



Digital Resilience

Digital Twins for Climate Resilience

D2.1 Digital Resilience Real Cases / Experiences Report

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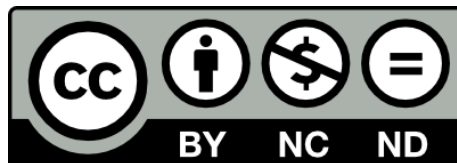
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EXECUTIVE SUMMARY

This executive summary presents the key messages of the Digital Resilience Real Cases / Experiences Report (D2.1). The report combines a multi-country needs analysis with a curated corpus of real-world implementations to determine how digital twins can bolster climate resilience across the construction and civil-infrastructure domain. By bringing together learner and practitioner perspectives with field-tested practices, the document outlines a pragmatic pathway from concept to applied competence.

Stakeholder feedback indicates high awareness of digital-twin concepts but a shortfall in sustained, hands-on experience. Respondents emphasise the value of case-based learning anchored in climate-resilience scenarios, foundational materials that clarify terminology and architecture, and practical guidance that connects tools to decisions in real projects. Preferences converge on learning experiences that are modular, applied, and oriented toward measurable improvements in design, operations, and risk-informed governance.

The real-case analyses surface recurring barriers and enabling practices. Common challenges include data availability and interoperability, cybersecurity and privacy, computational demands, real-time synchronisation, legacy-process integration, cost constraints, and skills gaps. Successful initiatives counter these through disciplined data-management and sharing practices, incremental scaling from focused use cases, and judicious use of cloud and edge resources. They integrate workflows that combine BIM, sensing, and analytical models; formalise governance through standards and guidelines; and rely on cross-functional teams to sustain adoption and trust.

These findings translate into clear curriculum implications. Training should interleave fundamentals (data, models, feedback loops), data competencies (quality assurance, semantics, interoperability), and computational tooling (simulation, BIM integration, and real-time monitoring). Climate-specific application strands should include energy and resource efficiency, stress-testing of assets under extreme events, and adaptation planning. Equally important are organisational integration, communication of insights to decision-makers, and baseline cyber-risk awareness. Overall, D2.1 provides an evidence-based foundation for DigitalResilience training that prioritises actionable competence over theory and positions digital twins as a practical lever for resilient design, operations, and governance under climate stress.



CONTENT

1. Introduction	4
2. Results and Analysis	4
3. Conclusion	9



1. INTRODUCTION

The DigitalResilience needs analysis was conducted to understand the background knowledge of target audiences and pinpoint curricular needs for digital twin technology in climate-resilient civil engineering. A mixed-method questionnaire of 16 questions (15 closed-ended and one open-ended) was administered across three countries – Turkey, Portugal, and Spain – reaching a diverse group of participants. These participants were categorized into Future Professionals, Young Professionals, and Stakeholders. Future Professionals comprised higher education students in civil engineering and related fields who have a strong interest in digital technologies and climate resilience. Young Professionals were recent graduates (within about five years) in similar fields who have entered the workforce and seek to enhance their skills in digital twinning and climate adaptation. The Stakeholders group included more seasoned individuals such as educators from vocational and higher education institutions (involved in curriculum development and training), researchers with expertise in digital twins and climate resilience, and industry experts in construction and engineering. By engaging these groups through the survey, the project aimed to gather insights that would inform the development of a tailored training curriculum, as well as recommendations and guidelines for integrating digital twin technology into education and practice. In parallel with the survey, the consortium reviewed a collection of real-world case studies and examples of digital twin applications in the construction and climate resilience domain. Analyzing these cases provided further context on practical challenges and successes, ensuring that the needs analysis would reflect both stakeholder perceptions and empirical lessons from the field.

2. RESULTS AND ANALYSIS

A total of 53 individuals responded to the needs analysis survey across Spain, Portugal, and Turkey, providing a balanced representation of the three target groups. Approximately one-third of the respondents were still university students, another third were recent graduates now working in the sector, and the remaining were educators, researchers, or industry experts. This balance means the findings capture perspectives from both newcomers and experienced stakeholders in the field of digital twins for construction. Among all respondents, awareness of digital twin technology was relatively high – about three-quarters of those surveyed had heard of the concept. However, hands-on experience was much more limited: only roughly 38% of participants had ever used any application related to digital twin technology in their work or studies. Formal education and training in this area were even scarcer. Only about one in four respondents had attended any course or training specifically on digital twin technology, underscoring a considerable gap in formal learning opportunities. This discrepancy between general awareness and practical experience indicates that while the concept of digital twins is circulating within the civil engineering and construction community, many individuals have not yet had the chance to apply it or receive structured instruction on it.

The survey results highlight a strong desire for educational resources to bridge this gap. A large majority of participants expressed that having access to case studies on the application of digital twins in construction and engineering would be highly useful. In fact, roughly 77% indicated such case-based learning resources would



be “definitely” or “most likely” beneficial for them, suggesting that practitioners and students alike are keen to learn from real examples. An even greater proportion, over four-fifths of respondents, felt that basic learning materials on digital twin technology would be useful to them. Similarly, about 81% affirmed the value of having guides and resources integrated into curricula or professional development. These findings demonstrate a clear appetite for foundational content and practical guidance on digital twins. Many of those who were unsure (responding neutral) about the usefulness of such resources turned out to be individuals who had never participated in any digital twin training before – implying that their neutrality may stem from unfamiliarity. Very few respondents believed that these resources would not be useful; notably, those who did express skepticism also tended to have neither prior training nor experience with digital twin applications, which suggests that exposure plays a role in perceived usefulness.

Despite the generally high awareness of digital twin technology, the survey also revealed that specific exposure to climate-resilience applications of digital twins is minimal. Nearly half of the respondents (around 46%) had never conducted any analysis related to climate change impacts – such as wind or thermal effect analysis – in the context of their work or studies. The other half (54%) had engaged in some form of climate-related analysis, but only about half of that subgroup had used digital twin technology as part of those analyses. In other words, a significant portion of those who deal with climate resilience in their work have not yet incorporated digital twin tools into that work. Furthermore, the vast majority of participants had never accessed guidelines or reference materials where digital twin applications are used specifically for climate resilience. Around 92% of respondents said they had not encountered any guideline documents marrying these topics. Likewise, almost no one had enrolled in training programs focused on using digital twins for climate resilience – only a single respondent (roughly 2%) had such experience. This lack of prior exposure underlines that the intersection of digital twinning and climate adaptation is a relatively new or underdeveloped area in training and practice, even if interest in it is growing.

Participants’ expectations and openness to future opportunities in this niche were cautiously optimistic. When asked how likely they would be to use guidelines for integrating digital twins into educational or professional training, many respondents signaled a positive outlook: a notable number said they would definitely or most likely make use of such guidelines if available. About 18 respondents fell into this optimistic group, reflecting a substantial demand. Meanwhile, around 25 respondents – nearly half of the sample – remained neutral on this question. These neutral respondents largely overlap with those who had never seen such guidelines before, which suggests that their hesitance could be due to uncertainty about what those guidelines would entail or how they might help. A smaller subset, roughly 10 people, felt that having such guidelines would not likely benefit them. A similar pattern appeared when participants considered enrolling in dedicated training programs that use digital twin applications for climate resilience: close to half signaled strong interest, and most of the rest were neutral (again likely owing to lack of familiarity), with only a handful not inclined to pursue such training. In summary, even though direct experience with digital twins in climate resilience is rare, there is a broad recognition among the community that more knowledge, case examples, and formal guidance in this area would be valuable. The survey data did not show stark differences between the three countries in these overall trends – future and young professionals in Spain, Portugal, and Turkey alike face these learning gaps – though it was noted that many of the respondents who had never heard of digital twins at all were from the non-EU cohort (in this case, largely the Turkish participants). This hints at some regional disparity in exposure, but the interest in learning about the technology was common across all countries.



In addition to the closed-ended questions, the questionnaire included an open-ended query that invited participants to elaborate on what they see as needs or opportunities for using digital twins in their field. The qualitative responses to this open question echoed and enriched the quantitative findings. A recurring theme in these responses was the need for useful tools and methods to achieve sustainable and eco-friendly design in construction. Respondents emphasized that digital twin technology should aid in optimizing designs for sustainability – for example, by improving energy efficiency or reducing waste – aligning with the European Union’s broader green objectives. Another area frequently mentioned was advanced building materials: participants expressed interest in how digital twins could help in selecting or innovating materials that enhance resilience (for instance, materials that perform better under extreme conditions or have lower environmental impact). Extreme weather and climate change adaptation emerged as a critical concern as well. Contributors highlighted the importance of using digital twins to model and prepare for scenarios like severe storms, heatwaves, or other climate-induced stresses on infrastructure. They see value in digital twins providing predictive insights and decision-support in the face of such extreme events. The notion of predictability and decision-support more generally was a prominent point – many believe digital twin tools could improve forecasting and scenario analysis, thereby supporting better decision-making in planning and managing projects. These qualitative insights reinforce the survey’s quantitative trends: they point to a strong demand for knowledge in leveraging digital twins for sustainability, material innovation, and climate resilience. All of these areas correspond to pressing challenges in construction and engineering today, and they dovetail with the practical issues and solutions that emerged from the analysis of real case studies.

The project’s case study analysis involved reviewing 44 real-world instances of digital twin implementation relevant to construction and climate resilience. These cases ranged from research prototypes to applied industry projects, and examining them provided a clearer picture of the challenges typically encountered in practice, as well as the lessons learned through those experiences. A number of common challenge themes were evident across many of the case studies. One predominant challenge relates to data. For a digital twin to function effectively – especially one aimed at complex tasks like simulating climate impacts on infrastructure – it requires large volumes of high-quality data from various sources. Many cases reported difficulties in acquiring sufficient data or in ensuring the data’s accuracy and relevance. In some instances, data needs to be collected in real time (for example, from sensors monitoring structural health or environmental conditions), and the case studies noted that maintaining a continuous, reliable data flow can be technically challenging. Additionally, data often originates from different systems and stakeholders, leading to issues of data integration and interoperability. Several digital twin initiatives struggled to integrate multiple datasets – for instance, combining engineering drawings with sensor readings and weather data – because the formats and standards varied, or because different organizations were hesitant to share information. This lack of standardization in data formats and the general complexity of harmonizing data from disparate sources was a recurring obstacle. Related to that, concerns about data privacy and security were occasionally highlighted, particularly in cases where sensitive information was involved or where continuous data streaming raised cybersecurity questions. In at least one case, the need for public consent and trust was mentioned – the idea that deploying certain AI-driven digital twin solutions would only be feasible if society trusted how their data was used and protected.

Another significant category of challenges revolved around technological and computational constraints. Digital twins can be computationally intensive, as they often involve real-time processing of data and complex simulations or AI algorithms to mirror and predict real-world behavior. A number of cases pointed out the high



computational demand required: running detailed physics-based models or AI analyses in real time (or near real time) demanded robust computing infrastructure and efficient algorithms. Without adequate computational resources or optimized code, some projects found it difficult to scale up their digital twin models or achieve the desired responsiveness. This issue sometimes manifested as a trade-off between model fidelity and performance – for example, higher resolution models or more sophisticated simulations offered better accuracy but could become too slow or costly to run continuously. Real-time monitoring itself was a challenge noted in multiple studies. Ensuring that digital twins reflect the latest state of the physical asset means continuously updating the model with new data (from sensors, drones, etc.), and any lag or interruption in data flow can reduce the twin's effectiveness. Cases that involved dynamic environments – such as active construction sites or infrastructure exposed to changing weather – emphasized how hard it can be to keep the digital model in sync with reality at all times. On the technological front, integrating new digital twin systems with legacy systems in construction was also highlighted as a hurdle. The construction and civil engineering sector is traditionally not as digitized as other fields, and one case explicitly noted that construction is among the least digitized industries, slow to adopt new technologies. Hence, introducing a cutting-edge digital twin into an existing workflow often meant dealing with outdated or non-digitized processes and ensuring compatibility with the tools and practices already in use. This kind of integration challenge is both technical and organizational: it requires not only the right software bridges and data pipelines, but also buy-in from people who must change their routine practices.

Cost and resource constraints formed another theme among the challenges. Several case studies mentioned the high cost associated with implementing digital twins. These costs come from various sources: purchasing and installing sensor networks for data collection, investing in computational infrastructure or cloud services to run complex models, and dedicating skilled personnel to develop and maintain the digital twin. For example, one case noted the expense of deploying sensors extensively across an infrastructure, while another pointed out the significant investment of time and expertise needed to set up a functional building-scale digital twin. In some instances, the maintenance costs (such as keeping sensors calibrated and operational over long periods) were also a concern. Especially for projects with constrained budgets, these financial and resource requirements could be prohibitive. A few challenges touched on the human and organizational factors as well. Resistance to change and the steep learning curve for staff were implicit in examples where digital processes had to replace or augment long-established manual ones. One case study described construction sites where numerous processes and stakeholders were not yet digitized; introducing a digital twin in such an environment meant that those stakeholders needed training and convincing of the twin's value. The need for specialized expertise to interpret digital twin outputs and to manage the systems was mentioned as a challenge too – essentially, the success of these projects often hinged on having people with the right skill sets, which ties back to the shortage of training noted by the survey respondents.

Importantly, the real-world cases did not only catalogue problems; each also offered lessons learned and successful strategies to address the challenges. Aggregating the insights from these examples provides guidance on how to surmount the difficulties outlined above. A striking lesson that emerged from multiple cases is the importance of robust data management and sharing practices. When projects were able to break down data silos – for instance, by establishing common data standards or platforms that different stakeholders could use collaboratively – they saw significant improvements in outcomes. One case highlighted that comprehensive data sharing across different agencies led to more effective climate resilience strategies, implying that no single entity can have all the data needed, but a collaborative approach yields a fuller picture



of the challenges at hand. Another lesson underlined the value of integrating digital twin technology with existing engineering tools. For example, combining Building Information Modeling (BIM) with real-time sensor data and finite element analysis was shown to produce a far more accurate and useful model of a complex structure. In the case of the Sydney Opera House, it was observed that linking detailed as-built BIM data with advanced structural analysis would help in understanding long-term phenomena like creep and shrinkage in the structure – an insight broadly applicable to managing other complex assets. This demonstrates how digital twins serve as a convergence point for various technologies (BIM, Internet of Things sensors, analytical models), and that integration can enhance predictive power and decision-support.

Many case studies provided evidence that advanced analytical techniques and modern computing infrastructure can successfully tackle the computational challenges. For instance, some projects achieved real-time performance by leveraging cloud computing or optimized algorithms, allowing them to process large datasets or run heavy simulations more efficiently. Others used edge computing strategies (processing data closer to where it is collected, such as on-site devices) to reduce latency and improve real-time responsiveness. The cases also suggest that starting with a clear focus and incrementally scaling up the digital twin can help manage complexity – rather than trying to model everything at once, successful examples often began with a specific use-case (like monitoring a particular aspect of a bridge’s health or a building’s energy consumption) and then expanded the twin’s scope as confidence and capability grew. Regarding cost management, one recurring lesson is the possibility of using low-cost technology and incremental implementation. In one example, very affordable humidity sensors and simple microcontroller-based devices were embedded in a building during construction; these proved their durability and provided valuable data without requiring a huge investment. The only caveat was that some types of measurements still lacked cheap solutions (for example, surface moisture meters in that case were harder to source cheaply), but overall, the principle of starting with cost-effective tools where possible was validated. Another case that dealt with bridge inspection demonstrated an integrated approach (using drones, photogrammetry, and digital twin models) which, after initial development, showed promise in reducing long-term operational costs by making inspections more efficient and less labor-intensive. These instances illustrate that while up-front costs can be high, strategic use of technology can yield cost savings and add value over time.

The human and organizational challenges were likewise addressed in the lessons. A clear takeaway is that interdisciplinary collaboration and stakeholder engagement are key to overcoming resistance and maximizing the benefits of digital twins. Projects that involved a mix of experts – civil engineers, data scientists, IT professionals, and decision-makers – tended to navigate the implementation hurdles more effectively. In practice, this meant creating teams or working groups that could tackle problems from multiple angles, ensuring that technical solutions met practical needs on the ground. Some case studies explicitly mention identifying both the benefits and bottlenecks of digital twin deployment, which helped organizations plan better for training needs and process changes. By acknowledging bottlenecks such as the need for significant expertise and then actively investing in building that expertise (through hiring or training), those organizations were able to realize the promised benefits of improved decision-making from the wealth of data that digital twins provide. In essence, a lesson repeatedly encountered was that technology alone is not enough – institutional readiness, capacity building, and good communication among stakeholders are all vital. Additionally, developing standards and guidelines turned out to be a crucial part of some success stories. Where clear protocols existed (or were created) for data format standards, for integrating models, or for ensuring cybersecurity, the implementation of digital twins proceeded much more smoothly. This reinforces



the survey finding that people see value in guides and structured resources; the case studies show that when such frameworks are in place, they can accelerate adoption and trust in the technology.

The convergence of insights from the survey and the case studies is noteworthy. The challenges identified in the case database – ranging from data issues to skill gaps – provide context for why the surveyed students and professionals are craving more knowledge and support. For example, the prevalence of data integration problems in real projects explains why a future professional would want more training on managing data and using digital tools effectively. Likewise, the fact that many case studies dealt with climate-related issues (like extreme weather impacts or sustainable design adaptations) resonates with participants' expressed interest in using digital twins for exactly those areas. Both sources of information emphasize the need for practical, applied knowledge: survey respondents want case studies, and case studies affirm specific areas where practice can be improved. There is also a shared recognition of the importance of decision-support and predictive capabilities – survey participants mentioned predictability and better decision-making as benefits, and case lessons show that digital twins can indeed provide those advantages if implemented well. This alignment strengthens the reliability of the needs analysis: it suggests that the stakeholders' perceptions and the on-the-ground realities are pointing in the same direction, highlighting critical gaps that the DigitalResilience project's curriculum can fill.

3. CONCLUSION

In conclusion, the needs analysis – through both stakeholder input and case study review – reveals a clear imperative to build capacity in digital twin technology for climate resilience in the construction and engineering sector. While awareness of digital twins is relatively high among upcoming and current professionals, there remains a significant gap when it comes to applying this technology in practice. The survey across Spain, Portugal, and Turkey showed that only a minority have practical experience or formal education in the topic, even though most recognize its importance and express a strong appetite for learning. Real-world examples reinforce why this gap exists: deploying digital twins is a complex task, entailing challenges in data management, technical integration, and organizational readiness that are not yet widely taught in traditional engineering education. However, those same examples also demonstrate that these challenges can be overcome – and that doing so yields substantial benefits, from more sustainable designs and efficient maintenance regimes to better preparedness for climate impacts.

The findings of this analysis directly inform the direction and content of the upcoming DigitalResilience learning pathways. A number of curriculum-relevant topics emerge as crucial. First, there is a need to cover the fundamentals of digital twin technology in an accessible, applied manner, ensuring that learners who have heard of the concept also understand how it works and how it can be used in practice. This includes introducing the key components of a digital twin (data, models, real-time feedback loops) and illustrating these with concrete examples from case studies. Next, the curriculum should emphasize data competencies: since data is the lifeblood of digital twins, modules should teach how to collect, process, and manage data for digital models. This could range from handling sensor data streams and ensuring data quality, to learning about interoperability standards and data sharing protocols that allow multiple systems to work together. In conjunction with data handling, the program must address computational tools and methods. Learners should become familiar with the software and platforms commonly used for creating digital twins – for instance,



simulation environments, BIM software integration, and possibly cloud-based services for handling large-scale computations. They should also gain an understanding of real-time monitoring systems and how to maintain a live link between the physical and digital.

Given the emphasis on climate resilience, dedicated content around applying digital twins to climate and sustainability challenges will be vital. This means the curriculum should include case-based explorations of topics like using digital twins for sustainable and eco-friendly design, optimizing building or infrastructure performance under climate stressors, and modeling extreme weather events. Participants could, for example, work on projects or case analyses where a digital twin is used to simulate and improve a building's energy efficiency or to predict how an asset would behave in a flood or heatwave scenario. These topics reflect the specific interests raised by survey respondents (sustainable design, material efficiency, extreme weather analysis) and are areas where case studies have shown digital twins can make a tangible impact. Another key theme for the learning pathways is integration and interdisciplinary collaboration. To mirror real-world conditions, the curriculum should prepare learners to integrate digital twin solutions with existing practices in engineering. This could involve teaching the integration of BIM with sensor data, showing how to incorporate digital twin workflows into project management, and underscoring the importance of working in teams that span multiple disciplines. Learners should come away understanding not just the technical creation of a digital twin, but also how to embed that twin into an organizational context – for instance, how to present twin-derived insights to decision-makers or how to use them in maintenance and operation routines. Addressing cybersecurity and data privacy in the curriculum will also be important, given that trust and data protection were noted as concerns. Even a basic introduction to these topics will raise awareness so that future professionals build systems responsibly and can alleviate stakeholder worries about digital solutions.

Ultimately, the curriculum outline shaped by this needs analysis will likely cover a blend of technical skills, practical applications, and strategic understanding. By including modules on data management, computational modeling, climate-focused applications, integration strategies, and emerging best practices (like standards and guidelines development), the learning pathways will equip future professionals with the tools to overcome the challenges identified in the case studies. Just as importantly, these pathways will address the gaps and interests voiced by the stakeholders: providing the case studies, guidance, and up-to-date knowledge that so many survey participants found lacking in their current education. In doing so, the DigitalResilience project will create a training program that is tightly aligned with real needs – empowering students, young engineers, and educators in Spain, Portugal, Turkey and beyond to confidently use digital twin technology as a powerful aid in building climate-resilient infrastructure. The lessons learned from both the successes and struggles of prior projects will thus be passed on in a structured way, helping to foster a new generation of professionals who can drive innovation in the construction and engineering sector while meeting the urgent demands of climate resilience.

