can benefit, without added per-project expense. In this way the platform multiplies engineering capability.

25.6 Implications for Research and Innovation

Beyond immediate features, this new model creates fertile ground for further academic and technical contributions. Because the platform handles routine delivery, researchers can integrate sophisticated methods and share them widely at zero marginal cost. For instance, university groups can plug in advanced optimization algorithms or machine-learning design aids into the engine; when proven, these enhancements instantly benefit all users without renegotiating fees.

This effectively decouples innovation from project budgets. Complex analyses – deep parametric studies, stochastic modelling, novel materials design – can be prototyped and field-tested through Charlie. The operating costs (e.g. cloud compute time) are shared across the platform, so a professor's new algorithm can be run across dozens of real projects for evaluation. This is akin to how *digital twins* and *AI-augmented design* are expected to accelerate infrastructure development: by providing "unprecedented insights into lifecycle performance" and enabling rapid design iteration.

In practice, the platform already serves as an educational and research ecosystem. Its audit logs and databases of past designs are rich data sources. Students and engineers can study how small parameter changes affect safety and cost at scale, something previously infeasible. More broadly, the success of Charlie suggests that civil engineering can adopt an "open innovation" stance: core design knowledge is codified once, and everyone moves forward together. Ultimately, by lowering the cost of complexity, this model allows the profession to implement deeper, more innovative engineering methods in every project. As predicted in contemporary studies, AI will continue to unlock "optimized, innovative, and cost-effective designs" that humans alone might not conceive, and our platform provides the mechanism to deliver them.

25.7 Conclusion

In summary, this thesis and its eight-year journey have demonstrated that practical innovation can profoundly reshape civil engineering delivery. By challenging traditional billing models and tightly integrating automation, quality, and sustainability, the Charlie platform has shown a new way forward. The result is a service that already outperforms manual design on speed, consistency, and cost, while embedding environmental stewardship and safety at its core. Looking ahead, the platform stands ready to evolve it will add new capabilities (quantity take-off, VR, advanced analysis, etc.) that further amplify these advantages. Beyond technical development, the true value of this work is the shift in mindset it embodies. Civil engineering can now treat design as a scalable service, not a bespoke ordeal – enabling every project to benefit from the latest research and the highest standards at no extra price to the client.

In closing, this chapter has not just reviewed accomplishments but sketched a vision: a future where engineers harness AI and digital tools to deliver better, greener infrastructure without extra cost. As the engineer-turned-entrepreneur behind Charlie, the author will continue pushing these ideas in both academia and industry. The hope is that this platform-based model will serve as an incubator for future advances, ensuring that more complex and creative engineering solutions become the norm rather than the exception.

Bibliography (selected). Anderson, M. (2025) *Temporary Works Go Digital: Enhancing Safety and Sustainability*. The Civil Engineer, 14 May 2025. Autodesk University (2017) *Virtual Reality for Planning, Design, and Construction*. Autodesk University Proceedings. Kumar, S. and Devi, V. (2025) 'Application of AI in Civil Engineering: A Comprehensive Review', *IOSR Journal of Mechanical and Civil Engineering*, 22(1), pp. 69–74. Waddington, A. (2023) *How Integrating AI is Transforming the Engineering Design Process*. Shepherd Gilmour (online blog), 21 January 2023.

Chapter 26: Overtime

26.1 Introduction

With the PhD concluding, I needed to extend my work to cover additional technical aspects. To do this, I embarked on a new project that asked a fundamental question: what if we abandoned the rigid formatting of traditional design processes and the well-trodden path of procurement? The aim was to create a new kind of tool—one that embodied the philosophies discussed throughout this thesis—focusing on speed and agility to deliver meaningful time gains without sacrificing material efficiency. I continued to reject the notion that the primary goal of advancing academic research in civil engineering should be a repetitive pursuit of marginal efficiency gains through increasingly complex mathematical proofs, only to have them nullified by conservative risk management. This, I believe, is where modern temporary works design currently stands—led numerically by insurance rather than by engineering.

For this new tool, we first considered abandoning traditional approval routes. The processes discussed earlier in the thesis sought to coexist symbiotically with existing methodologies and procedures; this concept, by contrast, challenges them directly. We intend to utilise finite-element methods (FEM) for calculations rather than reporting every step manually. However, the tool will still comply with existing standards through simple linear-static and simplified models, ensuring that the majority of design tasks—of almost any geometric form—can be processed without increasing risk. A key step in making this viable is to rapidly model the design both graphically (to communicate clearly with the end user through drawings) and nodally (for numerical analysis). Finally, the design process must remain understandable and familiar enough that it is not dismissed as alien by the wider consultancy community.

26.2 Establish Domain

Figure 25: Charlieverse avatar shown within our metaverse office/experiment space controlled via the mocap suit and VR headset

Firstly, I created a new metaverse-inspired environment to work within, encompassing a completely digital workflow and operating natively inside a 3D environment. We developed a large open industrial space with a small office area inside Unreal Engine, along with a character (shown above) to act as a human avatar for exploring the environment. Unreal Engine was chosen because it has extensive global support and accommodates a wide range of coding languages and workflows, making it a highly versatile and agile platform to work with.

Figure 26: Charlieverse video screen shot showing the space

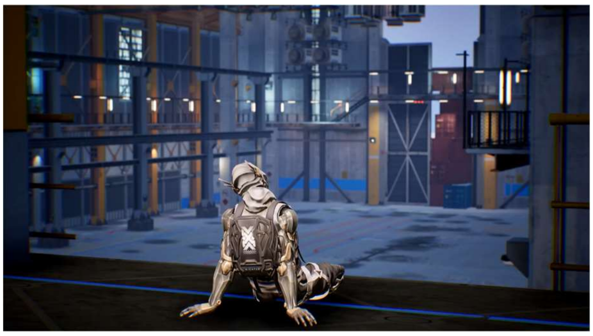


Figure 27: Second Charlieverse video screen shot demonstrating the space

To achieve this, we paired the environment with a Meta Quest 3 VR headset, connected directly to a computer, enabling real-time viewing and interaction within the space. We also integrated a Rokoko full-body motion capture suit to track complete body movements. This setup presented several immediate advantages: we were able to create realistic animations of ourselves within the environment, which proved highly engaging, and we could also invite others to join the space in real time.

While VR and working natively in 3D represent an exciting frontier, the ability to bring people into the space alongside me is a key feature. Viewers can instantly understand—and even enjoy—the experience when viewing the environment on a 2D screen, while the avatar is being piloted by an engineer familiar with the tool. This ensures that, as we advance rapidly, we remain inclusive and accessible to others.

26.3 Choice of first design

The native 3D nature of the new environment enables us to move beyond restricted, individual designs that only parametrically alter section sizes and arrays of objects, allowing us to explore more ambitious concepts. Through this, we identified between fifteen and twenty common categories of temporary works regularly used in everyday construction. While many exotic variants exist, most activities can be based on these core categories. As learned from previous automation projects, we focus on features that enable the rapid development of the most common schemes rather than attempting to encompass everything. For this chapter, we needed to choose a design type that is well established, widely used, and often required at short notice to achieve the greatest practical impact. Instead of focusing on a single design, we targeted one of the most common categories of temporary works design, taking advantage of the flexible 3D environment to quickly model any geometry and verify it.

After reviewing timesheet data, design standards, and assessing our goals, scaffolding was selected. Tube-and-fitting scaffolding is extremely versatile and widely used in the UK. Its configuration is uniform in placement but can be rapidly adapted to suit almost any situation.

To begin, three key objects were created for this proof of concept. The first was an element representing standards (vertical scaffold poles, not to be confused with the term for a general specification or requirement).

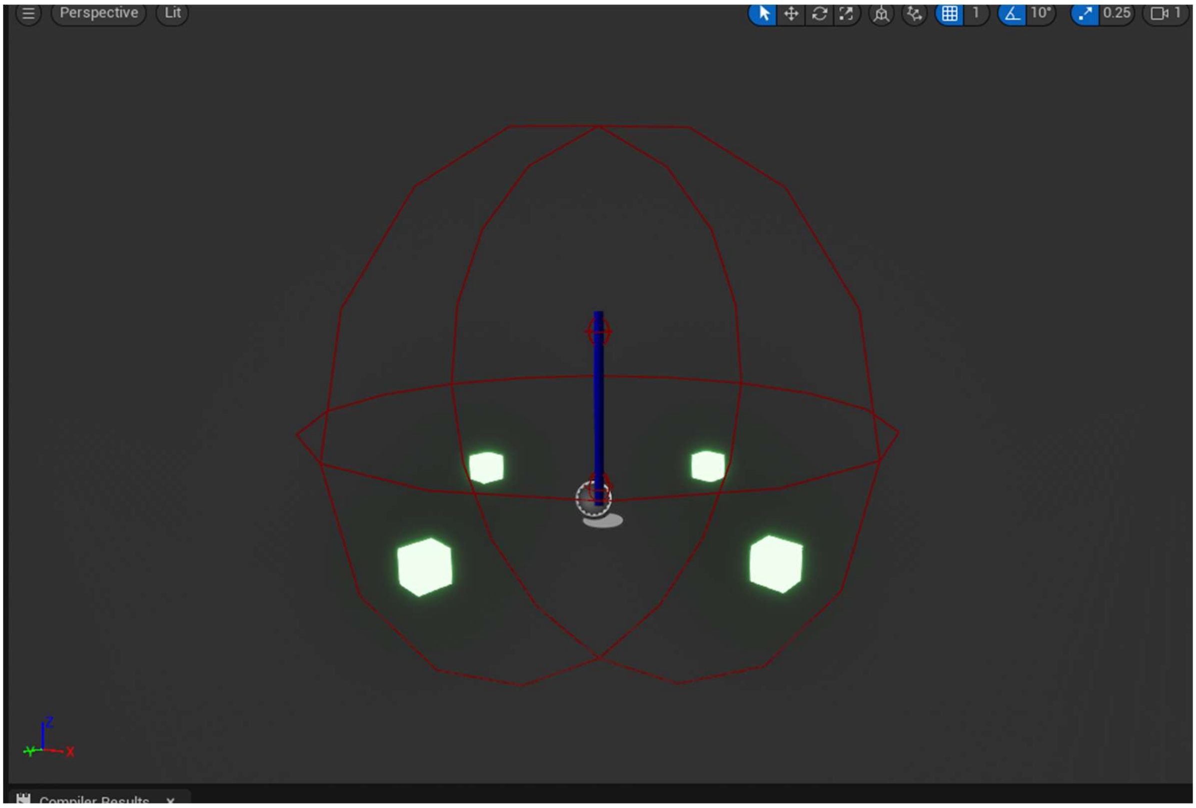


Figure 28: Unreal engine, creating spawnable "scaffold" components which nodal points for element stiffness matrix

After placement within the environment, each standard had four cubes positioned around it in alignment with the global X and Y axes. These were set at a default distance of 1.8 m (a typical bay size) but were adjustable to allow rapid spacing changes. When the user interacted with one of these cubes, a new standard would automatically snap into position at that cube's location, and the cube would then be removed—enabling the quick creation of bays in line with one another.

Each standard also had two key node points: one at the base and one at the top. These acted as snap points for braces and ledgers, forming the core structural components of the scaffold. When selecting two vertical node points (one from each of two standards), the correct length of pole would automatically spawn between them.

Another feature implemented was that when two standards were placed close together—within the larger sphere shown above—the system would spawn two cones perpendicular to the plane between them. These served as directional indicators, allowing rapid replication of a bay when selected in the direction of the cone’s point. This enabled the fast placement of multiple bays in sequence.

While we could explore further object types such as pulleys, access hatches, ladders, or sheeting, for this proof-of-concept we focused only on these key structural components that form the scaffolding frame. Loadings could also be applied later to simulate their behaviour if desired.

The visual representation of the standards could be refined in future iterations. For now, simplified shapes are shown spanning between nodal points, providing a clear visual aid to the scaffold’s geometry while simplifying the finite element method (FEM) inputs. In future versions, offsets, clash detection, and greater visual detail could be added to ensure that the resulting drawings are fully buildable and practical. For this stage, we maintained a balance between the numerical and modelling worlds to keep the system lightweight and efficient.

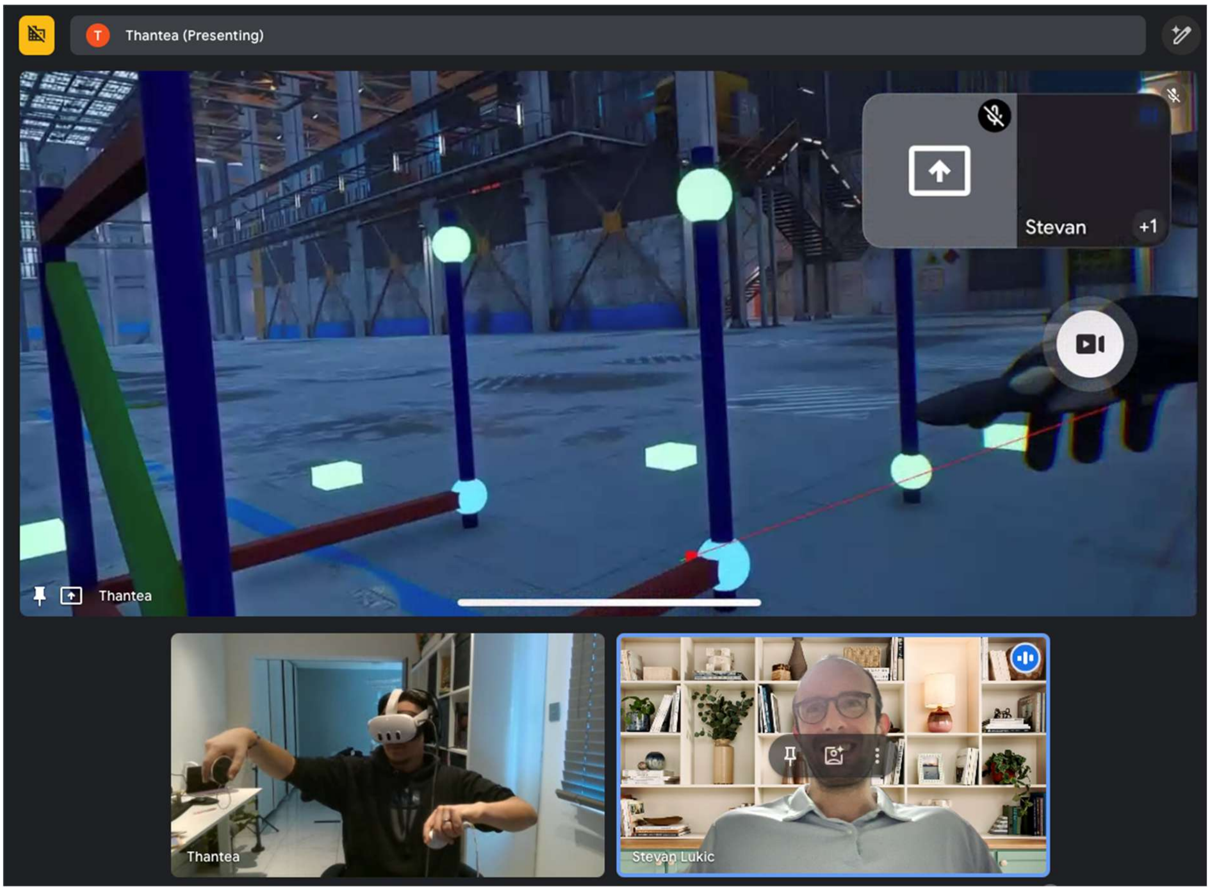


Figure 29: Meeting to preview the prototype to other digital leadership within Civils

In the image above, I am demonstrating the tool to Stevan Lukic of Civils.ai, showing how custom schemes can be placed rapidly. Object placement was conducted via the VR interface: the user could move freely within the environment and, by using a line trace from the controllers, select precise locations to place each object. The placement process was highly intuitive, and by connecting the headset's camera feed to a video conferencing tool, I was able to bring guests into the environment and discuss design placements live.

The combination of swift placement and immediate feedback made it almost possible to design in real time in response to requirements. Rather than relying on the traditional brief–design–review process, the workflow became far more fluid. A more developed version of this concept could enable a rapid prototyping and validation stage, followed by additional manual refinement outside of meetings. The 3D environment also opens new possibilities, such as importing 3D LiDAR scans of real-world structures or replacing the Richter industrial environment with a client's BIM model—allowing engineers to work directly within the client's digital space.

26.4 Numerical verification

The visualisation aspect of the tool is very promising, and it is clear that it could be developed further over time. However, the real task at hand is to numerically verify that the design is structurally sound. The tool allows us to rapidly assemble large schemes with only a few clicks, but without the mathematics it would remain just another modelling platform. It does, however, address what I see as the biggest issue with the adoption of finite element methods (FEM) in everyday practice.

It is clear to me that finite element analysis is a superior method for analysing complete structures. Yet, while numerical options continue to advance in complexity and computational capability, industry often continues to favour hand calculations for their speed and agility. A simplified linear-static 3D space-frame analysis is sufficient to outperform these hand calculations in both accuracy and confidence—especially with modern computing power—but it is rarely used because of the time required to assemble the model.

Our experimental tool aims to bridge this gap by automatically generating models with pre-defined joints and fixtures, allowing FEM analysis to compete with, and even exceed, the agility of hand calculations. This hybridised approach to digitally-enhanced engineering opens many opportunities—not only for the tool itself but also for bridging the gap between the highly technical academic sphere and the more pragmatic industrial environment.

To bring this project into that space, we utilised PyNite, a commonly used Python library for FEM analysis, and began integrating it within the digital environment. During element placement, data are stored by appending entries to a JSON file. Each element is recorded with its ID, type (standard, brace, or ledger), and start- and end-node 3D coordinates. When calculation mode is toggled, a script processes this data and merges spatially coincident coordinates into common node points. We are then able to convert this dataset into familiar member objects with defined end nodes and cross-sectional properties. Although all members currently share identical properties, future iterations could introduce additional object types, such as truss members.

For simplicity, we have initially defined the fixings in a simplified manner. The rotational degree of freedom is released along the member's longitudinal axis, simulating the pin-type connection of B-type couplers commonly used in scaffolding. Nodes located at floor level are fixed, and their reactions can later be used automatically for sliding-check calculations. Other common fixing points, such as ties to adjacent structures, could easily be implemented in future versions. While foundations are currently modelled as fixed, their reactions could also feed into simplified ground-bearing checks already developed elsewhere in this thesis. It is important to keep the analysis simplified and avoid modelling every interaction in FEM; however, it is equally important to confirm that the structure is capable of performing its intended function.

Loading conditions in line with TG20:21 are generally grouped into three main types and their combinations. Self-weight (dead load) is straightforward to implement—PyNite can calculate this automatically, making it trivial to include.

Platform live loads are another consideration. Scaffolding typically acts as an access structure, with different load classes applied to boards supported by transoms that transfer loads back to the ledgers. For our simplified proof-of-concept version, we apply a uniform line load along the ledgers, derived from the current bay spacing variable.

In addition, TG20:21 recommends a 2.5% lateral load to account for imperfections in scaffolding components, recognising that slightly bent poles or irregularities can affect overall performance. This is incorporated as a secondary horizontal load.

Wind loading is also an important factor. In this initial version, we have implemented only the working wind pressure, representing both working and peak wind load scenarios. In future, automatic wind-load generation could be added with more advanced features; for now, an additional line load is applied along all vertical members to represent wind effects.

Other loads, such as those from handrails or loading bays, could also be included later to increase flexibility, but for now this generic case performs well. Load combinations are suggested in the standards—for example, working wind with personnel loading, and peak wind with no personnel loading—to simulate the practice of suspending access during high winds. In our experimental build, we use a single load case combining live loads with working-wind loading.

PyNite then performs element stiffness assembly, applies boundary conditions, and solves for displacements, member forces, and reactions. While we do not go into detail here, it is worth noting that nonlinear analysis could be introduced in the future to model second-order effects such as P-Delta, which track self-reinforcing collapse behaviour. For now, aligning with industrial standards through linear static analysis is sufficient.

Post-processing: Once PyNite completes its run, results are extracted and displayed within the 3D environment. A range of lookup values exists for safe bending moments, shear capacities, axial compression, and deflection limits. We translated several of these into utilisation ratios and colour-coded them directly onto the 3D scaffold elements in the VR space, allowing for a quick visual assessment of the structure's overall performance.

In future, it will be useful to add tooltips for reading individual results directly within the environment. Pressed for time, this feature was only partially implemented but still proved valuable. If the tool were also able to generate technical reports or automatically compile parts of the documentation—drawing on earlier work in this thesis—it would form a robust platform capable of disrupting the status quo of engineering design, eliminating the need to repeat the same manual patterns again and again.

26.5 Conclusion

Although the process was slightly rushed, we were able to demonstrate a full workflow encompassing rapid modelling, exporting, analysis, importing, and visualising of results. The actual analysis time of the model was almost instantaneous, which made iterative design refinement both fast and intuitive. The synergy between a simplified FEM workflow and the speed and interactivity of working directly within a digital 3D environment makes this concept extremely powerful. While this project must conclude here, it could easily be developed further across the board if work were to continue — but we have successfully demonstrated its plausibility.

Ultimately, by incorporating the additional features discussed throughout this chapter, the tool should be capable of handling a large proportion of the scaffold design requests we receive daily, across a wide range of situations. By following the already established business model of reducing engineering time while maintaining product value, this new form of FEM-based tool could readily become the preferred option for most tasks, rather than being reserved for exceptional circumstances.

With the emergence of technologies such as AI-assisted coding, this type of project is becoming increasingly achievable for small teams operating on limited budgets, without the need for significant external investment. This spirit of exploratory work is something I intend to continue post-doctorate, funding future developments through the profits of the company we have established. The goal is to bring the future of civil engineering closer to reality, focusing on innovations that deliver the greatest impact in creating tangible, physical assets for the benefit of society.

Appendix A: Output Example Calculations

Customer: Test
Job: Test 1
Description: Piling Platform

By: AM
Checked: NC

Reference	Calculations	Output

Summary of input information (based on GI and Test1 loading)

Piling Rig Data: Operation: Piling Platform

Width of tracks, $B = 0.60m$

Length of tracks load case 1, $L_1 = 2.10m$ Ground bearing pressure load case 1, $q_1 = 250kN/m^2$

Length of tracks load case 2, $L_2 = 2.10m$ Ground bearing pressure load case 1, $q_2 = 250kN/m^2$

Ground Data (based on '0')

Layer 1 - Granular soil parameters, $\varphi_k = 30°$ $\gamma = 16kN/m^3$ $E = 30MPa$

Thickness of layer 1, $H = 1.00m$

Layer 2 - Cohesive soil parameters, $C_u = 20kN/m^2$ $\gamma = 17kN/m^3$ $E = 12MPa$

Depth to groundwater, $z_\gamma = 5.00mbgl$

Platform material:

Stone platform parameters, $\varphi_{pk} = 45°$ $\gamma_{pk} = 20kN/m^3$ $E = 75MPa$

Minimum thickness for load case 1 and 2 for cohesive soil parameters, D = 0.55m

Sub-grade layer 1 Granular

Loadcase	L_x @ platform formation	UDL	Utilisation
1	2.10 m	250 kN/m²	99.0%
2	2.10 m	250 kN/m²	90.0%

Sub-grade layer 2 Cohesive

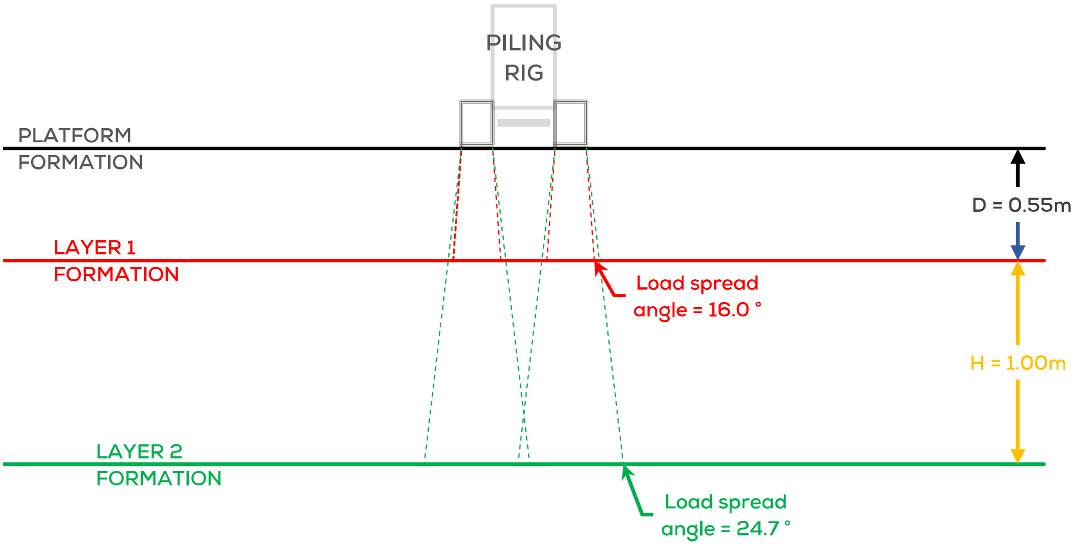
Loadcase	L_x @ layer 1 formation	UDL @ layer 1 formation	Utilisation
1	2.41 m	154 kN/m²	61.5%
2	2.37 m	163 kN/m²	53.3%

Absolute settlement utilisation, = 11.0%
Differential settlement utilisation, = 59.0%
} OK

Additional comments:

- φ denotes angle of internal friction of a granular (cohesionless) subgrade.
- Cu denotes the undrained shear strength of a cohesive subgrade.
- γ denotes the bulk unit weight of the subgrade.
- E denotes undrained elastic modulus of the subgrade.

Ground Model:



Reference	Calculations	Output

Calculations for subgrade layer 1 - Load case 1 in accordance with TWf2019:02

ULS check for load case 1 & granular over cohesive parameters

1. Variable Actions:

Applied load breadth, B — B = 0.60 m

Applied load length, L — L = 2.10 m

Applied load area, A

$A = B \times L =$ 0.60 x 2.10 — A = 1.26 m²

Characteristic applied ground bearing pressure, q_k — q_k = 250 kN/m²

Partial factor on variable actions, γ_Q — γ_Q = 1.30

Design applied ground bearing pressure, q_d

$q_d = q_k \times \gamma_Q =$ 250 x 1.30 — q_d = 325.0 kN/m²

Design applied load, Q_d

$Q_d = q_d \times A =$ 325.0 x 1.26 — Q_d = 410 kN

2. Sub-grade layer 1 parameters:

Sub-grade material characteristic angle of internal friction, φ_{sk} — φ_{sk} = 30 °

Partial factor on sub-grade strength, γ_φ — γ_φ = 1.25

Sub-grade material design angle of internal friction, φ_{sd}

$\varphi_{sd} = \tan^{-1}((\tan \varphi_{sk}) / \gamma_\varphi) =$ tan-1 x ((tan(30) / 1.25) — φ_{sd} = 24.79 °

Sub-grade material density, γ_s — γ_s = 16 kN/m³

Depth of groundwater below formation, z_γ — z_γ = 5.00 m

3. Sub-grade bearing resistance without platform:

Bearing capacity factor for gravity term, $N_{\gamma d}$

$N_{\gamma d} = 0.1054 \times e^{0.168\varphi sd} =$ 0.1054 x e^(0.168 x 24.79) — $N_{\gamma d}$ = 6.79

Design shape factor for gravity term, $s_{\gamma d}$

$s_{\gamma d} = 1 - (0.4 \times B/L) =$ 1 - (0.4 x 0.60/2.10) — $s_{\gamma d}$ = 0.89

Design bearing resistance, V_{Rd}

$V_{Rd} = 0.5 \times \gamma_s \times B \times N_{\gamma d} \times s_{\gamma d} \times A =$ 0.5 x 16 x 0.60 x 6.79 x 0.89 x 1.26 — V_{Rd} = 36 kN

Utilisation:

$1.0 < Q_d / V_{Rd} =$ 410 / 36 — Utilisation = 1126%

FAIL, requires a working platform — FAIL

Customer: Test
Job: Test 1
Description: Piling Platform
By: AM
Checked: NC

Reference	Calculations	Output

4. Platform parameters:

Platform material characteristic angle of internal friction, φ_{pk} — φ_{pk} = 45 °

Partial factor on platform material strength, γ_{φ} — γ_{φ} = 1.25

Platform material design angle of internal friction, φ_{pd}

$\varphi_{sd} = \tan^{-1}((\tan \varphi_{pk}) / \gamma_{\varphi}) =$ tan-1 x ((tan(45) / 1.25) — φ_{pd} = 38.66 °

Platform material density, γ_p — γ_p = 20 kN/m³

5.1 Effective area, dimensions and load spread angle:

Platform thickness, D — D = 0.55 m

Find ratio of applied pressure to effective pressure at formation using figure 26.

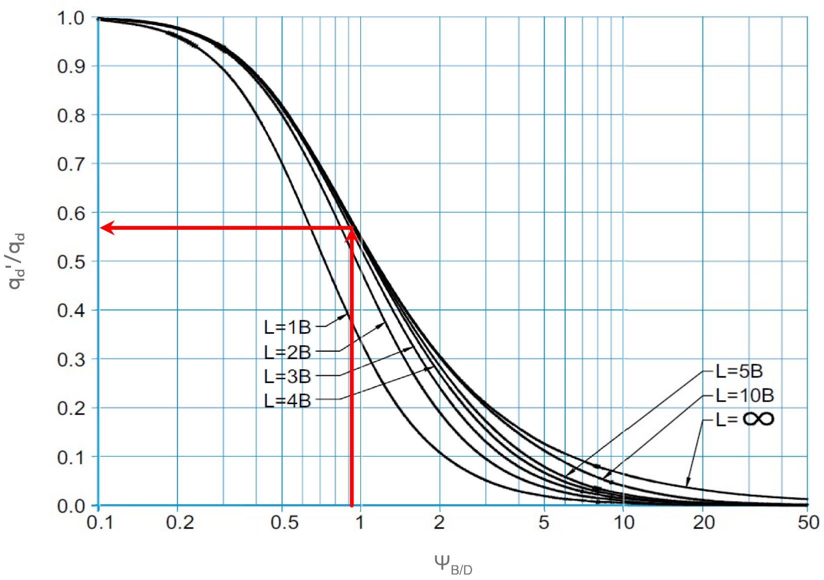
Ratio of applied load breadth to platform depth, $\Psi_{B/D}$

$\Psi_{B/D} = D / B =$ 0.55 / 0.60 — $\Psi_{B/D}$ = 0.92

Ratio of applied load length to breadth, $\Psi_{L/B}$

$\Psi_{L/B} = L / B =$ 2.10 / 0.60 — $\Psi_{L/B}$ = 3.50

Fig. 25



$\Psi_{B/D}$ = 0.92

L = 3.5 B

Ratio of applied pressure to effective pressure, ρ_q — ρ_q = 0.57

Design effective pressure, q_d'

$q_d' = \rho_d \times q_d =$ 0.57 x 325 — q_d' = 185 kN/m²

Design effective area, A'

$A' = Q_d / q_d' =$ 410 / 185 — A' = 2.21 m²

Customer: Test
Job: Test 1
Description: Piling Platform
By: AM
Checked: NC

Reference	Calculations	Output

Determine load spread width and angle solving with quadratic equation.

Quadratic factors

a = B — a = 1.00

b = L + B = 2.10 + 0.60 — b = 2.70

c = A - A' = 1.26 - 2.21 — c = -0.95

Quadratic solution, x

$x = -b + \sqrt{(b^2 - 4ac)} / 2a$ = (-2.70 + √(2.70² - 4 x 1.00 x -0.95)) / 2 x 1.00 — x = 0.31 m

Load spread width, b'

b' = x / 2 = 0.31 / 2 — b' = 0.16 m

Load spread angle, β

$\beta = \tan^{-1}(b' / D)$ = tan-1 x (0.16 / 0.55) — β = 15.95 °

Maximum load spread width for β = 26.6° (2V:1H)

b'_{max} = D / 2 = 0.55 / 2 — b'_{max} = 0.28 m

b' < b'max therefore use b'

Effective breadth, B'

B' = B + 2 x b' = 0.60 + 2 x 0.16 — B' = 0.91 m

Effective length, L'

L' = L + 2 x b' = 2.10 + 2 x 0.16 — L' = 2.41 m

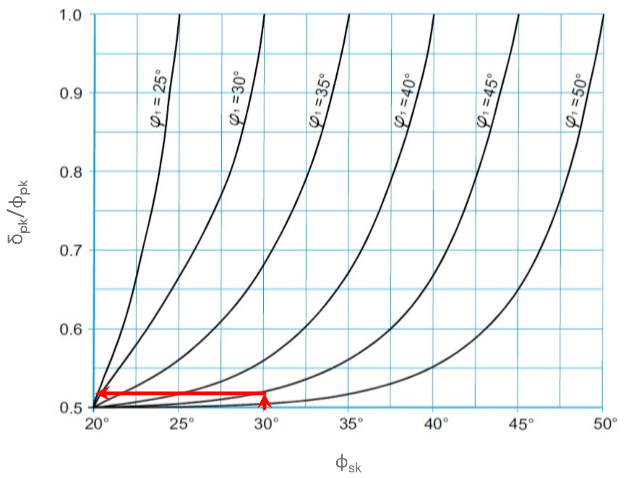
5.2 Effective angle of punching shear:

Determine punching shear angle using figure 27.

Platform material characteristic angle of internal friction, ϕ_{pk} — φ_{pk} = 45 °

Sub-grade material characteristic angle of internal friction, ϕ_{sk} — φ_{sk} = 30 °

Fig. 27



ϕ_{sk} = 30 °

ϕ' = 45 °

Reference	Calculations	Output

Nominal punching shear parameter, ρ_δ — ρ_δ = 0.52

Design punching shear angle, δ_{pd}

$\delta_{pd} = \rho_\delta \times \varphi_{pd} =$ 0.52 x 38.66 — δ_{pd} = 20.10 °

5.3 Lateral Loads in Platform

Coefficient of active lateral earth pressure for platform, K_{apd}

$K_{apd} = \{ \sin(90-\phi_{pd}) / [\sqrt{\sin(90+\delta_{pd})} + \sqrt{(\sin(\varphi_{pd}+\delta_{pd}) \times \sin(\varphi_{pd}))}] \}^2$

$= \{\sin(90-38.66)/[\sqrt{\sin(90+20.10)}+\sqrt{(\sin(38.66+20.10) \times \sin(38.66))}]\}^2$

K_{apd} = 0.21

Coefficient of passive lateral earth pressure for platform, K_{ppd}

$K_{ppd} = \{ \sin(90+\phi_{pd}) / [\sqrt{\sin(90-\delta_{pd})} - \sqrt{(\sin(\varphi_{pd}+\delta_{pd}) \times \sin(\varphi_{pd}))}] \}^2$

$= \{\sin(90+38.66)/[\sqrt{\sin(90-20.10)}-\sqrt{(\sin(38.66+20.10) \times \sin(38.66))}]\}^2$

K_{ppd} = 10.74

Find ratio of applied pressure to effective pressure at mid-depth of platform (figure 25)

Mid-point depth of platform, D_{mid}

$D_{mid} = D / 2 =$ 0.55 / 2 — D_{mid} = 0.28 m

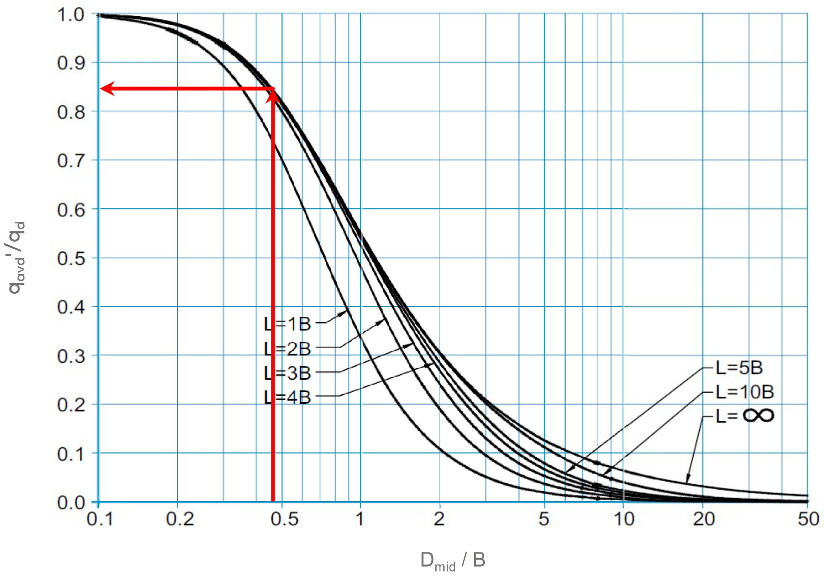
Mid-point depth to breadth ratio, D_{mid} / B

$D_{mid} / B =$ 0.28 / 0.60 — D_{mid} / B = 0.46

Ratio of applied load length to breadth, L / B

L / B = 2.10 / 0.60 — L / B = 3.50

Fig. 25



$D_{mid} / B =$ 0.46

L = 3.5 B

Ratio of applied pressure to effective pressure, ρ_q — ρ_q = 0.84

Reference	Calculations	Output

Average vertical pressure due to load, q_{avd}'

$q_{avd}' = \rho_q \times q_d =$ 0.84 x 325 — q_{avd}' = 274.1 kN/m²

Active lateral load in fill (per linear m), P_{apd}

$P_{apd} = K_{apd} \times (q_{avd}' + \gamma_p \times D / 2) \times D =$ 0.21 x (274 + 20 x 0.55 / 2) x 0.55 — P_{apd} = 32.44439192

Passive lateral load in fill (per linear m), P_{ppd}

$P_{ppd} = K_{ppd} \times \gamma_p \times D^2 / 2 =$ 10.74 x 20 x 0.55² / 2 — P_{ppd} = 32.49145045

5.4 Horizontal and Vertical Loads on Sub-grade

Horizontal load on sub-grade (per linear m), F_{Hs}

$F_{Hs} = P_{apd} - P_{ppd} =$ 32.4 - 32.5 — F_{Hs} = 0.0 kN/m

Vertical load on sub-grade (per linear m), F_{Vs}

$F_{Vs} = (q_d \times B + \gamma_p \times D \times B') / 2 =$ (325 x 0.60 + 20 x 0.55 x 0.91) / 2 — F_{Vs} = 102.5 kN/m

5.5 Total Vertical Load Effect on Sub-grade

Characteristic permanent action due to platform self weight, G_{pk}

$G_{pk} = \gamma_{pk} \times D \times B' \times L' =$ 20 x 0.55 x 0.91 x 2.41 — G_{pk} = 24 kN

Partial factor for permanent actions, γ_G — γ_G = 1.00

Design permanent action due to platform self weight, G_{pd}

$G_{pd} = \gamma_G \times G_{pk} =$ 1.00 x 24 — G_{pd} = 24 kN

Total design vertical action, V_{Ed}

$V_{Ed} = G_{pd} \times Q_d =$ 24 + 410 — V_{Ed} = 434 kN

5.6 Sub-grade Bearing Resistance with Platform

Bearing capacity factor for gravity term, $N_{\gamma d}$

$N_{\gamma d} = 0.1054 \times e^{0.168\varphi sd} =$ 0.1054 x e^(0.168 x 24.79) — $N_{\gamma d}$ = 6.79

Bearing capacity factor for overburden term, N_{qd}

$N_{qd} = e^{\pi \tan(\varphi sd)} \times \tan[45 + (\varphi_{sd} / 2)]^2 =$ e^πtan(24.79) x tan[45 + (24.79 / 2)]² — N_{qd} = 10.43

Shape factor for gravity term, $s_{\gamma d}$

$s_{\gamma d} = 1 - (0.4 \times B' / L') =$ 1 - (0.4 x 0.91 / 2.41) — $s_{\gamma d}$ = 0.85

Shape factor for overburden term, s_{qd}

$s_{qd} = 1 + (\tan(\phi_{sd}) \times B' / L') =$ 1 + (tan(24.79) x 0.91 / 2.41) — s_{qd} = 1.17

Inclination factor exponent, m

$m = (2 + (B' / L')) / (1 + (B' / L')) =$ (2 + (0.91 / 2.41)) / (1 + (0.91 / 2.41)) — m = 1.73

Customer: Test
Job: Test 1
Description: Piling Platform

By: AM
Checked: NC

Reference	Calculations	Output

Inclination factor for gravity term, $i_{\gamma d}$

$i_{\gamma d}$ = min { 1.0 ; [(1 - F_{Hs} / F_{Vs}))$^{m+1}$ = min { 1.0 ; [(1 - 0.00 / 102.53)^1.73 + 1] } — $i_{\gamma d}$ = 1.00

Inclination factor for overburden term, i_{qd}

i_{qd} = min { 1.0 ; [(1 - F_{Hs} / F_{Vs}))^{m} = min { 1.0 ; [(1 - 0.00 / 102.53)^1.73] } — i_{qd} = 1.00

Depth factor for gravity term, $d_{\gamma d}$ — $d_{\gamma d}$ = 1.00

Depth factor for overburden term, d_{qd}

d_{qd} = 1 + (2 x tan(ϕ_{sd}) x (1 - sin(ϕ_{sd})² x tan-1(D / B')

= 1 + ((2 x tan(24.79) x (1 - sin(24.79)² x tan-1(0.55/0.91)) — d_{qd} = 1.16

Groundwater factor for gravity term, $w_{\gamma d}$

$w_{\gamma d}$ = min { 1.0 ; max {0.5 ; [0.5 x (1 + z_γ / B')) } }

= min { 1.0 ; max {0.5 ; [0.5 x (1 + 5.00 / 0.91)) } } — $w_{\gamma d}$ = 1.00

Depth of groundwater below top of platform, z_q

z_q = z_q + D = 5.00 + 0.55 — z_q = 5.55 m

Groundwater factor for surcharge term, w_{qd}

w_{qd} = min { 1.0 ; max {0.5 ; [0.5 x (1 + z_q / D)) } }

= min { 1.0 ; max {0.5 ; [0.5 x (1 + 5.55 / 0.55)) } } — w_{qd} = 1.00

Bearing resistance, V_{Rd}

V_{Rd} = (0.5 x γ_s x B' x $N_{\gamma d}$ x $s_{\gamma d}$ x $i_{\gamma d}$ x $d_{\gamma d}$ x $w_{\gamma d}$ + γ_p x D x N_{qd} x s_{qd} x i_{qd} x d_{qd} x w_{qd}) B' x L'

= (0.5 x 16 x 0.91 x 6.79 x 0.85 x 1.00 x 1.00 x 1.00 + 20 x 0.55 x 10.43 x 1.17 x 1.00 x 1.16 x 1.00) x 0.91 x 2.41

V_{Rd} = 438.0063487

Utilisation:

1.0 < V_{Ed} / V_{Rd} = 434 / 438 — Utilisation = 99.0%

PASS, platform thickness/strength acceptable — OK

Reference	Calculations	Output

Calculations for subgrade layer 2 - Load case 1

ULS check for load case 1 & granular over cohesive parameters

6. Variable Actions:

Applied load breadth, B — B = 0.60 m

Applied load length, L — L = 2.10 m

Applied load area, A

$A = B \times L =$ 0.60 x 2.10 — A = 1.26 m²

Characteristic applied ground bearing pressure, q_k — q_k = 250 kN/m²

Partial factor on variable actions, γ_Q — γ_Q = 1.30

Design applied ground bearing pressure, q_d

$q_d = q_k \times \gamma_Q =$ 250 x 1.30 — q_d = 325.0 kN/m²

Design applied load, Q_d

$Q_d = q_d \times A =$ 325.0 x 1.26 — Q_d = 410 kN

7. Sub-grade layer 1 parameters:

Sub-grade layer 1 thickness, H — H = 1.00 m

Sub-grade material characteristic angle of internal friction, φ_{sk} — φ_{sk} = 30 °

Partial factor on sub-grade strength, γ_φ — γ_φ = 1.25

Sub-grade material design angle of internal friction, φ_{sd}

$\varphi_{sd} = \tan^{-1}((\tan \varphi_{sk}) / \gamma_\varphi) =$ tan-1 x ((tan(30) / 1.25) — φ_{sd} = 24.79 °

Sub-grade material density, γ_s — γ_s = 16 kN/m³

8. Sub-grade layer 2 parameters

Sub-grade layer characteristic undrained cohesion, c_{uk2} — c_{uk2} = 20 kN/m²

Partial factor on sub-grade strength, γ_φ — γ_c = 1.40

Sub-grade layer 2 design undrained cohesion, c_{ud2}

$c_{ud2} = c_{uk} / \gamma_c =$ 20 / 1.40 — c_{ud2} = 14.29 kN/m²

Customer: Test
Job: Test 1
Description: Piling Platform
By: AM
Checked: NC

Reference	Calculations	Output

9. Platform parameters:

Platform material characteristic angle of internal friction, φ_{pk} — φ_{pk} = 45 °

Partial factor on platform material strength, γ_{φ} — γ_{φ} = 1.25

Platform material design angle of internal friction, φ_{pd}

$\varphi_{sd} = \tan^{-1}((\tan \varphi_{pk}) / \gamma_{\varphi})$ = tan-1 x ((tan(45) / 1.25) — φ_{pd} = 38.66 °

Platform material density, γ_p — γ_p = 20 kN/m³

10.1 Effective area, dimensions and load spread angle:

Platform thickness, D — D = 0.55 m

Total depth to to of sub-grade layer 2, D'

D' = H + D = 1.00 + 0.55 — D' = 1.55 m

Find ratio of applied pressure to effective pressure at formation using figure 26.

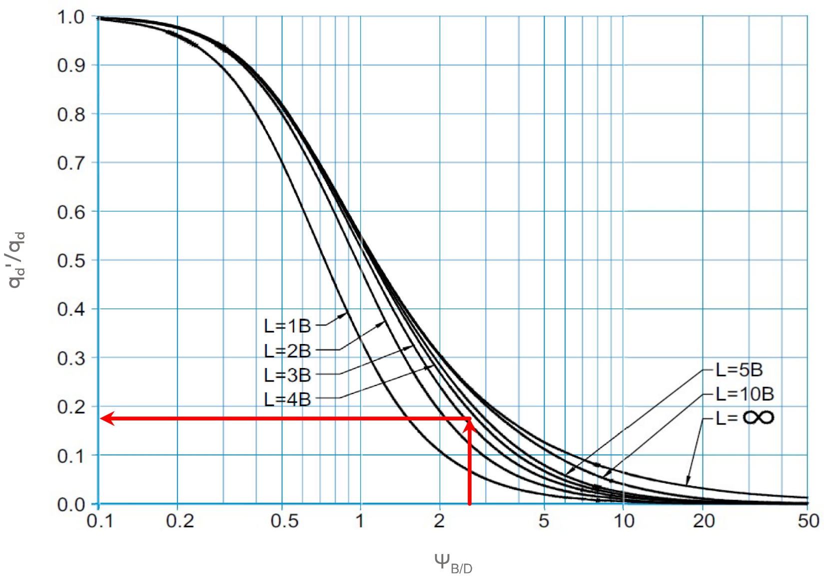
Ratio of applied load breadth to platform depth, $\Psi_{B/D}$

$\Psi_{B/D}$ = D' / B = 1.55 / 0.60 — $\Psi_{B/D}$ = 2.58

Ratio of applied load length to breadth, $\Psi_{L/B}$

$\Psi_{L/B}$ = L / B = 2.10 / 0.60 — $\Psi_{L/B}$ = 3.50

Fig. 25



$\Psi_{B/D}$ = 2.58

L = 3.5 B

Ratio of applied pressure to effective pressure, ρ_q — ρ_q = 0.18

Design effective pressure, q_d'

$q_d' = \rho_d \times q_d$ = 0.18 x 325 — q_d' = 57 kN/m²

Design effective area, A'

$A' = Q_d / q_d'$ = 410 / 57 — A' = 7.16 m²

Reference	Calculations	Output

Determine load spread width and angle solving with quadratic equation.

Quadratic factors

$a = B$ — $a = 1.00$

$b = L + B = 2.10 + 0.60$ — $b = 2.70$

$c = A - A' = 1.26 - 7.16$ — $c = -5.90$

Quadratic solution, x

$x = -b + \sqrt{(b^2 - 4ac)} / 2a = (-2.70 + \sqrt{(2.70^2 - 4 \times 1.00 \times -5.90)}) / 2 \times 1.00$ — $x = 1.43$ m

Load spread width, b''

$b'' = x / 2 = 1.43 / 2$ — $b'' = 0.71$ m

Load spread angle, β

$\beta = \tan^{-1}(b'' / D') =$ tan-1 x (0.71 / 1.55) — $\beta = 24.74\ °$

Maximum load spread width for β = 26.6° (2V:1H)

$b''_{max} = D' / 2 = 1.55 / 2$ — $b''_{max} = 0.78$ m

b'' < b''max therefore use b''

Effective breadth, B''

$B' = B + 2 \times b'' = 0.60 + 2 \times 0.71$ — $B'' = 2.03$ m

Effective length, L''

$L'' = L + 2 \times b''max = 2.10 + 2 \times 0.71$ — $L'' = 3.53$ m

10.2 Effective angle of punching shear in sub-grade layer 1:

Nominal bearing capacity factor for gravity term for sub-grade layer 1, $N_{\gamma d}$

$N_\gamma = 0.1054 \times e^{0.168\varphi sd} =$ 0.1054 x e^(0.168 x 24.79) — $N_\gamma = 16.28$

Nominal bearing capacity of sub-grade layer 1, q_{Rs1}

$q_{Rs1} = 0.5 \times N_\gamma \times B \times \gamma_p = 0.5 \times 16.28 \times 0.60 \times 20.0$ — $q_{Rs1} = 98$ kN

Bearing capacity for cohesion term for sub-grade layer 2, N_c — $N_c = 5.14$

Nominal bearing capacity of sub-grade layer 2, q_{Rs2}

$q_{Rs2} = N_c \times c_{uk2} = 5.14 \times 20$ — $q_{Rs2} = 103$ kN

Find design punching shear angle (figure 26)

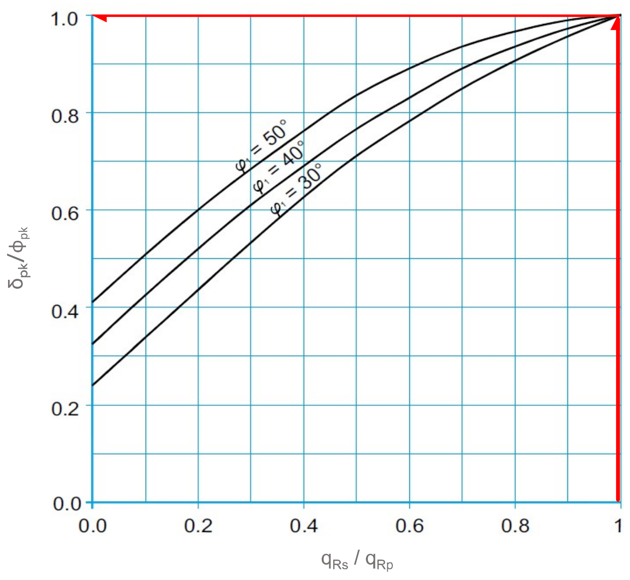
Ratio of nominal bearing capacities,

$q_{Rs2} / q_{Rs1} = 103 / 98$ — $q_{Rs2} / q_{Rs1} = 1.05$

Platform material characteristic angle of internal friction, ϕ_{pk} — $\varphi_{pk} = 30\ °$

Reference	Calculations	Output

Fig. 26



q_{Rs} / q_{Rp} = 1.05

ϕ' = 30 °

Nominal punching shear parameter, ρ_δ — ρ_δ = 1.00

Design punching shear angle, δ_{pd}

$\delta_{sd1} = \rho_\delta \times \varphi_{sd1}$ = 1.00 x 24.79 — δ_{pd} = 24.80 °

10.3 Lateral loads in sub-grade layer 1

Coefficient of active lateral earth pressure for platform, K_{asd1}

$K_{asd1} = \{ \sin(90-\phi_{sd1}) / [\sqrt{\sin(90+\delta_{sd1})} + \sqrt{(\sin(\varphi_{sd1}+\delta_{sd1}) \times \sin(\varphi_{sd1}))}] \}^2$

= {sin(90-24.79)/[√sin(90+24.80)+√(sin(24.79+24.80) x sin(24.79))]}²

K_{asd1} = 0.36

Coefficient of passive lateral earth pressure for platform, K_{psd1}

$K_{psd1} = \{ \sin(90+\phi_{sd1}) / [\sqrt{\sin(90-\delta_{sd1})} - \sqrt{(\sin(\varphi_{sd1}+\delta_{sd1}) \times \sin(\varphi_{sd1}))}] \}^2$

= {sin(90+24.79)/[√sin(90-24.80)-√(sin(24.79+24.80) x sin(24.79))]}²

K_{psd1} = 5.48

Find ratio of applied pressure to effective pressure at mid-depth of sub-grade layer 1 (figure 25)

Mid-point depth of sub-grade layer 1, H_{mid}

H_{mid} = (H / 2) + D = (1.00 / 2) + 0.55 — H_{mid} = 1.05 m

Mid-point depth to breadth ratio, H_{mid} / B

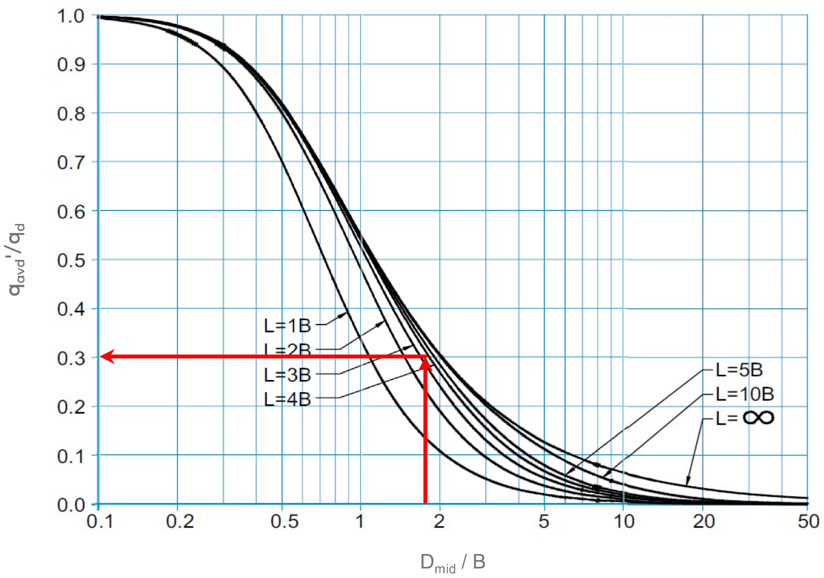
H_{mid} / B = 1.05 / 0.60 — H_{mid} / B = 1.75

Reference	Calculations	Output

Ratio of applied load length to breadth, L / B

L / B = 2.10 / 0.60 — L / B = 3.50

Fig. 25



D_{mid} / B = 1.75

L = 3.5 B

Ratio of applied pressure to effective pressure, ρ_q — ρ_q = 0.30

Average vertical pressure due to load, q_{avd}''

$q_{avd}'' = \rho_q \times q_d$ = 0.30 x 325 — q_{avd}'' = 97.0 kN/m²

Active lateral load in fill (per linear m), P_{apd}

$P_{asd1} = K_{asd1} \times (q_{avd}'' + \gamma_{s1} \times H / 2) \times H$ = 0.36 x (97 + 16 x 1.00 / 2) x 1.00 — P_{asd1} = 37.56630054

Passive lateral load in fill (per linear m), P_{ppd}

$P_{psd1} = K_{psd1} \times \gamma_{s,1} \times H^2 / 2$ = 5.48 x 16 x 1.00² / 2 — P_{psd1} = 43.85864206

10.4 Horizontal and Vertical Loads on sub-grade layer 2

Horizontal load on sub-grade (per linear m), F_{Hs2}

$F_{Hs2} = P_{asd1} - P_{psd1}$ = 37.6 - 43.9 — F_{Hs2} = 0.0 kN/m

Vertical load on sub-grade (per linear m), F_{Vs2}

$F_{Vs2} = (q_d \times B + (\gamma_p \times D + \gamma_{s1} \times H) \times B'') / 2$ = (325 x 0.60 + (20 x 0.55 + 16.00 x 1.00) x 2.03) / 2 — F_{Vs2} = 124.9 kN/m

10.5 Total Vertical Load Effect on sub-grade layer 2

Characteristic permanent action due to platform self weight, G_{pk}

$G_{pk} = (\gamma_p \times D + \gamma s1 \times H) \times B'' \times L''$ = (20 x 0.55 + 16.00 x 1.00) x 2.03 x 3.53 — G_{pk} = 193 kN

Partial factor for permanent actions, γ_G — γ_G = 1.00

Design permanent action due to platform self weight, G_{pd}

$G_{pd} = \gamma_G \times G_{pk}$ = 1.00 x 193 — G_{pd} = 193 kN

Reference	Calculations	Output

Total design vertical action, V_{Ed}

$V_{Ed} = G_{pd} \times Q_d =$ 193 + 410 — V_{Ed} = 603 kN

10.6 Sub-grade Layer 2 Bearing Resistance with Platform

Bearing capacity factor for cohesion term, N_{cd}

$N_{cd} = \pi + 2$ — N_{cd} = 5.14

Shape factor for cohesion term, s_{cd}

$s_{cd} = 1 + (0.21 \times B'' / L'') + (0.17 \times \sqrt{(D' / B'')})$

$= 1 + (0.21 \times 2.03 / 3.53) + (0.17 \times \sqrt{(1.55/2.03)})$ — s_{cd} = 1.27

Depth factor for cohesion term, d_{cd}

$d_{cd} = 1 + (0.27 \times \sqrt{(D' / B'')}) = 1 + (0.27 \times \sqrt{(1.55 / 3.53)})$ — d_{cd} = 1.18

Inclination factor for cohesion term, i_{cd}

$i_{cd} = \min \{ [0.5 \times (1 + \sqrt{(1 - (2 \times F_{Hs2} / (B'' \times c_{ud2})))}] ; 1.0 \}$

$= \min \{ [0.5 \times (1 + \sqrt{(1 - (2 \times 0.00 / (2.03 \times 14.29)))}] ; 1.0 \}$

(If $2F_{Hs} > B''c_{ud2}$, i_{cd} is limited to 0.5) — i_{cd} = 1.00

Bearing resistance, V_{Rd}

$V_{Rd} = (c_{ud2} \times N_{cd} \times s_{cd} \times d_{cd} \times i_{cd} + (\gamma_p \times D + \gamma_{s1} \times H)) \times B'' \times L''$

$= (14.29 \times 5.14 \times 1.27 \times 1.18 \times 1.00 + (20 \times 0.55 + 16 \times 1.00)) \times 2.03 \times 3.53$

V_{Rd} = 979.9928856

Utilisation:

$1.0 < V_{Ed} / V_{Rd} =$ 603 / 980 — Utilisation = 61.5%

PASS, platform thickness/strength acceptable — OK

Reference	Calculations	Output

Calculations for subgrade layer 1 - Load case 2 in accordance with TWf2019:02

ULS check for load case 2 & granular over cohesive parameters

11. Variable Actions:

Applied load breadth, B	B =	0.60 m
Applied load length, L	L =	2.10 m
Applied load area, A		
$A = B \times L =$ 0.60 x 2.10	A =	1.26 m²
Characteristic applied ground bearing pressure, q_k	q_k =	250 kN/m²
Partial factor on variable actions, γ_Q	γ_Q =	1.00
Design applied ground bearing pressure, q_d		
$q_d = q_k \times \gamma_Q =$ 250 x 1.00	q_d =	250.0 kN/m²
Design applied load, Q_d		
$Q_d = q_d \times A =$ 250.0 x 1.26	Q_d =	315 kN

12. Sub-grade layer 1 parameters:

Sub-grade material characteristic angle of internal friction, φ_{sk}	φ_{sk} =	30 °
Partial factor on sub-grade strength, γ_φ	γ_φ =	1.25
Sub-grade material design angle of internal friction, φ_{sd}		
$\varphi_{sd} = \tan^{-1}((\tan \varphi_{sk}) / \gamma_\varphi) =$ tan-1 x ((tan(30) / 1.25)	φ_{sd} =	24.79 °
Sub-grade material density, γ_s	γ_s =	16 kN/m³
Depth of groundwater below formation, z_γ	z_γ =	5.00 m

13. Sub-grade bearing resistance without platform:

Bearing capacity factor for gravity term, $N_{\gamma d}$		
$N_{\gamma d} = 0.1054 \times e^{0.168\varphi sd} =$ 0.1054 x e^(0.168 x 24.79)	$N_{\gamma d}$ =	6.79
Design shape factor for gravity term, $s_{\gamma d}$		
$s_{\gamma d} = 1 - (0.4 \times B/L) =$ 1 - (0.4 x 0.60/2.10)	$s_{\gamma d}$ =	0.89
Design bearing resistance, V_{Rd}		
$V_{Rd} = 0.5 \times \gamma_s \times B \times N_{\gamma d} \times s_{\gamma d} \times A =$ 0.5 x 16 x 0.60 x 6.79 x 0.89 x 1.26	V_{Rd} =	36 kN

Utilisation:

$1.0 < Q_d / V_{Rd} =$ 315 / 36	Utilisation =	866%
FAIL, requires a working platform		FAIL

Reference	Calculations	Output

14. Platform parameters:

Platform material characteristic angle of internal friction, φ_{pk} — φ_{pk} = 45 °

Partial factor on platform material strength, γ_{φ} — γ_{φ} = 1.25

Platform material design angle of internal friction, φ_{pd}

$\varphi_{sd} = \tan^{-1}((\tan \varphi_{pk}) / \gamma_{\varphi}) =$ tan-1 x ((tan(45) / 1.25) — φ_{pd} = 38.66 °

Platform material density, γ_p — γ_p = 20 kN/m³

15.1 Effective area, dimensions and load spread angle:

Platform thickness, D — D = 0.50 m

Find ratio of applied pressure to effective pressure at formation using figure 26.

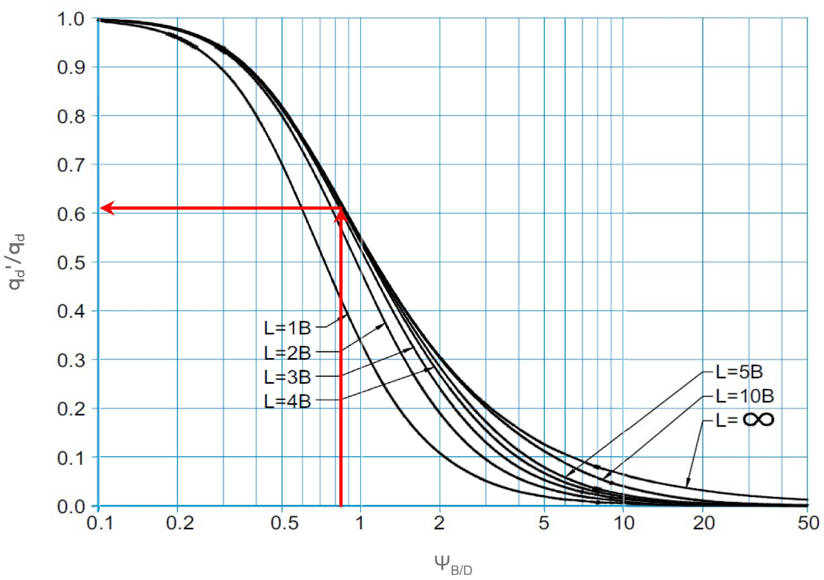
Ratio of applied load breadth to platform depth, $\Psi_{B/D}$

$\Psi_{B/D} = D / B =$ 0.50 / 0.60 — $\Psi_{B/D}$ = 0.83

Ratio of applied load length to breadth, $\Psi_{L/B}$

$\Psi_{L/B} = L / B =$ 2.10 / 0.60 — $\Psi_{L/B}$ = 3.50

Fig. 25



$\Psi_{B/D} =$ 0.83

L = 3.5 B

Ratio of applied pressure to effective pressure, ρ_q — ρ_q = 0.61

Design effective pressure, q_d'

$q_d' = \rho_d \times q_d =$ 0.61 x 250 — q_d' = 153 kN/m²

Design effective area, A'

$A' = Q_d / q_d' =$ 315 / 153 — A' = 2.06 m²

Reference	Calculations	Output

Determine load spread width and angle solving with quadratic equation.

Quadratic factors

a = B — a = 1.00

b = L + B = 2.10 + 0.60 — b = 2.70

c = A - A' = 1.26 - 2.06 — c = -0.80

Quadratic solution, x

$x = -b + \sqrt{(b^2 - 4ac)} / 2a$ = $(-2.70 + \sqrt{(2.70^2 - 4 \times 1.00 \times -0.80)}) / 2 \times 1.00$ — x = 0.27 m

Load spread width, b'

b' = x / 2 = 0.27 / 2 — b' = 0.13 m

Load spread angle, β

$\beta = \tan^{-1}$ (b' / D) = tan-1 x (0.13 / 0.50) — β = 15.10 °

Maximum load spread width for β = 26.6° (2V:1H)

b'_{max} = D / 2 = 0.50 / 2 — b'_{max} = 0.25 m

b' < b'max therefore use b'

Effective breadth, B'

B' = B + 2 x b' = 0.60 + 2 x 0.13 — B' = 0.87 m

Effective length, L'

L' = L + 2 x b' = 2.10 + 2 x 0.13 — L' = 2.37 m

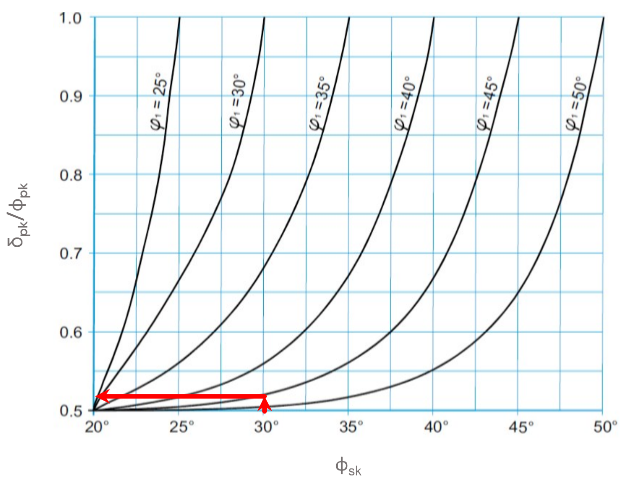
15.2 Effective angle of punching shear:

Determine punching shear angle using figure 27.

Platform material characteristic angle of internal friction, ϕ_{pk} — φ_{pk} = 45 °

Sub-grade material characteristic angle of internal friction, ϕ_{sk} — φ_{sk} = 30 °

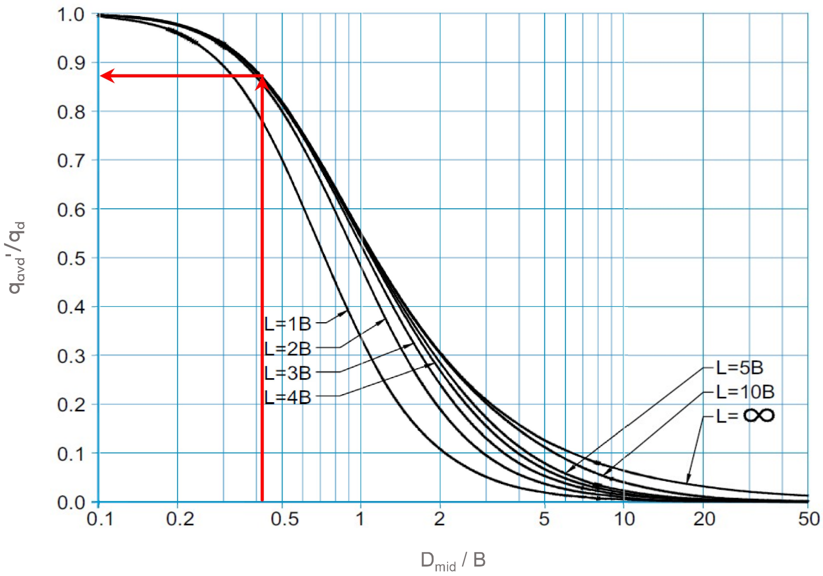
Fig. 27



ϕ_{sk} = 30 °

ϕ' = 45 °

Customer: Test
Job: Test 1
Description: Piling Platform
By: AM
Checked: NC

Reference	Calculations	Output
	Nominal punching shear parameter, ρ_δ $\quad \rho_\delta$ =	0.52
	Design punching shear angle, δ_{pd}	
	$\delta_{pd} = \rho_\delta \times \varphi_{pd} = 0.52 \times 38.66$ $\quad \delta_{pd}$ =	20.10 °
	15.3 Lateral Loads in Platform	
	Coefficient of active lateral earth pressure for platform, K_{apd}	
	$K_{apd} = \{ \sin(90-\phi_{pd}) / [\sqrt{\sin(90+\delta_{pd})} + \sqrt{(\sin(\varphi_{pd}+\delta_{pd}) \times \sin(\varphi_{pd}))}] \}^2$	
	$= \{\sin(90-38.66)/[\sqrt{\sin(90+20.10)}+\sqrt{(\sin(38.66+20.10) \times \sin(38.66))}]\}^2$	
	K_{apd} =	0.21
	Coefficient of passive lateral earth pressure for platform, K_{ppd}	
	$K_{ppd} = \{ \sin(90+\phi_{pd}) / [\sqrt{\sin(90-\delta_{pd})} - \sqrt{(\sin(\varphi_{pd}+\delta_{pd}) \times \sin(\varphi_{pd}))}] \}^2$	
	$= \{\sin(90+38.66)/[\sqrt{\sin(90-20.10)}-\sqrt{(\sin(38.66+20.10) \times \sin(38.66))}]\}^2$	
	K_{ppd} =	10.74
	Find ratio of applied pressure to effective pressure at mid-depth of platform (figure 25)	
	Mid-point depth of platform, D_{mid}	
	$D_{mid} = D / 2 = 0.50 / 2$ $\quad D_{mid}$ =	0.25 m
	Mid-point depth to breadth ratio, D_{mid} / B	
	$D_{mid} / B = 0.25 / 0.60$ $\quad D_{mid} / B$ =	0.42
	Ratio of applied load length to breadth, L / B	
	L / B = 2.10 / 0.60 $\quad$ L / B =	3.50
Fig. 25	 $D_{mid} / B = 0.42$; L = 3.5 B	
	Ratio of applied pressure to effective pressure, ρ_q $\quad \rho_q$ =	0.87

Reference	Calculations	Output

Average vertical pressure due to load, q_{avd}'

$q_{avd}' = \rho_q \times q_d =$ 0.87 x 250 — q_{avd}' = 217.4 kN/m²

Active lateral load in fill (per linear m), P_{apd}

$P_{apd} = K_{apd} \times (q_{avd}' + \gamma_p \times D / 2) \times D =$ 0.21 x (217 + 20 x 0.50 / 2) x 0.50 — P_{apd} = 23.46277986

Passive lateral load in fill (per linear m), P_{ppd}

$P_{ppd} = K_{ppd} \times \gamma_p \times D^2 / 2 =$ 10.74 x 20 x 0.50² / 2 — P_{ppd} = 26.85243839

15.4 Horizontal and Vertical Loads on Sub-grade

Horizontal load on sub-grade (per linear m), F_{Hs}

$F_{Hs} = P_{apd} - P_{ppd} =$ 23.5 - 26.9 — F_{Hs} = 0.0 kN/m

Vertical load on sub-grade (per linear m), F_{Vs}

$F_{Vs} = (q_d \times B + \gamma_p \times D \times B') / 2 =$ (250 x 0.60 + 20 x 0.50 x 0.87) / 2 — F_{Vs} = 79.3 kN/m

15.5 Total Vertical Load Effect on Sub-grade

Characteristic permanent action due to platform self weight, G_{pk}

$G_{pk} = \gamma_{pk} \times D \times B' \times L' =$ 20 x 0.50 x 0.87 x 2.37 — G_{pk} = 21 kN

Partial factor for permanent actions, γ_G — γ_G = 1.00

Design permanent action due to platform self weight, G_{pd}

$G_{pd} = \gamma_G \times G_{pk} =$ 1.00 x 21 — G_{pd} = 21 kN

Total design vertical action, V_{Ed}

$V_{Ed} = G_{pd} \times Q_d =$ 21 + 315 — V_{Ed} = 336 kN

15.6 Sub-grade Bearing Resistance with Platform

Bearing capacity factor for gravity term, $N_{\gamma d}$

$N_{\gamma d} = 0.1054 \times e^{0.168\varphi sd} =$ 0.1054 x e^(0.168 x 24.79) — $N_{\gamma d}$ = 6.79

Bearing capacity factor for overburden term, N_{qd}

$N_{qd} = e^{\pi\tan(\varphi sd)} \times \tan[45 + (\varphi_{sd} / 2)]^2 =$ e^πtan(24.79) x tan[45 + (24.79 / 2)]² — N_{qd} = 10.43

Shape factor for gravity term, $s_{\gamma d}$

$s_{\gamma d} = 1 - (0.4 \times B' / L') =$ 1 - (0.4 x 0.87 / 2.37) — $s_{\gamma d}$ = 0.85

Shape factor for overburden term, s_{qd}

$s_{qd} = 1 + (\tan(\phi_{sd}) \times B' / L') =$ 1 + (tan(24.79) x 0.87 / 2.37) — s_{qd} = 1.17

Inclination factor exponent, m

$m = (2 + (B' / L')) / (1 + (B' / L')) =$ (2 + (0.87 / 2.37)) / (1 + (0.87 / 2.37)) — m = 1.73

Reference	Calculations	Output

Inclination factor for gravity term, $i_{\gamma d}$

$i_{\gamma d} = \min\{1.0 ; [(1 - F_{Hs} / F_{Vs})]^{m+1} = \min\{1.0 ; [(1 - 0.00 / 79.35)\text{^}1.73 + 1]\}$ $i_{\gamma d}$ = 1.00

Inclination factor for overburden term, i_{qd}

$i_{qd} = \min\{1.0 ; [(1 - F_{Hs} / F_{Vs})]^{m} = \min\{1.0 ; [(1 - 0.00 / 79.35)\text{^}1.73]\}$ i_{qd} = 1.00

Depth factor for gravity term, $d_{\gamma d}$ $d_{\gamma d}$ = 1.00

Depth factor for overburden term, d_{qd}

$d_{qd} = 1 + (2 \times \tan(\phi_{sd}) \times (1 - \sin(\phi_{sd})^2 \times \tan\text{-}1(D / B')$

$= 1 + ((2 \times \tan(24.79) \times (1 - \sin(24.79)^2 \times \tan\text{-}1(0.50/0.87))$ d_{qd} = 1.15

Groundwater factor for gravity term, $w_{\gamma d}$

$w_{\gamma d} = \min\{1.0 ; \max\{0.5 ; [0.5 \times (1 + z_\gamma / B')]\}\}$

$= \min\{1.0 ; \max\{0.5 ; [0.5 \times (1 + 5.00 / 0.87)]\}\}$ $w_{\gamma d}$ = 1.00

Depth of groundwater below top of platform, z_q

$z_q = z_q + D = 5.00 + 0.50$ z_q = 5.50 m

Groundwater factor for surcharge term, w_{qd}

$w_{qd} = \min\{1.0 ; \max\{0.5 ; [0.5 \times (1 + z_q / D)]\}\}$

$= \min\{1.0 ; \max\{0.5 ; [0.5 \times (1 + 5.50 / 0.50)]\}\}$ w_{qd} = 1.00

Bearing resistance, V_{Rd}

$V_{Rd} = (0.5 \times \gamma_s \times B' \times N_{\gamma d} \times s_{\gamma d} \times i_{\gamma d} \times d_{\gamma d} \times w_{\gamma d} + \gamma_p \times D \times N_{qd} \times s_{qd} \times i_{qd} \times d_{qd} \times w_{qd})\ B' \times L'$

$= (0.5 \times 16 \times 0.87 \times 6.79 \times 0.85 \times 1.00 \times 1.00 \times 1.00 + 20 \times 0.50 \times 10.43 \times 1.17 \times 1.00 \times 1.15 \times 1.00) \times 0.87 \times 2.37$

V_{Rd} = 373.0181902

Utilisation:

$1.0 < V_{Ed} / V_{Rd} = 336 / 373$ Utilisation = 90.0%

PASS, platform thickness/strength acceptable OK

Reference	Calculations	Output

Calculations for subgrade layer 2 - Load case 2

ULS check for load case 2 & granular over cohesive parameters

16. Variable Actions:

Applied load breadth, B — B = 0.60 m

Applied load length, L — L = 2.10 m

Applied load area, A

$A = B \times L =$ 0.60 x 2.10 — A = 1.26 m²

Characteristic applied ground bearing pressure, q_k — q_k = 250 kN/m²

Partial factor on variable actions, γ_Q — γ_Q = 1.00

Design applied ground bearing pressure, q_d

$q_d = q_k \times \gamma_Q =$ 250 x 1.00 — q_d = 250.0 kN/m²

Design applied load, Q_d

$Q_d = q_d \times A =$ 250.0 x 1.26 — Q_d = 315 kN

17. Sub-grade layer 1 parameters:

Sub-grade layer 1 thickness, H — H = 1.00 m

Sub-grade material characteristic angle of internal friction, φ_{sk} — φ_{sk} = 30 °

Partial factor on sub-grade strength, γ_φ — γ_φ = 1.25

Sub-grade material design angle of internal friction, φ_{sd}

$\varphi_{sd} = \tan^{-1}((\tan \varphi_{sk}) / \gamma_\varphi) =$ tan-1 x ((tan(30) / 1.25) — φ_{sd} = 24.79 °

Sub-grade material density, γ_s — γ_s = 16 kN/m³

18. Sub-grade layer 2 parameters

Sub-grade layer characteristic undrained cohesion, c_{uk2} — c_{uk2} = 20 kN/m²

Partial factor on sub-grade strength, γ_φ — γ_c = 1.40

Sub-grade layer 2 design undrained cohesion, c_{ud2}

$c_{ud2} = c_{uk} / \gamma_c =$ 20 / 1.40 — c_{ud2} = 14.29 kN/m²

Customer: Test
Job: Test 1
Description: Piling Platform

By: AM
Checked: NC

Reference	Calculations	Output

19. Platform parameters:

Platform material characteristic angle of internal friction, φ_{pk} — φ_{pk} = 45 °

Partial factor on platform material strength, γ_{φ} — γ_{φ} = 1.25

Platform material design angle of internal friction, φ_{pd}

$\varphi_{sd} = \tan^{-1}((\tan \varphi_{pk}) / \gamma_{\varphi}) =$ tan-1 x ((tan(45) / 1.25) — φ_{pd} = 38.66 °

Platform material density, γ_p — γ_p = 20 kN/m³

20.1 Effective area, dimensions and load spread angle:

Platform thickness, D — D = 0.50 m

Total depth to to of sub-grade layer 2, D'

D' = H + D = 1.00 + 0.50 — D' = 1.50 m

Find ratio of applied pressure to effective pressure at formation using figure 26.

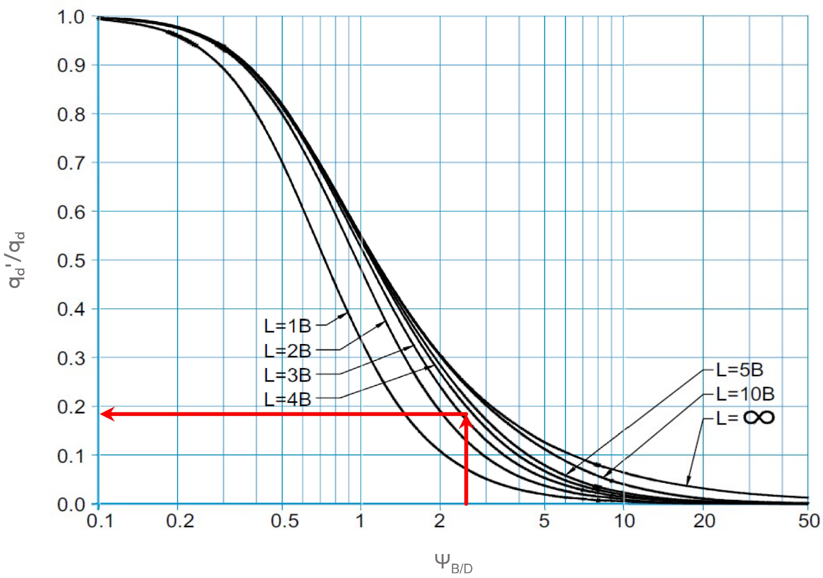
Ratio of applied load breadth to platform depth, $\Psi_{B/D}$

$\Psi_{B/D}$ = D' / B = 1.50 / 0.60 — $\Psi_{B/D}$ = 2.50

Ratio of applied load length to breadth, $\Psi_{L/B}$

$\Psi_{L/B}$ = L / B = 2.10 / 0.60 — $\Psi_{L/B}$ = 3.50

Fig. 25



$\Psi_{B/D}$ = 2.50

L = 3.5 B

Ratio of applied pressure to effective pressure, ρ_q — ρ_q = 0.19

Design effective pressure, q_d'

$q_d' = \rho_d \times q_d =$ 0.19 x 250 — q_d' = 46 kN/m²

Design effective area, A'

$A' = Q_d / q_d' =$ 315 / 46 — A' = 6.80 m²

Reference	Calculations	Output

Determine load spread width and angle solving with quadratic equation.

Quadratic factors

$a = B$ | $a = 1.00$

$b = L + B = 2.10 + 0.60$ | $b = 2.70$ m

$c = A - A' = 1.26 - 6.80$ | $c = -5.54$ m²

Quadratic solution, x

$x = -b + \sqrt{(b^2 - 4ac)} / 2a = (-2.70 + \sqrt{(2.70^2 - 4 \times 1.00 \times -5.54)}) / 2 \times 1.00$ | $x = 1.36$ m

Load spread width, b''

$b'' = x / 2 = 1.36 / 2$ | $b'' = 0.68$ m

Load spread angle, β

$\beta = \tan^{-1} (b'' / D') =$ tan-1 x (0.68 / 1.50) | $\beta = 24.45$ °

Maximum load spread width for β = 26.6° (2V:1H)

$b''_{max} = D' / 2 = 1.50 / 2$ | $b''_{max} = 0.75$ m

b'' < b''max therefore use b''

Effective breadth, B''

$B' = B + 2 \times b' = 0.60 + 2 \times 0.68$ | $B'' = 1.96$ m

Effective length, L''

$L'' = L + 2 \times b'' = 2.10 + 2 \times 0.68$ | $L'' = 3.46$ m

20.2 Effective angle of punching shear in sub-grade layer 1:

Nominal bearing capacity factor for gravity termfor sub-grade layer 1, $N_{\gamma d}$

$N_\gamma = 0.1054 \times e^{0.168\varphi sd} =$ 0.1054 x e^(0.168 x 24.79) | $N_\gamma = 16.28$

Nominal bearing capacity of sub-grade layer 1, q_{Rs1}

$q_{Rs1} = 0.5 \times N_\gamma \times B \times \gamma_p = 0.5 \times 16.28 \times 0.60 \times 20.0$ | $q_{Rs1} = 98$ kN

Bearing capacity for cohesion term for sub-grade layer 2, N_c | $N_c = 5.14$

Nominal bearing capacity of sub-grade layer 2, q_{Rs2}

$q_{Rs2} = N_c \times c_{uk2} = 5.14 \times 20$ | $q_{Rs2} = 103$ kN

Find design punching shear angle (figure 26)

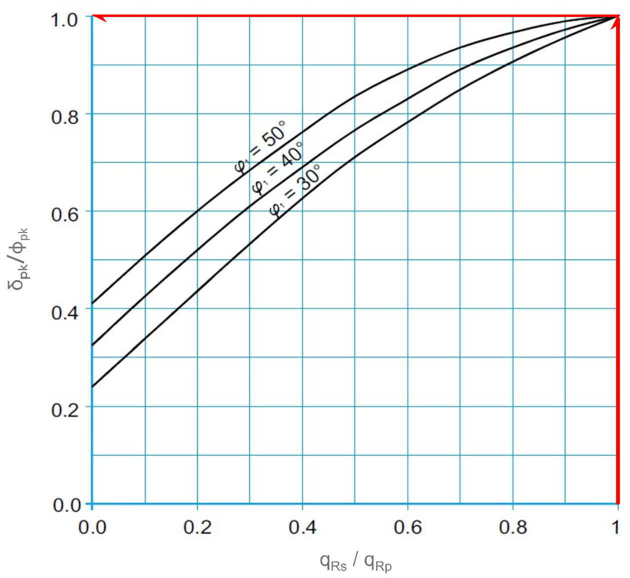
Ratio of nominal bearing capacities,

$q_{Rs2} / q_{Rs1} = 103 / 98$ | $q_{Rs2} / q_{Rs1} = 1.05$

Platform material characteristic angle of internal friction, ϕ_{pk} | $\varphi_{pk} = 30$ °

Reference	Calculations	Output

Fig. 26



q_{Rs} / q_{Rp} = 1.05

ϕ' = 30 °

Nominal punching shear parameter, ρ_δ — ρ_δ = 1.00

Design punching shear angle, δ_{pd}

$\delta_{sd1} = \rho_\delta \times \varphi_{sd1}$ = 1.00 x 24.79 — δ_{pd} = 24.80 °

20.3 Lateral loads in sub-grade layer 1

Coefficient of active lateral earth pressure for platform, K_{asd1}

$$K_{asd1} = \{ \sin(90-\phi_{sd1}) / [\sqrt{\sin(90+\delta_{sd1})} + \sqrt{(\sin(\varphi_{sd1}+\delta_{sd1}) \times \sin(\varphi_{sd1}))}] \}^2$$

$$= \{\sin(90-24.79)/[\sqrt{\sin(90+24.80)}+\sqrt{(\sin(24.79+24.80) \times \sin(24.79))}]\}^2$$

K_{asd1} = 0.36

Coefficient of passive lateral earth pressure for platform, K_{psd1}

$$K_{psd1} = \{ \sin(90+\phi_{sd1}) / [\sqrt{\sin(90-\delta_{sd1})} - \sqrt{(\sin(\varphi_{sd1}+\delta_{sd1}) \times \sin(\varphi_{sd1}))}] \}^2$$

$$= \{\sin(90+24.79)/[\sqrt{\sin(90-24.80)}-\sqrt{(\sin(24.79+24.80) \times \sin(24.79))}]\}^2$$

K_{psd1} = 5.48

Find ratio of applied pressure to effective pressure at mid-depth of sub-grade layer 1 (figure 25)

Mid-point depth of sub-grade layer 1, H_{mid}

H_{mid} = (H / 2) + D = (1.00 / 2) + 0.50 — H_{mid} = 1.00 m

Mid-point depth to breadth ratio, H_{mid} / B

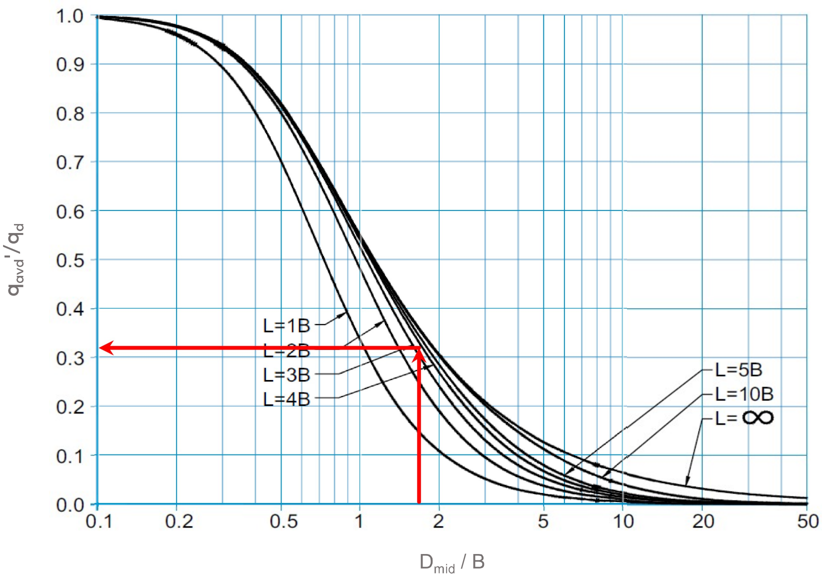
H_{mid} / B = 1.00 / 0.60 — H_{mid} / B = 1.67

Reference	Calculations	Output

Ratio of applied load length to breadth, L / B

L / B = 2.10 / 0.60 — L / B = 3.50

Fig. 25



D_{mid} / B = 1.67

L = 3.5 B

Ratio of applied pressure to effective pressure, ρ_q — ρ_q = 0.32

Average vertical pressure due to load, q_{avd}''

$q_{avd}' = \rho_q \times q_d$ = 0.32 x 250 — q_{avd}'' = 79.0 kN/m²

Active lateral load in fill (per linear m), P_{apd}

$P_{asd1} = K_{asd1} \times (q_{avd}'' + \gamma_{s1} \times H / 2) \times H$ = 0.36 x (79 + 16 x 1.00 / 2) x 1.00 — P_{asd1} = 31.13513501

Passive lateral load in fill (per linear m), P_{ppd}

$P_{psd1} = K_{psd1} \times \gamma_{s,1} \times H^2 / 2$ = 5.48 x 16 x 1.00² / 2 — P_{psd1} = 43.85864206

20.4 Horizontal and Vertical Loads on sub-grade layer 2

Horizontal load on sub-grade (per linear m), F_{Hs2}

$F_{Hs2} = P_{asd1} - P_{psd1}$ = 31.1 - 43.9 — F_{Hs2} = 0.0 kN/m

Vertical load on sub-grade (per linear m), F_{Vs2}

$F_{Vs2} = (q_d \times B + (\gamma_p \times D + \gamma_{s1} \times H) \times B'') / 2$ = (250 x 0.60 + (20 x 0.50 + 16.00 x 1.00) x 1.96) / 2 — F_{Vs2} = 100.5 kN/m

20.5 Total Vertical Load Effect on sub-grade layer 2

Characteristic permanent action due to platform self weight, G_{pk}

$G_{pk} = (\gamma_p \times D + \gamma s1 \times H) \times B'' \times L''$ = (20 x 0.50 + 16.00 x 1.00) x 1.96 x 3.46 — G_{pk} = 177 kN

Partial factor for permanent actions, γ_G — γ_G = 1.00

Design permanent action due to platform self weight, G_{pd}

$G_{pd} = \gamma_G \times G_{pk}$ = 1.00 x 177 — G_{pd} = 177 kN

Reference	Calculations	Output

Total design vertical action, V_{Ed}

$V_{Ed} = G_{pd} \times Q_d =$ 176.9 + 315.0 — V_{Ed} = 492 kN

20.6 Sub-grade Layer 2 Bearing Resistance with Platform

Bearing capacity factor for cohesion term, N_{cd}

$N_{cd} = \pi + 2$ — N_{cd} = 5.14

Shape factor for cohesion term, s_{cd}

$s_{cd} = 1 + (0.21 \times B'' / L'') + (0.17 \times \sqrt{(D' / B'')})$

$= 1 + (0.21 \times 1.96 / 3.46) + (0.17 \times \sqrt{(1.50/1.96)})$ — s_{cd} = 1.27

Depth factor for cohesion term, d_{cd}

$d_{cd} = 1 + (0.27 \times \sqrt{(D' / B'')}) = 1 + (0.27 \times \sqrt{(1.50 / 3.46)})$ — d_{cd} = 1.18

Inclination factor for cohesion term, i_{cd}

$i_{cd} = \min \{ [0.5 \times (1 + \sqrt{(1 - (2 \times F_{Hs2} / (B'' \times c_{ud2}))})] ; 1.0 \}$

$= \min \{ [0.5 \times (1 + \sqrt{(1 - (2 \times 0.00 / (1.96 \times 14.29))})] ; 1.0 \}$

(If $2F_{Hs} > B''c_{ud2}$, i_{cd} is limited to 0.5) — i_{cd} = 1.00

Bearing resistance, V_{Rd}

$V_{Rd} = (c_{ud2} \times N_{cd} \times s_{cd} \times d_{cd} \times i_{cd} + (\gamma_p \times D + \gamma_{s1} \times H)) \times B'' \times L''$

$= (14.29 \times 5.14 \times 1.27 \times 1.18 \times 1.00 + (20 \times 0.50 + 16 \times 1.00)) \times 1.96 \times 3.46$

V_{Rd} = 923.11 kN/m³

Utilisation:

$1.0 < V_{Ed} / V_{Rd} =$ 492 / 923 — Utilisation = 53.3%

PASS, platform thickness/strength acceptable — OK

Reference	Calculations	Output

Determine settlement beneath tracks in accordance with TWf2019:02

21. Variable Actions (worst case - Load Case 1)

Track Spacing, S — S = 1.80 m

Track width, B — B = 0.60 m

Track contact length, L — L = 2.10 m

Track contact area, A

$A = B \times L = 0.60 \times 2.10$ — A = 1.26 m²

Characteristic applied track load, Q_k — Q_k = 315 kN

Characteristic applied ground bearing pressure, q_k — q_k = 250 kN/m²

22. Sub-grade layer 1 parameters:

Minimum subgrade thickness layer, H — H = 1.00 m

Sub-grade density, $\gamma_{s,1}$ — $\gamma_{s,1}$ = 16 kN/m³

Sub-grade undrained elastic modulus, $E_{u,1}$ — $E_{u,1}$ = 30.0 MPa

23. Sub-grade layer 2 parameters:

Sub-grade density, $\gamma_{s,2}$ — $\gamma_{s,2}$ = 17 kN/m³

Sub-grade undrained elastic modulus, $E_{u,2}$ — $E_{u,2}$ = 12.0 MPa

24. Platform parameters:

Platform thickness, D — D = 0.55 m

Platform density, γ_p — γ_p = 20 kN/m³

Platform material elastic modulus, $E_{u,p}$ — $E_{u,p}$ = 75.0 MPa

25.Groundwater parameters

Depth of groundwater beneath surface of sub-grade, z_γ — z_γ = 5.00 m

Nearest sub-division of sub-layer rounded up, = 1.00 m

Nearest sub-division of water level, rounded down, = 5.00 m

Customer: Test
Job: Test 1
Description: Piling Platform

By: AM
Checked: NC

Reference	Calculations	Output

26. Depth of influence:

Find depth for 20% overburden = increase in pressure due to loading (figure 25)

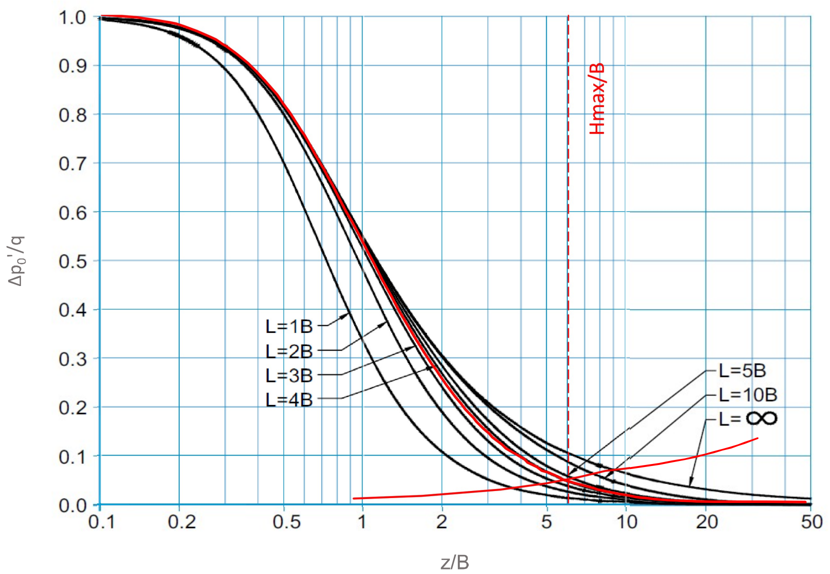
Ration of applied load length to breadth, L/B

L/B = 2.10 / 0.60 — L/B = 3.50

Height of divisions for calculating settlement, = 1.00

z (m)	z/B	Δz (m)	γ' (kN/m³)	g' = Δz γ' (kN/m²)	$Dp_0' = \Sigma g'$ (kN/m²)	Dp_0'/q	$0.2Dp_0'/q$
0.55	0.92	0.55	20.0	11.0	11.0	0.044	0.009
1.00	1.67	0.45	16.0	7.2	18.2	0.073	0.015
2.00	3.33	1.00	16.0	16.0	34.2	0.137	0.027
3.00	5.00	1.00	16.0	16.0	50.2	0.201	0.040
4.00	6.67	1.00	16.0	16.0	66.2	0.265	0.053
5.00	8.33	1.00	16.0	16.0	82.2	0.329	0.066
6.00	10.00	1.00	6.0	6.0	88.2	0.353	0.071
7.00	11.67	1.00	6.0	6.0	94.2	0.377	0.075
8.00	13.33	1.00	6.0	6.0	100.2	0.401	0.080
9.00	15.00	1.00	6.0	6.0	106.2	0.425	0.085
10.00	16.67	1.00	6.0	6.0	112.2	0.449	0.090
11.00	18.33	1.00	6.0	6.0	118.2	0.473	0.095
12.00	20.00	1.00	6.0	6.0	124.2	0.497	0.099
13.00	21.67	1.00	6.0	6.0	130.2	0.521	0.104
14.00	23.33	1.00	6.0	6.0	136.2	0.545	0.109
15.00	25.00	1.00	6.0	6.0	142.2	0.569	0.114
16.00	26.67	1.00	6.0	6.0	148.2	0.593	0.119
17.00	28.33	1.00	6.0	6.0	154.2	0.617	0.123
18.00	30.00	1.00	6.0	6.0	160.2	0.641	0.128
19.00	31.67	1.00	6.0	6.0	166.2	0.665	0.133

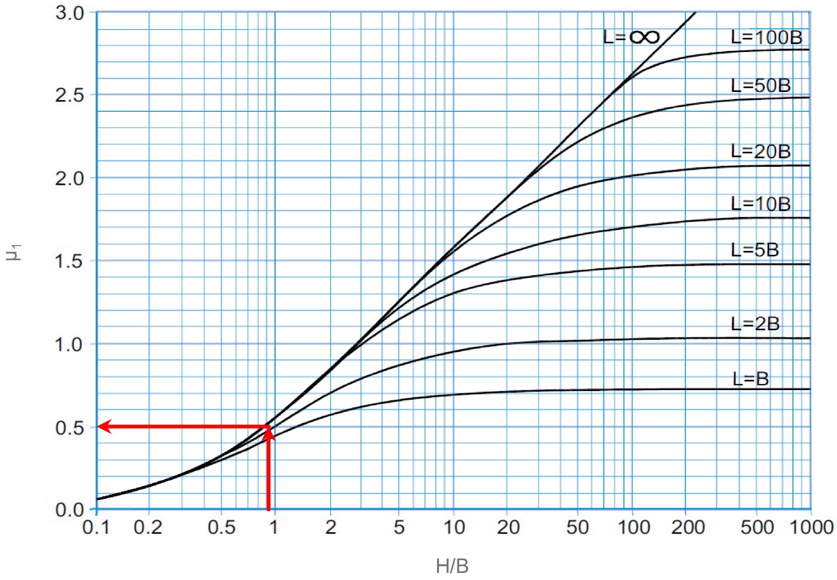
Fig. 25



Customer: Test
Job: Test 1
Description: Piling Platform
By: AM
Checked: NC

Reference	Calculations	Output
	Ratio of depth of influence to applied load breadth, H_{max}/B	
	$\rho_H = H_{max} / B$	H_{max}/B = 6.04
	Depth of influence,	
	$H_{max} = \rho_H \times B =$ 6.04 x 0.60	H_{max} = 3.62 m
	27. Settlement in platform:	
	Depth to underside of platform, H_p	$H_p = D$ = 0.55 m
	Ratio of depth to applied load breadth, H_p/B	
	$H_p/B =$ 0.55 / 0.60	H_p/B = 0.92
	Ratio of applied load length to breadth, L/B	
	L/B = 2.10 / 0.60	L/B = 3.50

Fig. 29



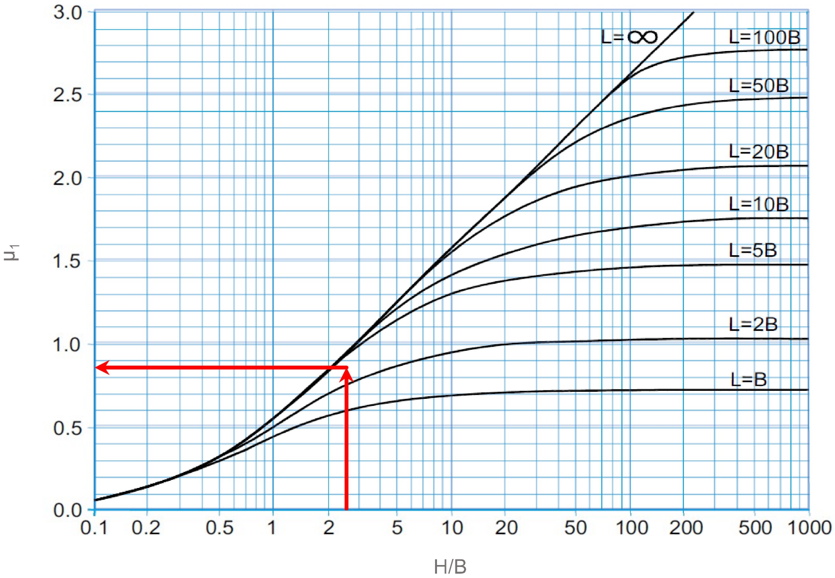
$H_p/B =$ 0.92

L = 3.5 B

Reference	Calculations	Output
	Settlement factor, $\mu_{1,p}$	$\mu_{1,p}$ = 0.50
	Settlement in platform, ρ_1	
	$\rho_1 = q \times B \times \mu_{1,p} / E_{up} =$ (250 x 0.60 x 0.50 / (75 x 10³)) x 10³	ρ_1 = 1.00 mm
	28.1 Settlement in subgrade layer 1:	
	Depth to underside of layer 1. H_1	
	$H_1 = D + H =$ 0.55 + 1.00	H_1 = 1.55 m
	Ratio of depth to applied load breadth, H_p/B	
	$H_1/B =$ 1.55 / 0.60	H_1/B = 2.58
	Ratio of applied load length to breadth, L/B	
	L/B = 2.10 / 0.60	L/B = 3.50

Reference	Calculations	Output

Fig. 29



$H_p/B =$ 2.58

L = 3.5 B

Settlement factor, $\mu_{1,1}$ — $\mu_{1,1}$ = 0.85

Settlement in layer 1, ρ_2

$\rho_2 = q \times B \times (\mu_{1,1} - \mu_{1,p}) / E_{up} =$ (250 x 0.60 x (0.85 - 0.50) / (30 x 10^3)) x 10^3 — ρ_2 = 1.74 mm

28.2 Settlement in subgrade layer 2:

Depth to underside of layer 2 (depth of influence). H_2

$H_2 = H_{max} =$ 3.62 — $H_2 = H_{max}$ = 3.62 m

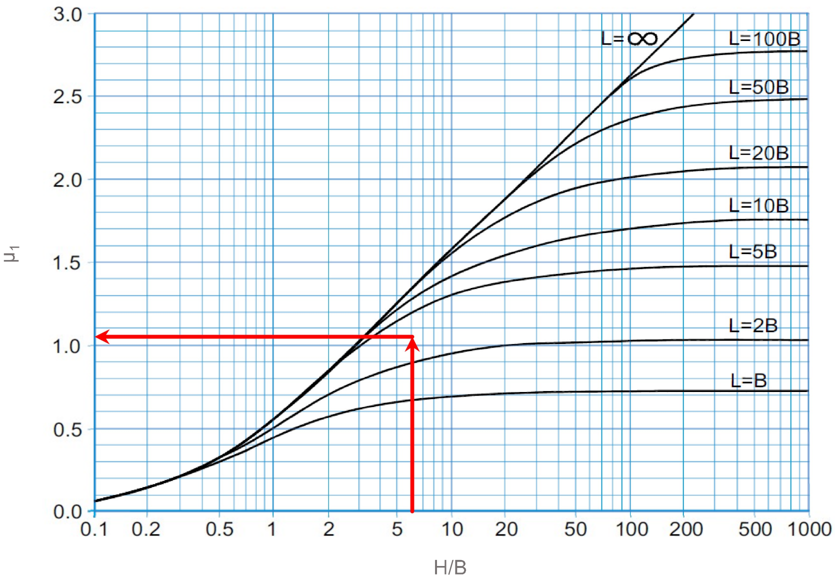
Ratio of depth to applied load breadth, H_p/B

$H_2/B =$ 3.62 / 0.60 — H_2/B = 6.03

Ratio of applied load length to breadth, L/B

L/B = 2.10 / 0.60 — L/B = 3.50

Fig. 29



$H_p/B =$ 6.03

L = 3.5 B

Reference	Calculations	Output

Settlement factor, $\mu_{1,2}$ — $\mu_{1,2}$ = 1.05

Settlement in layer 2, ρ_3

$\rho_3 = q \times B \times (\mu_{1,2} - \mu_{1,1}) / E_{u2} = (250 \times 0.60 \times (1.05 - 0.85) / (12 \times 10^3)) \times 10^3$ — ρ_3 = 2.53 mm

29. Absolute settlement

Absolute settlement, ρ_E

$\rho_E = \rho_1 + \rho_2 + \rho_3 = 1.00 + 1.74 + 2.53$ — ρ_E = 5.27 mm

Allowable absolute settlement, ρ_{max}

$\rho_{max} = \min\{ [B/10] ; 50.00\} = \min\{ [0.60 / 10] \times 10^3 ; 50.00\}$ — ρ_{max} = 50.00 mm

Utilisation,

$1.0 < \rho_E / \rho_{max} = 5.27 / 50.00$ — Utilisation = 11%

PASS, utilisation ≤ 100%

30. Differential settlement

Shortest distance between centres of piling rig tracks, L_x — L_x = 1.80 m

Maximum differential settlement, $\Delta\rho_E$

$\Delta\rho_E = \rho_E / L_x = 5.27 / 1.80$ — $\Delta\rho_E$ = 2.93 mm/m

Allowable differential settlement, $\Delta\rho_{max}$ — Allowable differential settlement, $\Delta\rho_{max}$ = 5.00 mm/m

Utilisation,

$1.0 < \Delta\rho_E / \Delta\rho_{max} = 2.93 / 5.00$ — Utilisation = 59%

PASS, utilisation ≤ 100%

Reference	Calculations	Output
	[This page has been specifically left blank]	

Appendix B: Output Example Check certification.

RICHTER

CALCULATIONS & RISK ASSESSMENTS

Piling Platform

PROJECT	Test 1
CLIENT	Test
DOCUMENT NUMBER	1001-RIC-XX-XX-CA-Z-10001_P01
REVISION	P01
DATE	21/07/23

www.richter.global

ENGINEERING VALUE TOGETHER

RICHTER

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G91_1001_100_P01

DOCUMENT CONTROL

PROJECT	Test 1
JOB/TASK REF	1001 - 100
TASK TITLE	Piling Platform
DOCUMENT NUMBER	1001-RIC-XX-XX-CA-Z-10001_P01
REVISION	P01

	NAME	POSITION	SIGNATURE	DATE
DESIGNED BY	Abbas Miah	Graduate Engineer		
CHECKED BY	Nicholas Cage	Senior Engineer		
APPROVED BY	John V	Director		

ISSUE HISTORY

REV.	ISSUE DATE	DESCRIPTION	DESIGNED BY	CHECKED BY	APPROVED BY

RICHTER

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G91_1001_100_P01

CONTENTS

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

DESIGN INFORMATION RECEIVED

NUMBER	TITLE	REVISION

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G91_1001_100_P01

BASIS OF DESIGN / ASSESSMENT

SUMMARY OF DESIGN

Design of working platform to support the following plant:

Rig: Test1

KEY ASSUMPTIONS

The platform is predominantly flat with no gradient greater than 1:10
There are no buried services that can be influenced and/or loaded by the platform or the plant it supports.
Where there are adjacent slopes, buried structures or retaining walls these will be assessed by others.
The loading information and "FPS" track load data is an accurate representation of all plant loads applied.
Other than the above plant loading no other significant loads are applied to the platform.
Any load spreaders or mats placed on the platform to spread loads are fit for purpose and are assessed by others.
The geotechnical information provided to Richter is an accurate representation of site conditions.

ACTIONS

Standing, traveling, handling/lifting track pressure of 250 kN/m2 is applied over an area of 2.1m x 0.6m and a Penetrating/Extracting track pressure of 250kN/m2 is applied over an area of 2.1m x 0.6m

STRUCTURAL DESIGN

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

RICHTER

Test 1 - Piling Platform

1001-100
G91_1001_100_P01

www.richter.global

BASIS OF DESIGN / ASSESSMENT

GEOTECHNICAL DESIGN

• The working platform is designed in accordance with TWF Method, installed and compacted in accordance with SHW Series 600 Specification of Highways works.
• The 2 load cases considered in this design are as follows:
- Load case 1 applies to standing, travelling and handling
- Load case 2 applies to penetrating and extracting
• The working platform requirements are determined using the most onerous ground properties provided:

Granular Subgrade:
Density of material γ = 16 kN/m³
Angle of internal friction Φ = 30°
Elastic Modulus = 30 MPa

Cohesive Subgrade:
Density of material γ = 17 kN/m³
Undrained shear strength cu = 20 kN/m²
Elastic Modulus = 12 MPa

Platform characteristics
Density of material γ = 20kN/m³

DEPARTURES / DEROGATIONS

The following have not been designed or checked here:
Any load spreaders or mats placed on the platform to spread loads.
Any slopes, retaining walls or buried structures, if present, that may be loaded or influenced by the platform or plant using the platform.

DESIGN REFERENCES

- **BRE 470 Working platforms for tracked plant**
- **Working Platforms - Design of granular working platforms for construction plant - A guide to good pracice - TWf 2019:02**
- **BS 5975:2019 Code of practice for temporary works procedures and the permissible stress design of falsework**
- **BS 8004:2015 Code of practice for foundations**
- **BS EN 1990:2002+A1:2010 Eurocode. Basis of Structural Design**
- **BS EN 1991-3:2006 Eurocode 1. Actions on structures. Actions induced by cranes and machinery**

DESIGN SOFTWARE USED

- None

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G94_1001_100_P01

DESIGN RISK ASSESSMENT

NO.	HAZARD	LIKELIHOOD	SEVERITY	RISK RATING	DESIGN CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING	ADDITIONAL CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING
1	Poor ground conditions lead to failure (excessive settlement, bearing failure).	2	3	6	Design uses conservative ground parameters based upon GIR. Factors of safety in accordance with EC7 used and designed to TWF Method.	1	3	3	No further measures required.	1	4	4
2	Striking/damaging power cables, drains, pipes and other services	2	3	6	Based on information provided of the site, there are no buried services in proximity of the works.	1	3	3	No further measures required.	1	3	3
3	Un-even ground and soft spots	4	3	12	Subgrade to be proof rolled. Any soft spots to be removed and replaced with compacted platform material	2	3	6	No further measures required.	1	4	4
4	Low quality of working platform material leads to failure	3	3	9	Design to closely specify material used and correct method for placement, refer to BRE 470 and SHW	2	2	4	No further measures required.	1	4	4

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G94_1001_100_P01

DESIGN RISK ASSESSMENT

NO.	HAZARD	LIKELIHOOD	SEVERITY	RISK RATING	DESIGN CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING	ADDITIONAL CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING
5	Use of alternative plant - not designed for.	3	4	12	The design considers the use of the 1st and 2nd load cases for piling rigs.	1	2	2	If entirely different plant is required, the design engineer to be consulted prior to works commencing onsite.	1	4	4
6	High ground water level causes loss of ground strength	4	4	16	User inputs ground water (GW) information. Design calculates ground strength accordingly and clearly shows expected GW level.	1	3	3	User to confirm ground water conditions are as shown on the drawing.	1	4	4
7	Adjacent ground slope or retaining wall or buried structure leads to loss of ground strength and or failure of adjacent works	4	4	16	Automated designer checks that designed support is outside the 'danger area' defined by CIRIA 703 section 2.6. Confirmed on drawing	1	4	4	Where the support is within the 'danger area' defined by CIRIA 703 section 2.6 a separate check is required.	1	4	4
8	Platform deteriorates and/or becomes contaminated over prolonged use leading to loss of strength	4	4	16	Drawing clearly indicates mat requires regular inspection, clearance of contamination and maintenance	1	4	4	No further measures required	1	4	4

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G94_1001_100_P01

DESIGN RISK ASSESSMENT

NO.	HAZARD	LIKELIHOOD	SEVERITY	RISK RATING	DESIGN CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING	ADDITIONAL CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING
9	Rain water ponds on the surface causing loss of strength	3	4	12	Mat to be laid to falls, fall indicated on drawing	1	4	4	No further measures required	1	4	4
10	Bearing resistance is reduced at the edges of the mat.	3	4	12	Define minimum edge distance such that edge effects are insignificant	1	4	4	No further measures required	1	4	4
11	The existing ground has vegetation, debris and organic soil (topsoil) inappropriate to sustain load	3	3	9	Require the removal of debris, vegetation and top soil prior to placing the granular mat.	1	3	3	No further measures required	1	3	3
12	Placed platform material and existing ground below mix at the interface during placement causing loss of strength	3	4	12	Provide geofabric separation membrane between the two	1	4	4	No further measures required	1	3	3

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G94_1001_100_P01

DESIGN RISK ASSESSMENT

NO.	HAZARD	LIKELIHOOD	SEVERITY	RISK RATING	DESIGN CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING	ADDITIONAL CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING
13	Placed membrane prevents flow of surface water causing ponding above and loss of strength.	3	4	12	Geotextile to be fabric type, not plastic or PVC	1	4	4	No further measures required	1	3	3

RICHTER

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G94_1001_100_P01

RISK ASSESSMENT MATRIX

ASSESSED RISK VALUE							
ASSESSED RISK VALUE (ARV) SEVERITY (S) x PROBABILITY (P)			SEVERITY				
			No Injury / damage	Minor Injury / damage	Major Injury / damage	Single fatality / collapse / failure	Multpile fatality / collapse / failure
			1	2	3	4	5
PROBABILITY	Negligible	1	1	2	3	4	5
	Unlikely	2	2	4	6	8	10
	Possible	3	3	6	9	12	15
	Likely	4	4	8	12	16	20
	Highly likely / Frequent	5	5	10	15	20	25

Low Risk - score between 1 - 6	Medium Risk - score between 7 - 11	High Risk - score between 12 - 25

NOTE: No Richter design is issued with a risk rating greater than 6 after Additional Control Measures have been implemented.

Identification of Residual hazards

The following symbol is used on Richter drawings to identify where the end user shall implement the additional cointrol measures indicated.

- 'DRA 01, 02' example indicates the associated risk as per the design risk assessment

DRA 01, 02

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G96_1001_100_P01

SUSTAINABILITY RISK ASSESSMENT

NO.	HAZARD	LIKELIHOOD	SEVERITY	RISK RATING	DESIGN CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING	ADDITIONAL CONTROL MEASURES	LIKELIHOOD	SEVERITY	RISK RATING
1	Co2e generation due to excavation of existing material and transportation of existing material	3	3	9	Excavation requirements minimised	2	3	6	Contractor to ensure excavated material cannot be reused locally before exporting from site.	2	3	6
2	Co2e generation due to importing and installing new material	3	3	9	TWF Method used for working platform design as it provides more economical designs reducing excavation and export requirements	2	3	6	6F2 recycled material to be used in platform	2	3	6
3	Failure of working platform, platform depth needs to be extended	3	4	12	Design follows TWF Method for calculation.	1	3	3	No further measures required	1	3	3
4	Dust: In prolonged dry weather platform surface will generate dust	3	3	9	Use course well graded material, well rolled and compacted, require maintenance	1	3	3	Wet surface of platform in prolonged dry weather to control dust	1	3	3

RICHTER

Huddersfield Office

Independence House,
Holly Bank Road,
Huddersfield,
HD3 3LX
+44 (0) 1484 637 994

www.richter.global

Test 1 - Piling Platform

1001-100
G98_1001_100_P01

DESIGN CHECK CERTIFICATE

PROJECT	Test 1		PROJECT/TASK NO.	1001
DESIGN TITLE	Piling Platform			
BRIEF REF.	XXXX		CHECK CATEGORY	2
CHECK CERTIFICATE NUMBER		G98_1001_100_P01	REVISION	P01

DESIGNED BY	Abbas Miah	SIGNATURE	
POSITION	Graduate Engineer	DATE	

INFORMATION CHECKED (Drawing/document ref.)

DESIGN CRITERIA AND REFERENCES

- BRE 470 Working platforms for tracked plant
- Working Platforms - Design of granular working platforms for construction plant - A guide to good pracice - TWf 2019:02
- BS 5975:2019 Code of practice for temporary works procedures and the permissible stress design of falsework
- BS 8004:2015 Code of practice for foundations
- BS EN 1990:2002+A1:2010 Eurocode. Basis of Structural Design
- BS EN 1991-3:2006 Eurocode 1. Actions on structures. Actions induced by cranes and machinery

FURTHER COMMENTS

CERTIFICATION

We certify that reasonable skill and care has been used to check the concept, adequacy and correctness of the above design in accordance with the design brief, criteria and references listed.

CHECKED BY	Nicholas Cage	SIGNATURE	
POSITION	Senior Engineer	DATE	

We certify that this check has been conducted by a competent person to the above check category in accordance with Richter ISO9001 certified design procedures.

APPROVED BY	John V	SIGNATURE	
POSITION	Director	DATE	

Appendix C: Output Example Sustainability (prototype)

Reference	Calculations	Output

iStructE Guide: How to calculate embodied carbon

Working Platform – ECO Report

Key Assumptions

- 6F2 or 6F5 material is assumed to be used for the construction of working platform.
- Sands and aggregates are assumed to be produced from recycled resources, no heat treatment, bulk, loose.
- Material is assumed to be supplied from local manufacturers by road (max distance 50km).
- Minimum of 300mm of Topsoil is assumed to be excavated prior to the construction of working platform.
- Total project cost is assumed to be £20,000.

Document Reference

- 1337-RIC-XX-XX-DR-Z-42001 P01
- 1337-RIC-XX-XX-DR-Z-42002 P01
- 1337-RIC-XX-XX-DR-Z-42003 P01
- 1337-RIC-XX-XX-DR-Z-42004 P01

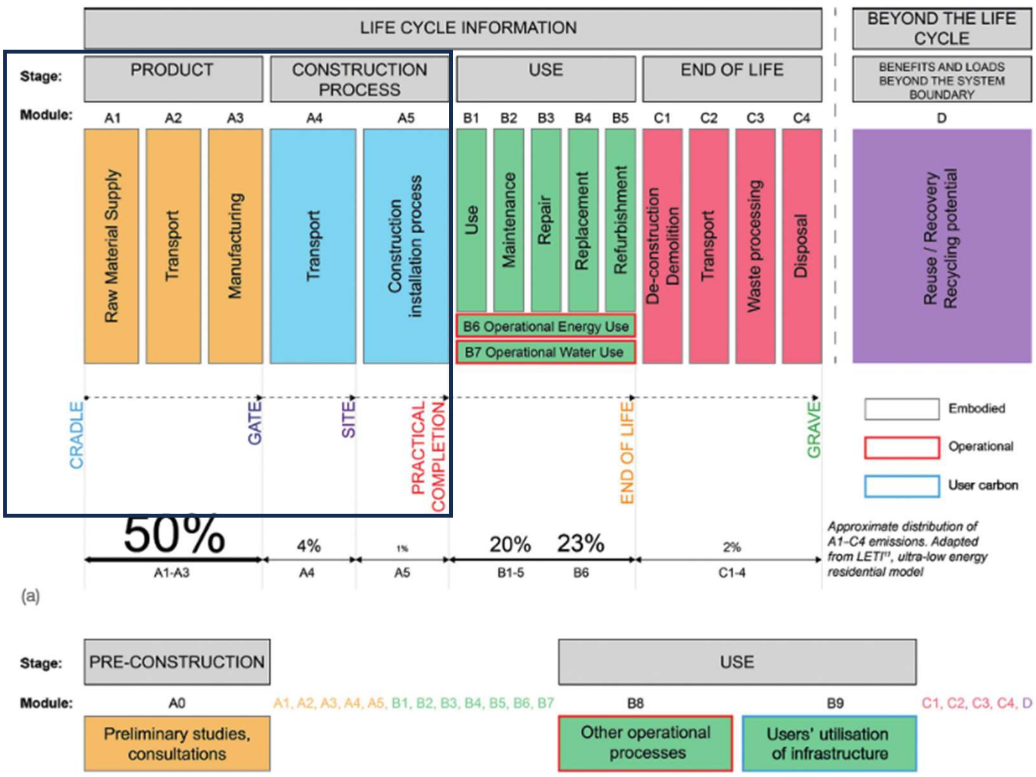


Figure 1 BS EN 15978 Life cycle stages

Limitations/Exclusions

- This ECO report only considers modules A1-A5.
- Embodied Carbon resulting from modules B1-B5, C1-C4 and D are excluded.

Table 1 Design & Carbon Data

DESIGN METHOD	DEPTH (m)	WEIGHT (t)	CARBON EQUIVALENT, tCO_2e	CARBON VALUATION, £40/tCO_2e
BR470	1.42	14479.96	239.230	9569.2
EC7	0.300	3059.2	49.46	1978.4
T-Value	0.300	3059.2	49.46	1978.4
TWf	0.650	6628.2	109.510	4380.4

*Use Carbon Price Tracker tool for current price, link below:
[Carbon Price Tracker | Ember (ember-climate.org)](ember-climate.org)

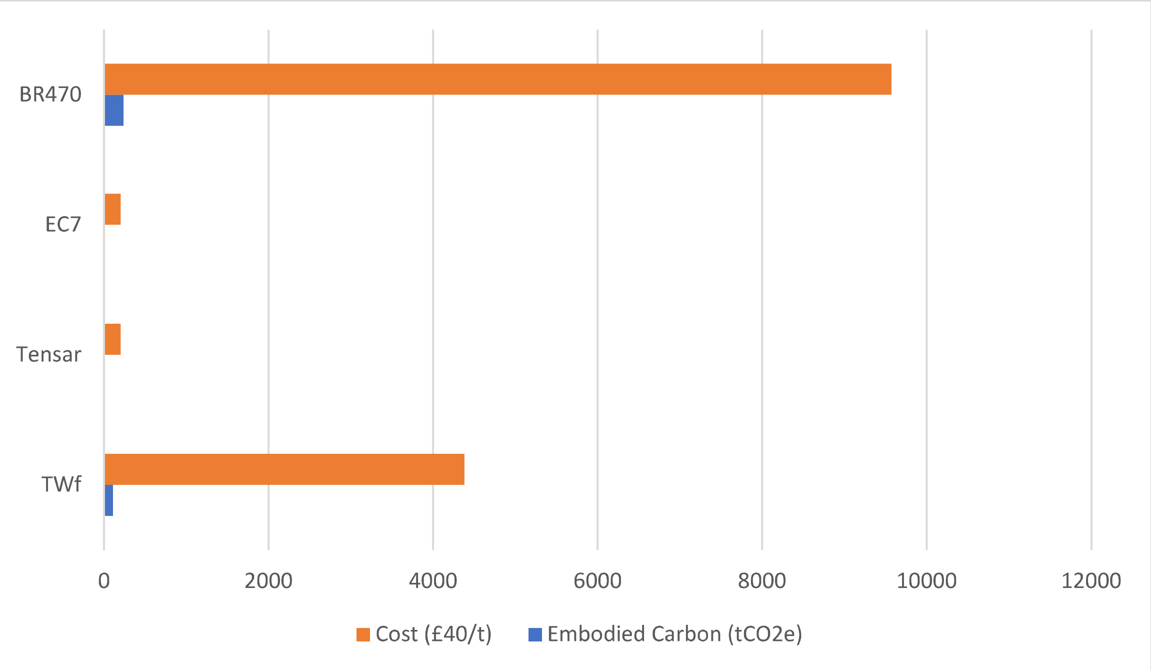


Figure 2 Carbon Value Comparison

<u>Carbon Cost Review</u>

- The above chart compares embodied carbon content and associated carbon cost for each method.
- It is evident that Eurocode 7 method provides the most cost effective and eco friendly solution for the required working platform.
- Eurocode 7 method Carbon cost is £204.00 whereas BR470 method Carbon cost is £9569.20, and TWf method Carbon cost is £4380.40.
- Therefore, Eurocode 7 is the chosen method for this design.
- Overall savings, when EC7 method compared to BR470, is £9365.20.

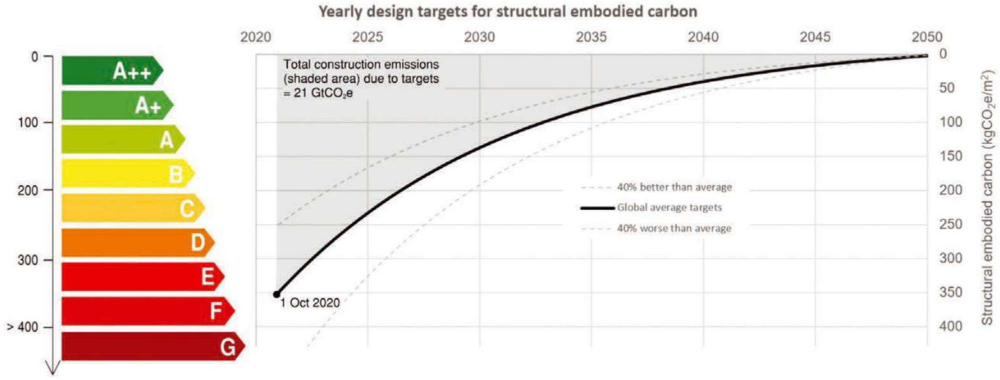


Figure 3 SCORS Rating (iStructE guide)

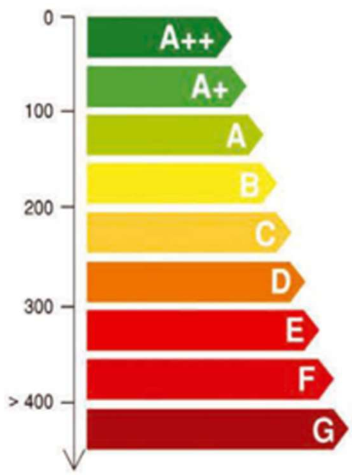
<u>SCO_2RS Rating</u>

Working Platform Area = 100m x 50m

Table 2 Embodied Carbon Data

Working Platform Design Method	Embodied Carbon per square meter ($kgCO2e/m^2$)
BR470	47.32
EC7	10.09
T-Value	10.09
TWf	21.85

From the table above, EC7 is gives the lowest embodied carbon per square meter area.



A++ 10.09 $kgCO_2e/m^2$

Figure 4 Project SCORS Rating

This project has a SCORS rating of A++

Rating based on total A1-A5 emissions for substructure and superstructure, excluding sequestration or offsetting, in accordance with the *IStructE guide How to calculate embodied carbon* *(EXAMPLE RATING ONLY, NOT TO BE USED FOR EXTERNAL SUBMISSIONS)*

BIBLIOGRAPHY

Albogamy, A., Dawood, N. and Scott, D. (2014) 'A risk-management approach to address construction delays from the client aspect', *Computing in Civil and Building Engineering*, pp. 1497–1505. Available at: http://itc.scix.net/data/works/att/w78-2014-paper-186.pdf (Accessed 27 December 2023).

Allplan (2023) *10 practical examples of design automation*. Munich: ALLPLAN.

Almirall, E., Bakici, T. and Wareham, J. (2013) 'A smart-city initiative: the case of Barcelona', *Journal of the Knowledge Economy*, 4 (2), pp. 135–148. Available at: https://link.springer.com/article/10.1007/s13132-012-0084-9 (Accessed 27 December 2023).

American Concrete Institute (ACI) (2019) *Foundations for dynamic equipment*. ACI 351.3R-19. Farmington Hills, MI: ACI.

Anon. (1928) *A brief history of the Institution of Civil Engineers with an account of the Charter Centenary Celebration June 1928*. London: William Clowes & Sons.

Appleby, S. (2003) 'Multilingual information technology', *BT Technology Journal*, 21 (1), pp. 75–83. Available at: https://digital-library.theiet.org/content/books/10.1049/pbbt008e_ch9 (Accessed 27 December 2023).

Bailey, J. et al. (2015) 'Predictive risk modelling of real-world wastewater network incidents', *Procedia Engineering*, 119, pp. 1288–1298. Available at: https://doi.org/10.1016/j.proeng.2015.08.1076 (Accessed 27 December 2023).

Bell, B. and Simpkin, S. (2013) 'Domesticating parametric design', *Architectural Design*, 83 (2), pp. 88–91. Available at: https://doi.org/10.1002/ad.1560 (Accessed 28 December 2023).

Bentley (Valois, F.) (2025) 'How generative AI is transforming civil site design and engineering', *Building Transformations*, 12 February. Available at: https://www.buildingtransformations.org/articles/how-generative-ai-is-transforming-civil-site-design-and-engineering (Accessed 12 February 2025).

Bharwani, S. (1996) 'The MIT design studio of the future: virtual design review', *Computer Supported Cooperative Work*, 10, abstract only. Available at: https://dl.acm.org/citation.cfm?id=318423 (Accessed 27 December 2023).

Bielefeldt, A.R. (2013) 'Pedagogies to achieve sustainability learning outcomes in civil and environmental engineering students', *Sustainability*, 5 (10), pp. 4479–4501. Available at: https://doi.org/10.3390/su5104479 (Accessed 28 December 2023).

Blocken, B. (2014) 'Fifty years of computational wind engineering: past, present and future', *Journal of Wind Engineering and Industrial Aerodynamics*, 129, pp. 69–102. Available at: https://doi.org/10.1016/j.jweia.2014.03.005 (Accessed 27 December 2023).

British Standards Institution (2017) *BS 8888:2017 Technical product documentation and specification*. London: BSI.

British Standards Institution (2019) *BS 5975:2019 Code of practice for temporary works procedures and the permissible stress design of falsework*. London: BSI.

Bryden Wood (2025) *Automating design*. London: Bryden Wood.

Burnett, N. et al. (2024) *The UK's plans and progress to reach net zero by 2050.* House of Commons Library Research Briefing CBP-9888. Available at: https://commonslibrary.parliament.uk/research-briefings/cbp-9888/ (Accessed May 2025).

Chandwani, V., Agrawal, V. and Nagar, R. (2013) 'Applications of soft computing in civil engineering: a review', *International Journal of Computer Applications*, 81 (10), pp. 13–20. Available at: https://doi.org/10.5120/14047-2210 (Accessed 28 December 2023).

Chesbrough, H. (2003) *Open innovation: the new imperative for creating and profiting from technology*. Boston, MA: Harvard Business School Press.

ConSIG Construction Wiki (2020) *Temporary works design – a quality-management perspective*. DesigningBuildings Wiki. Available at: https://www.designingbuildings.co.uk/wiki/Temporary_Works_Design_-_A_Quality_Management_Perspective (Accessed 24 May 2025).

Coules, H.E. (2018) 'On predicting the interaction of crack-like defects in ductile fracture', *International Journal of Pressure Vessels and Piping*, 162, pp. 98–101. Available at: https://doi.org/10.1016/j.ijpvp.2018.01.003 (Accessed 27 December 2023).

Dowsett, B. (2024) 'HMRC R&D tax-credit statistics: bad news for SMEs, good news for large companies', *Myriad UK Insights*. Available at: https://myriad.uk.net (Accessed March 2025).

Dunne, P.E. (n.d.) *Mechanical calculators prior to the 19th century (Lecture 3)*. Computer Science Dept., University of Liverpool. Available at: http://www.csc.liv.ac.uk/~ped/teachadmin/histsci/htmlform/lect3.html (Accessed 14 December 2023).

Eadie, R. (2014) 'The impact of building information modelling (BIM) on public-sector tender documents for civil-engineering works', *Proceedings of the ICE – Management, Procurement and Law*, 167 (5), pp. 250–261. (Paper originally circulated as ULster University working paper, 2014.)

Eastman, C., Teicholz, P., Sacks, R. and Liston, K. (2008) *BIM Handbook: A Guide to Building Information Modeling for Owners, Managers, Designers, Engineers and Contractors.* Hoboken, NJ: John Wiley & Sons.

Fryer, T. (2019) 'Out with the old, in with the twin', *Engineering & Technology*, 14 (1), pp. 46–47. Available at: https://doi.org/10.1049/et.2019.0104 (Accessed 27 December 2023).

Grieves, M. and Vickers, J. (2017) 'Digital twin: Mitigating unpredictable, undesirable emergent behavior in complex systems', in Kahlen, F.-J., Flumerfelt, S. and Abbas, A. (eds) *Transdisciplinary Perspectives on Complex Systems: New Findings and Approaches.* Cham: Springer, pp. 85–113.

Hall, M. (2023) 'AI delivers swift design solutions', *Richter Global Journal*, 1 February. Available at: https://www.richter.global/journal/ai-delivers-swift-design-solutions (Accessed 2 March 2025).

Hammond, G.P. and Jones, C.I. (2020) *Inventory of carbon and energy (ICE), version 3.0.* Bath: University of Bath.

HSE Construction Engineering Specialist Team (2010) *Temporary works management procedures* (SIM 02/2010/04). London: HSE.

Kamel, E. et al. (2024) 'A parametric integrated design approach for life-cycle zero-carbon buildings', *Sustainability*, 16 (5), 2001. https://doi.org/10.3390/su16052001.

Kumar, S. and Devi, V. (2025) 'Application of AI in civil engineering: a comprehensive review', *IOSR Journal of Mechanical and Civil Engineering*, 22 (1), pp. 69–74.

Landsburgh, C. (2023) 'All you need to know about the revised PAS 2080 standard on carbon management', *AECOM Without Limits* blog, April. Available at: https://aecom.com/without-limits/article/all-you-need-to-know-about-the-revised-pas-2080-standard-on-carbon-management/ (Accessed May 2025).

McKinsey & Company (2020) *Decoding digital transformation in construction*. McKinsey Insights, 14 October. Available at: https://www.mckinsey.com/capabilities/operations/our-insights/decoding-digital-transformation-in-construction (Accessed 28 February 2025).

OpenAsset (2025) 'AI in civil engineering: fifteen surprising ways it's already being used', *AEC Marketing Blog*, 8 May. Available at: https://openasset.com/resources/ai-in-civil-engineering/ (Accessed 5 March 2025).

Panko, R.R. (1998) 'What we know about spreadsheet errors', *Journal of End-User Computing*, 10 (2), pp. 15–21.

Rogers, C. (2016) 'The need for verification, validation and QA of computer-aided calculation', *The Structural Engineer*, 94 (3), pp. 48–51.

Rogers, E.M. (2003) *Diffusion of innovations* (5th ed.). New York: Free Press.

RSM UK (2023) ‘How much is an R&D tax-relief claim worth for SMEs?’, *RSM UK Insights*. Available at: https://rsmuk.com (Accessed March 2025).

Sacks, R., Koskela, L., Dave, B. and Owen, R. (2010) ‘Interaction of lean and building information modeling in construction’, *Journal of Construction Engineering and Management (ASCE)*, 136(9), pp. 968–980.

Sawhney, R. (2024) ‘How to turn professional services into products’, *MIT Sloan Management Review*, 14 August.

Sheedy, C. (2021) ‘PI insurance in engineering: beyond the rising premiums’, *CreateDigital*, 17 November. Available at: https://createdigital.org.au/pi-insurance-in-engineering-beyond-the-rising-premiums/ (Accessed 24 May 2025).

Soltani, J. (2024) ‘Unlocking business potential: the power of outcome-based services in the age of Industry 4.0’, *Schneider Electric Blog*, 9 May. Available at: https://blog.se.com (Accessed 5 March 2025).

Succar, B. (2009) ‘Building information modelling framework: A research and delivery foundation for industry stakeholders’, *Automation in Construction*, 18(3), pp. 357–375.

Temporary Works Forum (2019) *TWf2019:02 – Working platforms: design of granular working platforms for construction plant*. London: TWf.

Temporary Works Forum (2020) *Embodied carbon in temporary works: guidance document.* London: TWf.

The Civil Engineer (2025) ‘Temporary works go digital: enhancing safety and sustainability’, *The Civil Engineer*, 14 May.

Valois, F. – see *Bentley (Valois, F.)* above.

Venkatesh, V. et al. (2003) ‘User acceptance of information technology: toward a unified view’, *MIS Quarterly*, 27 (3), pp. 425–478.

Waddington, A. (2023) ‘How integrating AI is transforming the engineering design process’, *Shepherd Gilmour Blog*, 21 January.