TOWARDS GREENER TRANSPORTATION INFRASTRUCTURE THROUGH INNOVATIVE DIGITAL TWINS ASSESSMENT: STUDY CASE IN UZBEKISTAN

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ABSTRACT

The aim of this paper is to evaluate the use of digital due diligence in infrastructure projects through a real case study. As part of the Sustainable Development Goals, innovative digital tools are being developed to provide an advanced impact assessment, and virtual models such as digital twins are a promising technology for infrastructure projects. These models can not only provide an accurate representation, but also be used to run simulations, identify, and evaluate performance issues and generate possible improvements, leading to a more resilient and sustainable design.

The selected case study, the upgrade of the 4R180 rural road section located in Uzbekistan, was supported by the Asian Development Bank (ADB) in partnership with ORIS, to pilot a multiple-scenario digital analysis of its pavement design. First, data gathering was required to define the local context and the design solutions to be evaluated. Then, through the ORIS platform, the project and design options were digitised. The assessment of the results obtained from the ORIS platform showed that the pavement performance over its lifespan can be significantly improved by making informed and data-driven decisions at an early stage of the project.

1. INTRODUCTION

Road networks remain valuable assets for all communities around the world, making an enormous contribution to both their economic and social development. Therefore, the expansion of the network and improvement of the transportation facilities must address the primary needs of the population, but the design and construction of new infrastructures must also evolve to integrate the climate crisis, resource scarcity and social inequalities, using new digital technologies to achieve the Sustainable Development Goals envisioned for 2030.

Road engineering has seen remarkable progress in the last few decades at both construction and maintenance stages. Examples include, among others, the development of new supporting tools for the optimization of road alignments based on the project topography, the introduction of multi-criteria appraisals in which the social and environmental impact is also accounted for, or the progressive automatization of the road inspection and network monitoring (Hatta Antah et al., 2021; Inti & Kumar, 2021; Bongiorno et al., 2019).

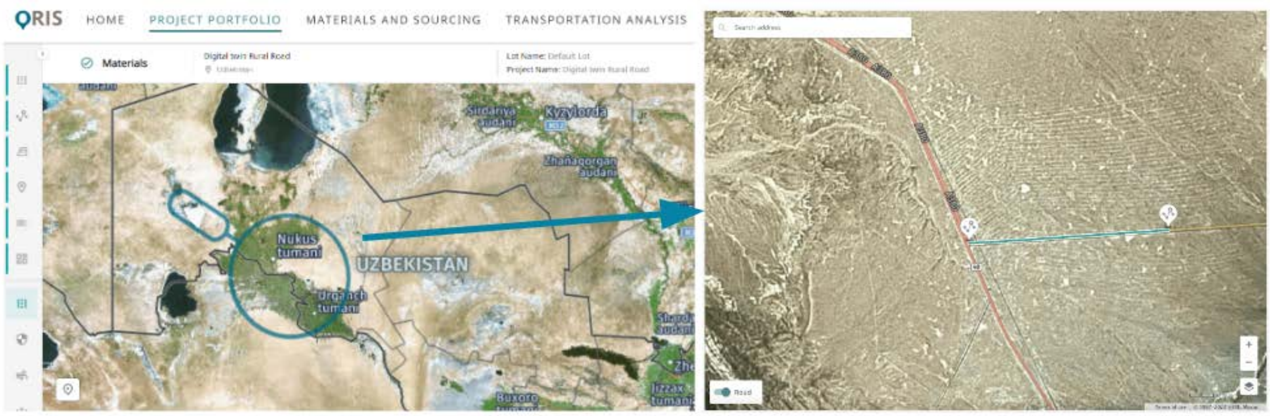
There is, however, a lack of research on the material optimization, even though it is a major factor not only on the project cost but also on its carbon footprint, counting up to

70% of embedded carbon emissions (Lokesh et al., 2022). Therefore, innovative research on road engineering should move towards the design optimization by the use of digital tools that, through data management and artificial intelligence, can also evaluate the local environment and material resources availability of the project, ultimately leading to a resilient and sustainable design.

This paper aims to evaluate the use of digital due diligence in road infrastructure projects through a real case study located in Uzbekistan. This paper includes the use of ORIS, the first construction materials platform, to: (i) Analyse the project environment and design constraints, including local sourcing, traffic and weather conditions; (ii) evaluate several design options and maintenance scenarios with a multi-objective optimization of the structure performance as to cost, carbon emissions, material consumption and resilience to climate change and; (iii) assess road safety performance based on the proposed designs.

1.1 Project Context

Located in Uzbekistan, the A380 highway is 1,204 kilometres long and is part of the Central Asia Regional Economic Cooperation (CAREC) corridor. ADB has been supporting the rehabilitation of the CAREC corridor in Uzbekistan through multiple projects, and the rehabilitation of the 4R180 road, in western Uzbekistan, is part of the investment around the CAREC (Roads, 2022).



Source: ORIS platform 4R180 Project

Figure 1: Location of the 4km rural road upgrade connected to A380 Highway in Uzbekistan

As the development of the A380 highway will increase the daily traffic along the section connected to 4R180, it is also expected a threefold rise in the traffic of this rural road. Therefore, this section has been chosen as a pilot project to test the benefits of digital due diligence through ORIS, an intelligent materials platform, see Figure 1, to design a sustainable and cost-effective road upgrade resilient to climate change and with improved road safety in the provided time frame, which was ten weeks.

1.2 Digital Twin Implementation

Digital twins are virtual models designed to accurately reflect a physical object and replicate vital areas of functionality and produce data associated with the physical object's performance. Once informed with such data, the virtual model can be used to run simulations, evaluate performance issues, and generate possible improvements (Gao,

et al., 298-301). It is also important to remark the difference between a digital twin and a simulation, largely associated with the scale of the analysis: While a simulation typically studies one process, a digital twin can itself run any number of useful simulations in order to study multiple processes. Thus, digital twins can be perceived as a virtual environment that can offer a more valuable insight for an in-depth study when compared to simulations.
To build a digital twin of the 4R180 road into the ORIS platform, the project data was integrated along with its real environment characteristics: local sourcing, traffic, and weather conditions. Thus, this digital twin was used to assess multiple pavement design options compliant with local standards, along the following lines:

- Analysis of several pavement designs with a multi-objective analysis in which costs, carbon emissions, resilience, and resource consumption were accounted for.
- Evaluation of feasible maintenance scenarios for durability and resilience to climate change.
- Assessment of road safety on the proposed alignments and designs (both vertical and horizontal), considering multiple road safety parameters such as the project geometry and traffic estimations.
- Incorporation of hydrological calculations for drainage structures to design optimum sections of structure and waterway openings (road hydraulic transparency) in case of peak water flows and floods.

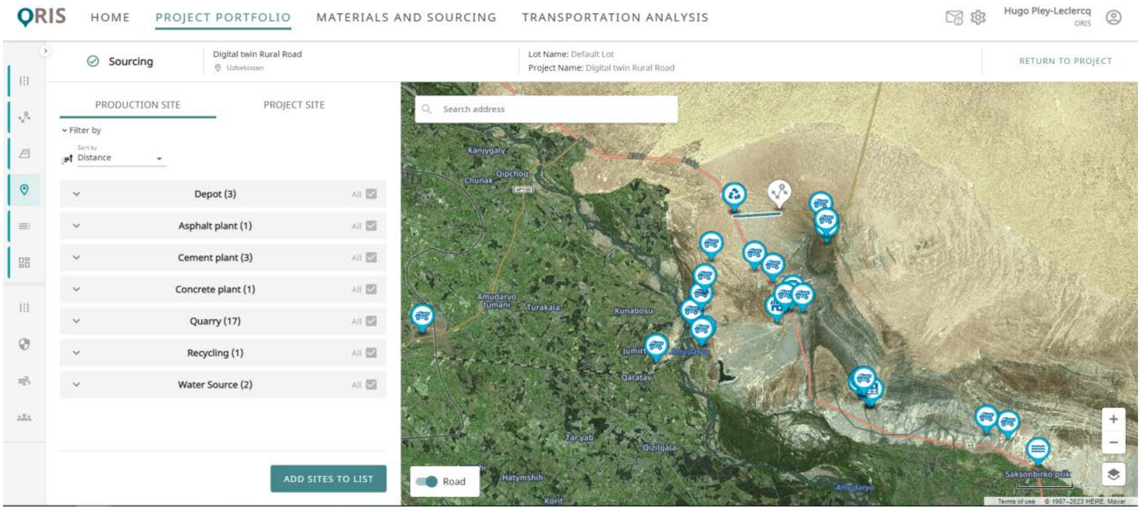
2. METHODOLOGY AND IMPUT DATA

ORIS is the first construction materials platform for a smart use of resources and low impact infrastructure, based on materials data knowledge and sharing. The platform allows to compute parameters and data such as materials properties, geolocation, expected traffic and weather conditions for an effective and sustainable construction efficiency. Based on this data-driven analysis, users can make informed decisions for smart materials consumption. ORIS is supported by advanced technologies, including Artificial Intelligence, that enables it to make unique predictions and recommendations based on the data and information collected by the platform.

2.1 Data Collection for Material Sourcing

The first phase of the project was to incorporate into the ORIS database local materials sourcing capabilities and standards. The sourcing database was built using satellite recognition, artificial intelligence and ORIS detection algorithms to identify the 28 sites locally available for the project, including asphalt and cement plants, quarries, and recycling facilities among others, see Figure 2. The combined used of the abovementioned resources allowed the project team to allocate more time on the project refinement and benefit at the same time from a more granular analysis of the main project challenges at an early stage of the project.

As to the materials pricing, it was incorporated based on a local survey conducted in November 2021, but also on references for similar projects and local experience. As local suppliers did not produce an Environmental Product Declaration (EPD) for their materials - meaning that the carbon emissions are unknown - ORIS compiled local and international data to define the carbon footprint for each material for then, based on those initial carbon evaluations, calculating the overall impact of the construction.



Source: ORIS platform 4R180 Project

Figure 2: Platform input of a geolocalized data set (road and material sourcing)

2.2 Data Collection for Traffic Assessment

Traffic conditions were also considered in this analysis, based on traffic studies conducted between years 2017 and 2021. The following assumptions were made:

- A design life of 20 years.
- An annual average daily traffic of 1000 vehicles. As the 4R180 road provides access to a quarry, it was considered that 40% of the total vehicle count was heavy traffic.
- Constant growth factor of 5.5% over the analysis period.

2.3 Project Conditions for Modelization

The next phase of the project was to input data specifics to the project and its conditions to develop the most appropriate pavement design, as seen in Figure 3. For this analysis 6 base designs were calculated (designs G1, G2, G6, G8, G7, G9), including flexible, semi rigid, and rigid pavement with virgin aggregates and recycled layers. Additionally, 4 alternative designs based on the initial designs were added to the analysis with 2 low carbon scenarios (Design 9 and 10: LC = Low Carbon, RCC = Roller Compacted Concrete) and 2 thin asphalt layer topping, see Table 1.

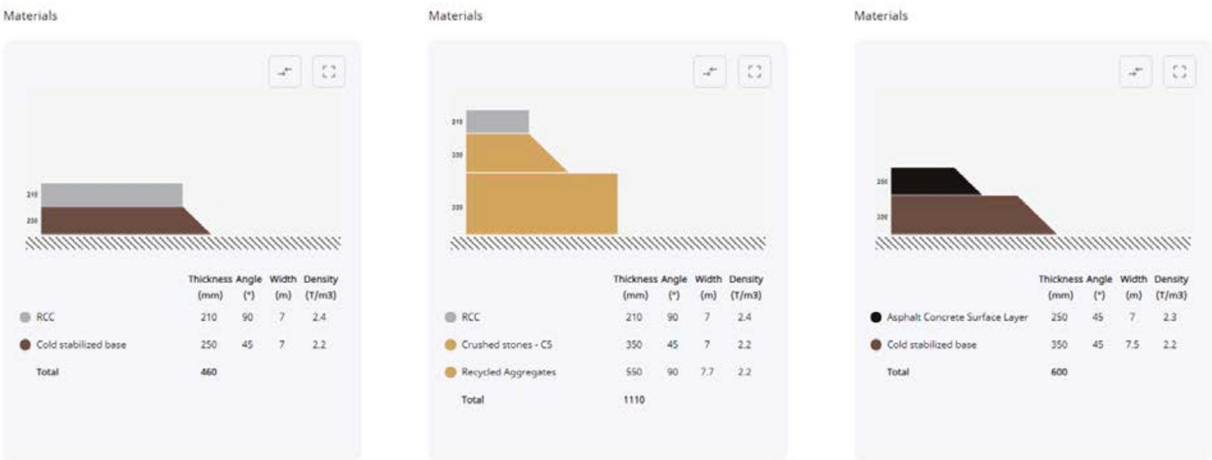


Figure 3: Capture of G1, G2 and G6 design options from the ORIS platform

Table 1: Design scenarios for the 4R180 digital due diligence

ORIS Number	1	2	3	4	5	6	7	8	9	10
Pavement name	**G1**	**G2**	**G6**	**G8**	**G7**	**G9**	**G1 RCC**	**G2 RCC**	**LC RCC**	**LC RCC**
Rigid: Roller compacted concrete pavement	X	X							X	X
Rigid: Portland cement concrete pavement					X	X				
Flexible: Asphalt pavement				X						
Semi-rigid: Asphalt with recycled base layer			X							
RCC topped with asphalt							X	X		
Classical scheme with removal of the existing pavement		X		X		X		X		X
Recycling pavement to be used in place as cold stabilised base	X		X		X		X		X	

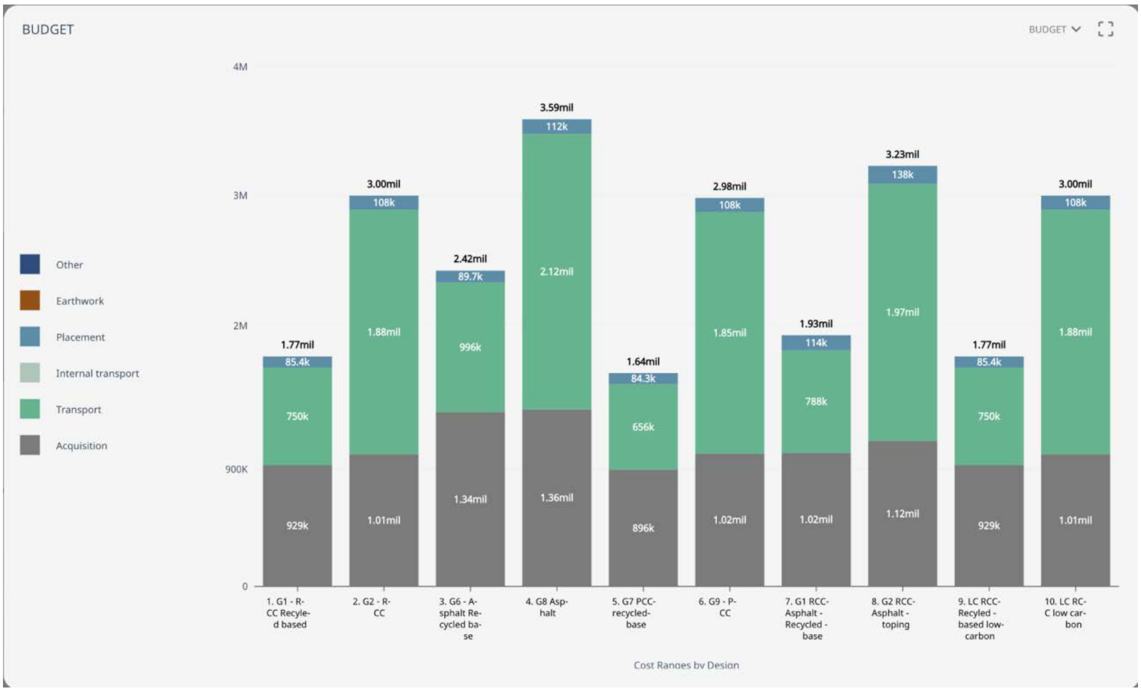
3. PAVEMENT DESIGN OPTIMIZATION

Through the modelization set up in the ORIS platform, the project team performed a pavement design analysis comparing the Base Case (asphalt road with granular base) with the alternative designs. This analysis identified improvement opportunities to lower costs by 51% (1.8 million dollars), spare 14.7 thousand tons of natural resources and enable the use of 24,1 thousand tons of recycled materials.

3.1 ORIS Cost Calculation and Natural Resources Consumption

The total cost of the pavement included: Product stage cost (raw material supply, transport, and manufacturing costs), transportation cost (finished product transportation from production site to the project main access point), internal transportation cost (transportation of finished products from the main access point at the site to other work locations as needed), and construction installation process cost.

The results from the platform showed that both concrete pavements and pavements containing recycled base from the existing pavement perform well as to construction cost for the selected designs. As seen in Figure 4, the design option G1 (RCC with recycled base) presented a cost reduction of 51% compared to the design option G8 (asphalt with classic aggregate base) and 27% compared to the G6 pavement design option (asphalt with recycled base). This cost optimization was associated with the transportation cost of the asphalt, as two cement factories were near the project, and the production cost of asphalt in smaller quantities.



Source: ORIS platform 4R180 Project

Figure 4: Operation costs overview for each design analysed

3.2 Benefits of Using Recycled Materials

Through the abovementioned assessment, half of the designs included recycling the existing road to use it as the base layer, for a further material and pavement design optimization. The results obtained from the design options that included using a cold recycled base with materials from the existing pavement showed an overall great performance of the material consumption and project cost, compared to the base case scenarios. What is more, when comparing pavement design options 2 and 9, the material consumption was reduced by 21,6 thousand tons of virgin materials, the project cost by 1.82 million dollars, and about 15 thousand tons of materials could be reused.

4. ALIGNING THE CARBON PERFORMANCE OF THE PROJECT WITH CLIMATE GOALS

By challenging the identified alternatives with low-carbon and circular solutions, the project's environmental footprint was significantly improved with 6.69 thousand tons of CO_2eq avoided (16.8% compared to the Base Case).

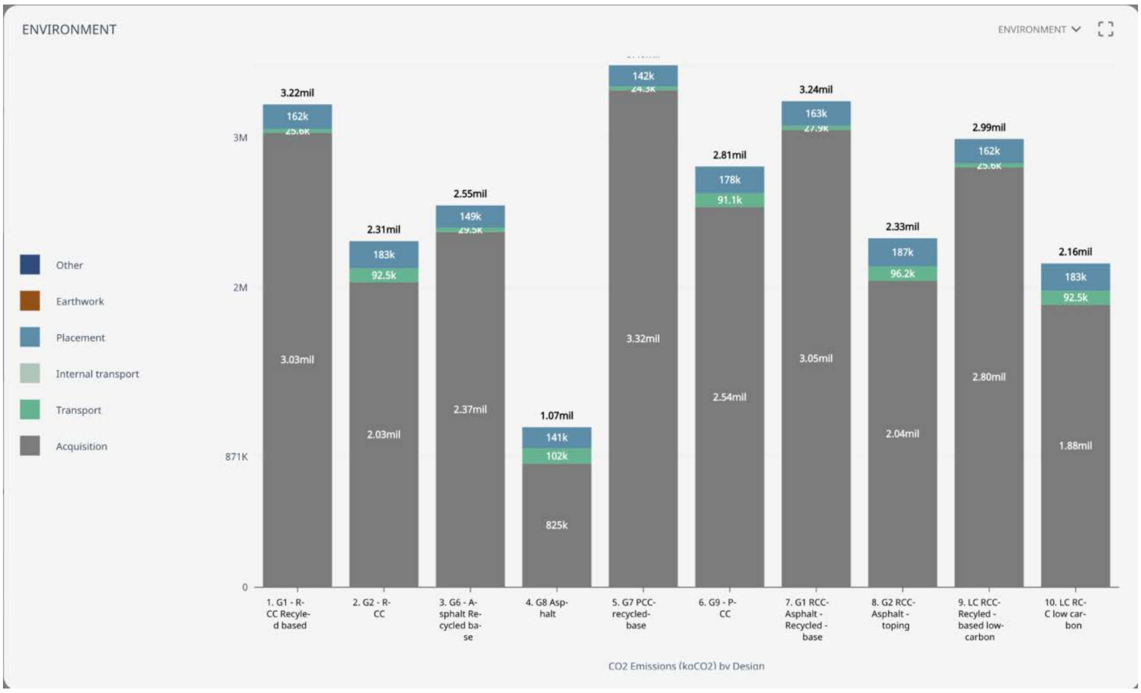
4.1 ORIS Life-Cycle Assessment

Life cycle assessment (LCA) is a methodology for assessing the environmental impact of a product, service or technology, considering all the stages of its life cycle, from raw material extraction all the way to the demolition at the end-of-life. It is a standard method widely used to assess the carbon footprint with great accuracy. Currently, carbon footprint analysis for the infrastructure sector is being limited to the embodied carbon emissions from material production and road construction phases, and rarely including in the assessment the maintenance activities. However, the operational phase of the infrastructure can have a contribution as significant as the embodied carbon. Besides, the end-of-life scenarios can give wide ramifications in decision making due to the valorisation of demolished waste. For this reason, the carbon footprint analysis through the whole life cycle of a road helps to identify carbon hotspots and therefore, provides valuable data for the decision-making process.

The ORIS LCA analysis is limited to the climate change indicator (CO_2eq) and material consumption. In compliance with the LCA standards (ISO 14040, ISO 14044 and EN 15084), the ORIS platform carbon emissions calculator considers the following:

- The product stage.
- The construction stage.
- The use phase stage, considering the carbonation, albedo effect processes, deflection, roughness and texture impact on vehicle consumption.
- The maintenance phase.
- The operational energy use.
- The disposal of deconstruction-related waste.

By using the ORIS platform, the team concluded that carbon emissions could be reduced by 14% (490 tons CO_2eq) on this project by an adequate pavement design selection, see Figure 5.



Source: ORIS platform 4R180 Project

Figure 5: Carbon emissions for each design option

4.2 Carbon Emissions Reduction

Further reductions in the carbon emissions were explored through the ORIS platform, to identify solutions based on international standards. Based on ORIS LCA calculation methodology, cement products with blended mix addition (slag) were selected as a low carbon solutions and the replacement of the concrete and treated bases with low carbon products from hydraulic blended material showed that with the same design but using those materials, (Design n°1 vs n°9 and Design n°2 vs n°10 – see Table 1) the carbon footprint could be reduced up to 7%.

5. DIGITIZING THE ROAD SAFETY PERFORMANCE ASSESSMENT

One of the objectives of the project was to reduce fatalities on this road section using the international Road Assessment Program (iRAP) methodology, to identify the risk of any fatalities and define countermeasures, which represented a total investment of 50 thousand dollars, to reach the 3 star minimum UN safety target.

5.1 ORIS Road Safety Assessment and iRAP Methodology

The iRAP Star Rating is an objective measure of the level of safety, which is calculated through the evaluation of more than 52 road attributes that can affect the risk of death or serious injury of vehicle occupants, motorcyclists, bicyclists, and pedestrians on 100-metre length sections. Then, fatalities and serious injuries are estimated by drawing on the road attribute data used for Star Ratings flow data for each road use, and network-level crash data to provide an estimation of Fatal and Serious Injuries (FSIs) along each segment of a road and support the prioritisation of investments.

The ORIS platform integrates a safety evaluation through the iRAP Star Rating and FSI estimation methodology, and the following assumptions were made for the 4R180 project, based on the traffic study released by the local authorities:

- Operating speed of 90 km/h.
- Road users are mainly vehicles (trucks) and motorcycles.
- User flow of 1000 vehicles per day and lane for both directions, assuming 1 to 5% of motorcycles.
- Neither pedestrians or cyclists are expected along or across the road.

5.2 Countermeasures Plan

The safety assessment yielded Star Ratings below 3 for the different types of road users, which is lower than the UN minimum targets. Therefore, an improvement plan to reach the minimum iRAP Star Rating of 3 was proposed, and the countermeasure plan included not only an improvement of the intersection’s geometry, but also measures to calm the traffic before reaching the intersections. The implementation of those countermeasures increased the safety for all road users, and the targets of 3 stars was achieved. The additional investment for recommended measures was evaluated at 50 thousand dollars to reduce the serious injuries and fatalities.

6. CLIMATE CHANGE EXPOSURE ANALYSIS FOR A RESILIENT ROAD

Climate change is expected to impact the project over its design life in terms of heat, frost/thaw cycles and water run-off floods. The analysis conducted with the ORIS platform identified a 1.7 million dollars investment on adaptation and mitigation measures to limit damages and avoid early repair needs.

6.1 ORIS Resilience Assessment

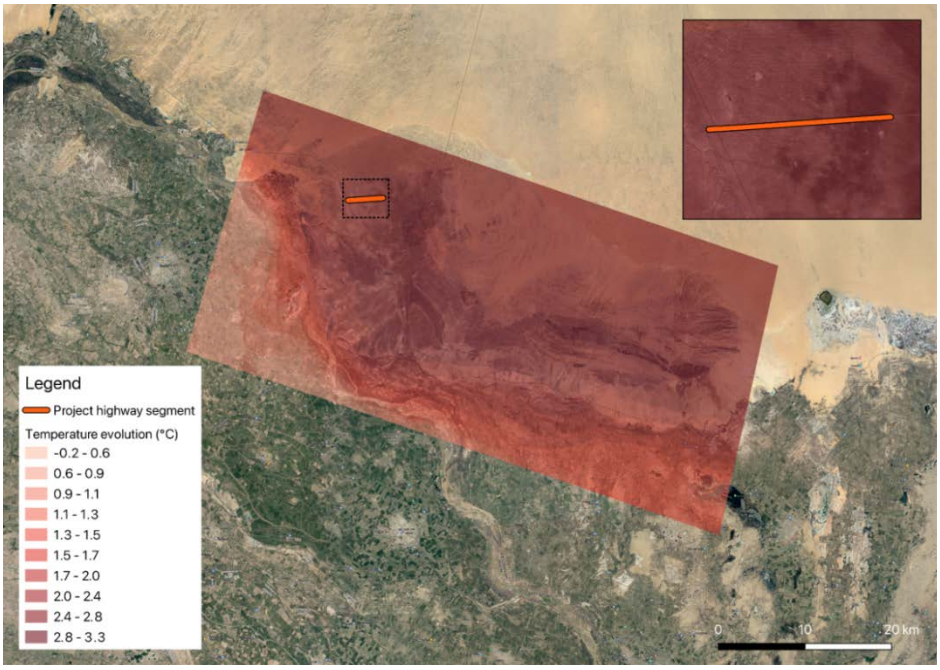
The resilience assessment performed for the region around the project is centred on three main climate variables and risks:

- Maximum temperature (CEDAarchive, 2022) (Worldclim, 2022).
- Frost change frequency (chelsea-climate, 2022).
- Annual precipitation (chelsea-climate, 2022).

The values used for the analysis of the current situation were obtained from historical data from years 2018 to 2020, and the model used for predicting climate evolution was based on the modelization of the Intergovernmental Panel on Climate Change (IPPC, 2021). Based on the client request, the worst climate change scenario (highest emissions scenario of any developed in the Shared Socio-economic Pathway process) was taken into consideration, named SSP 8.5.

6.2 Heat Assessment

The heat evolution over the south area of the project is influenced by the Amu Darya River, whereas the impact of climate change is more severe in the 4R180 project location, with a rise between 1.5 and 3.3°C over the next 30 years, Figure 6. As to the number of hot days, it is expected to increase from 148 to 153 days per year, and the average temperature as well, between 1.1 and 3.3°C in the next 30 years. Therefore, concrete structures will be the preferred choice on this project, as they are less prone to temperature variations that can affect the overall performance of the infrastructure (Ramadhan & Wahhab, 1997).



Source: ORIS platform 4R180 Project

Figure 6: Temperature evolution from 2020 to 2050

6.3 Frost Assessment

The freeze-thaw damage can be one of the major causes of highway deterioration and it is important to have detailed data for the project. As this project is surrounded by a desert, the thermal amplitude tends to be high, meaning that minimum and maximum temperatures can be quite distant from each other on a same given day.

On average, the number of freeze-thawing cycles will be diminished by 12.15 from 111 cycles per year. Even with a 10 % reduction of the cycles per year, the frost / thaws cycle remains a high constraint for the structure with 99 cycles per year. Therefore, stabilising the subgrade with a hydraulic binder can be a feasible adaptation measure.

6.4 Precipitation Assessment

The annual precipitation in the region of the project is quite low over the years, mainly because it is a very dry region.

Usually, the drought periods profoundly affect the whole country and that is why it is of extreme importance to assess the precipitation evolution over the years considering the SSP 8.5 scenario. The annual precipitation in the region of the project is quite low over the years, see Figure 7, in which the precipitation values shown are expressed in terms of millimetres of rainfall per year.

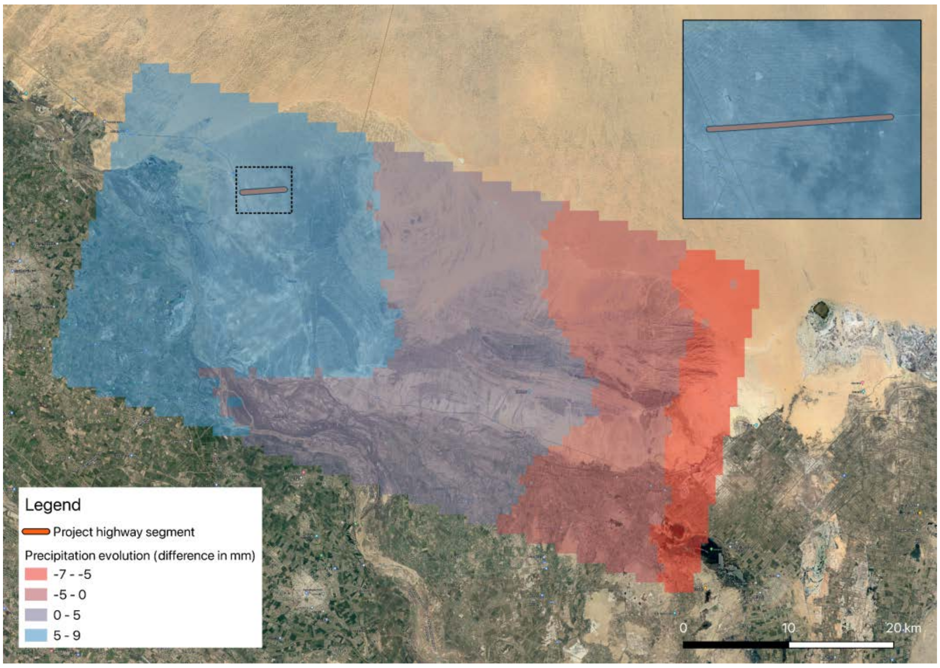


Figure 7: Precipitation evolution expressed by the difference between 2050 and 2018, from the ORIS platform

The annual precipitation evolution is stable with a small raise of the values on the studied area. Rainfall will remain concentrated on short periods of time. As there is no great change expected for the rain falls in the next 30 years, no countermeasure is foreseen for this hazard and the climate change impact.

7. CONCLUSION

The case study of the 4R180 rural road in Uzbekistan showcased that challenging initial designs can lead to unexpected opportunities for improvement. By creating a digital twin, the project team was able to identify alternative designs with a lower carbon footprint and at a lower cost. It also allowed the project team to assess the project's safety and resilience and evaluate possible countermeasures. The main findings of this study were:

- Digital due diligence and multiple scenario analysis in the ORIS platform allowed to create quick iterations and obtain key outcomes in a shorter period of time than classical early-stage studies, reducing the pavement and material cost by up to 51% (1.82 million dollars).

- Circular solutions could be identified for the case study thought an advanced digital approach, reducing the consumption of natural resources by 36% (14.7 thousand tons of natural materials), saving 14% of carbon emissions (490 tons of CO_2eq), and using 24.1 thousand tons of recycled materials.
- Long-term risks to climate change adaptation were identified through the ORIS platform as to heat, freeze/thaw cycles and water run-off floods, and it was proposed for this project to use a hydraulic binder to stabilise the subgrade and concrete pavements were a preferred choice over flexible pavements.
- Improving road safety and reaching the minimum requirement for the UN goals is possible by using a digital platform integrating international methodologies such as iRAP. On this case study, with an investment of 50 thousand dollars it would be possible to improve the predicted safety performance and meet the UN safety target.

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