BOUW EN TECHNIEK

THE RENOVATION CHALLENGE

AND HOW ARTIFICIAL INTELLIGENCE ENABLES PRODUCTIVITY GROWTH

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By 2050, the vast majority (85-95%) of existing houses, utility buildings and civil infrastructure in Europe will be there. We need to renovate, decarbonize and upgrade these built objects to ensure their availability for its users, minimize emissions and reduce the use of raw materials and energy. With a shortage of skilled labour and lagging productivity, we need to embrace the potential of digital technologies. This paper outlines how artificial intelligence can enable productivity growth for the renovation challenge. It gives insight in the renovation challenge, the potential of artificial intelligence and key considerations and actions to apply it at scale.

1 THE RENOVATION CHALLENGE

The renovation challenge

The vast majority of the existing houses, real estate and infrastructure that we have today, will be required in 2050. However, major developments like aging assets, climate change, decarbonization and social economic developments have a significant impact on the performance of these assets. Renovating, including transforming and upgrading these existing built assets is one of the biggest challenges in the built environment. It is an essential strategy: it secures the availability of houses, offices and roads for our society and economy, minimizes emissions, and reduces the use of virgin materials and energy.

This renovation challenge is large and complex. We have over 220 million buildings that need to be renovated [1] and over 1 million bridges [2] in Europe only. Also on national level in the Netherlands the numbers are large (figure 1).

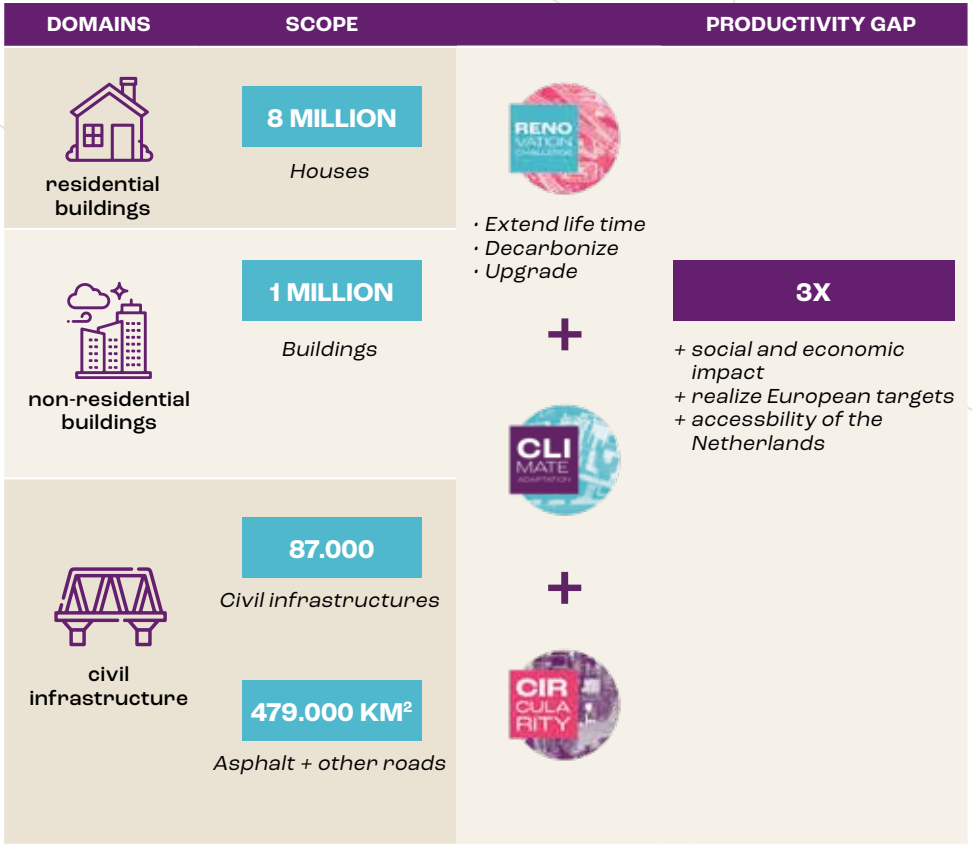


FIGURE 1: overview of the renovation challenge in the Netherlands

Extending the lifetime of structures, decarbonization and adapting assets to changing user needs are complex and impactful interventions in the existing built assets that we use on a daily basis.

But the challenge is even larger: lagging productivity and a growing shortage of skilled labour in our architecture, engineering, construction and operations industry prevent us from making steps at scale.

National mission for renovation in the Netherlands

In one of the national missions for the Dutch built environment we collectively work on this renovation challenge. In this mission, led by TKI Bouw and Techniek, we aim in a mission driven innovation approach to develop and scale the required interventions and innovations.

In a mission driven innovation approach public and private partners are working together on innovations for complex socio-economisch problems. The envisaged impact of this mission is to grow productivity of the renovation market by factor two to three: from the current €8 billion to €18 billion per annum for the Netherlands only [3]. This factor three also aligns with the renovation wave as identified by European Commission in their strategy for the built environment [4].

An essential part of achieving the impact of this mission is to integrate and exploit the potential of data and scalable technologies, like digital twins and artificial intelligence. This interplay between the green (renovation challenge) transition and digital transition, is increasingly referred to as the twin transition [5].

From all the technologies, especially artificial intelligence is identified as a key enabler for productivity growth for renovation. As TKI Bouw en Techniek we identified the potential added value for the Netherlands of artificial intelligence for the renovation challenge up to €1 billion per annum. This is achieved by growth in labour- and capital productivity and acceleration of the project execution by automation of tasks. But artificial intelligence can also help us to better understand the system of renovation and which interventions are effective, resulting in better decisions with better outcomes.

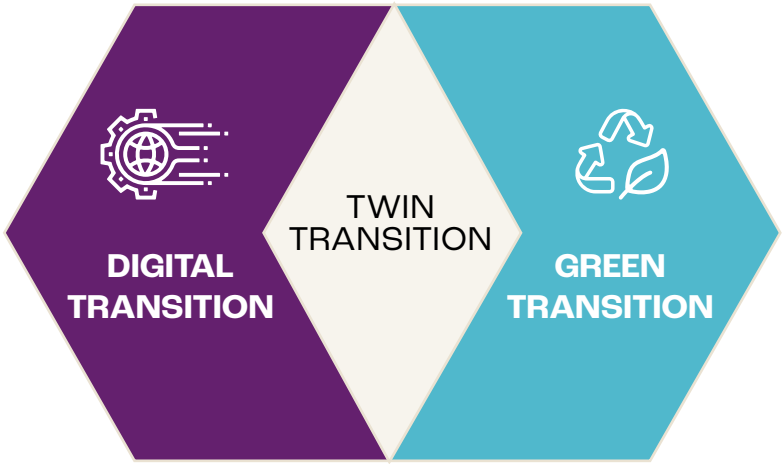


FIGURE 2: twin transition

2 WHAT IS ARTIFICIAL INTELLIGENCE?

Despite the potential social, environmental and economic impacts, there is not yet an industry wide focus, collaboration and application of artificial intelligence for the renovation challenge. Therefore, as TKI Bouw en Techniek we developed this position paper to help all our stakeholders to accelerate in the application and adoption of artificial intelligence for the renovation challenge. In this paper we discuss the definitions of artificial intelligence, some practical applications and the key enablers to embrace the potential.

Artificial intelligence and the National Technology Strategy of the Netherlands

Let's first look at what artificial intelligence is. We base our description in this paper on the National Technology Strategy of the Netherlands. In this strategy, artificial intelligence is identified as one of the ten key technology developments for the Netherlands. This strategy, published in January 2024, provides the following description of artificial intelligence:

Artificial intelligence is a system technology aimed at simulating human behaviour by machines. Artificial intelligence includes various learning strategies, like supervised machine learning, unsupervised learning, reinforcement learning and deep learning [6] .

In this National Technology Strategy, three key principles for artificial intelligence are defined:

- Artificial intelligence plays an important role in the transitions we face as society, including the renovation challenge.
- The Netherlands focusses on a decentralised and federated system for data sharing.
- We aim for a balanced view between human knowledge and opportunities of artificial intelligence.

Various forms of artificial intelligence in our industry

To provide an overview in the context of the built environment of artificial intelligence and its various forms, we use the metaphor of a tree. This metaphor is inspired by the book Augment It by Mehdi Nourbakhsh [7], which focusses on applying artificial intelligence within the architecture, engineering, construction and operations industry. The metaphor provides an overview and the coherence between the concepts of artificial intelligence relevant to the sector.

The basis of artificial intelligence lies in various scientific fields, named in the roots. These areas ensure that the tree receives nutrition to grow. The tree has different branches, and some branches also have smaller branches, as is the case with machine learning. For example the methodology behind ChatGPT is also one of the components of natural language processing, which is in turn a component of artificial intelligence.

Together, the trunk and the branches lead to an overview of the various forms of artificial intelligence for the sector.

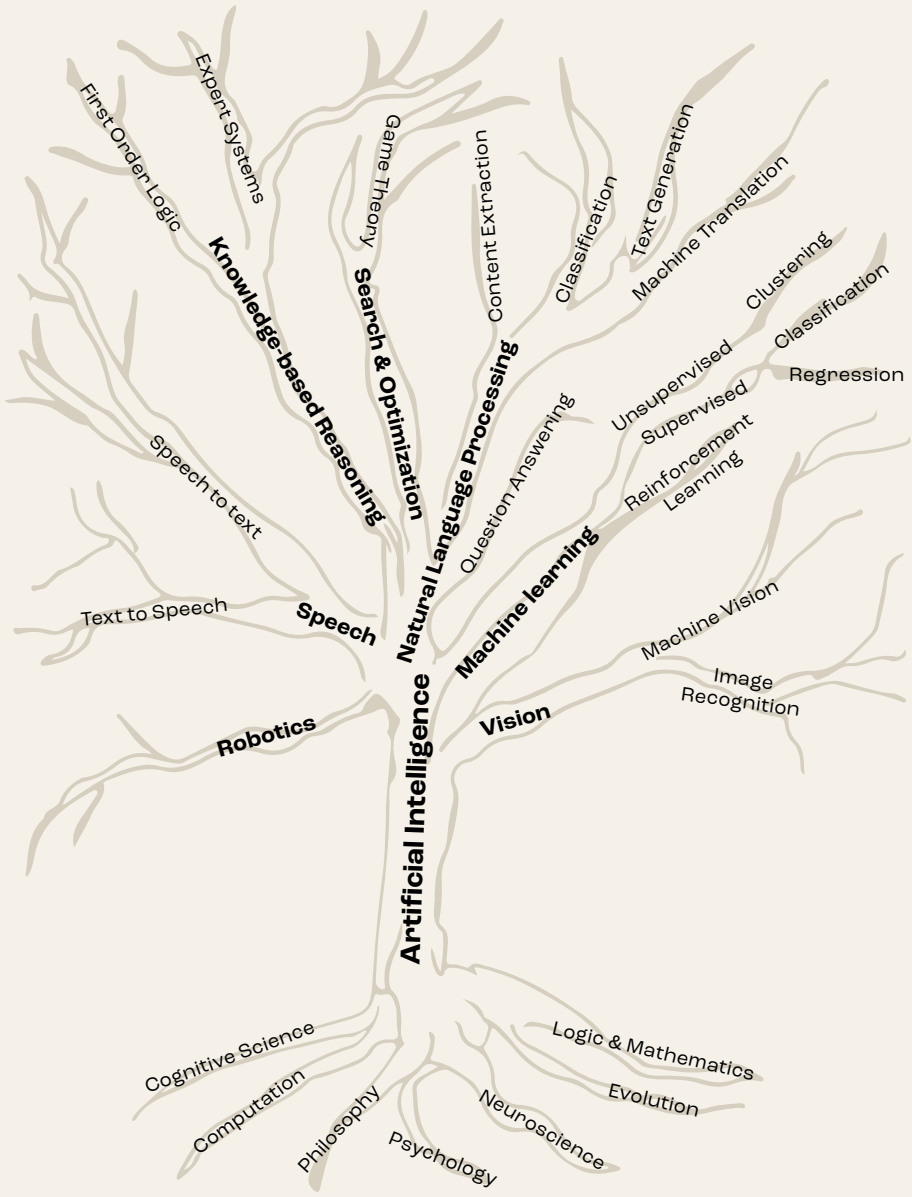


FIGURE 3: applications of artificial intelligence in the industry

Three types of artificial intelligence for our renovation challenge

Based on this description of artificial intelligence and the various concepts for our industry, we highlight three types of artificial intelligence with most significant relevance for the renovation challenge:

- Computer vision is focused on automated recognition and analysis of images. Computer vision has been applied for quite some time, for example of analysing cracks in beams, monitoring safety on construction sites or assessing the maintenance status of façades. However, there is still a lot of potential to be unlocked. For example, using spatial artificial intelligence to generate spaces based on multiple data points. Another example is using synthetic data and artificial intelligence to generate data about not directly visible places like foundations or within critical structures.
- Hybrid artificial intelligence is combining machine learning with human understanding of the behaviour of systems. It helps us to understand the existing behaviour and performance of buildings and civil infrastructures and their underlying systems. This helps us in decision making by analysing interventions and their expected outcomes and impact.
- Generative artificial intelligence has been on the rise lately with exponential speed. In many ways generative artificial intelligence can accelerate the execution of projects. For example by automating procurement and tender processes and automated validations of renovation designs against local regulations.

All these forms hold great potential, but are also heavily depending on good quality of data, discussed next.

Artificial intelligence fueled by data and technology

Artificial intelligence cannot be viewed separately from data and wider technology developments.

Relevant data developments

Data is the basis for many artificial intelligence applications. Data is a collection of facts, observations and events in the form of numbers, texts and times. Processing data leads to information; analysing and interpreting information leads to knowledge [7].

For our renovation mission, we have various forms of data. We have data about the built object, such as geometry and maintenance status; data about the delivery of the renovation project, such as planning and costs; data about the use of the built object during operations, such as energy consumption and comfort performance; and data about the broader impact of the building on its environment, such as accessibility and relationships with the surrounding energy system to which the building is connected.

These various forms of data are increasingly combined in digital twins which helps to better understand our built environment and help us to make better decisions with better outcomes. These digital twins increasingly are using artificial intelligence to enable their more predictive and prescriptive potential.

Most applications for artificial intelligence need a certain volume of data. Quality of data in our sector is often poor and accessibility of this data is difficult.

To improve this, on national and international level there are various initiatives like:

- Application of open data standards to enable seamless exchange of data between various stakeholders in the value chain, like the IFC standard of buildingSMART International.
- Jointly developing and applying large-scale structures for labelling and interpreting data. This leads to more structured data. Various concepts play an important role here, such as ontology (a standardised, structured representation of information and objects in a specific domain), (knowledge) graphs (implementation of ontology in a specific context), object type libraries (a generic information model in which object types are organised in a structured way) and linked data (an innovative concept for linking different data files and information structures).
- In line with the National Technology Strategy, focus on data spaces: using structures for data sharing in which parties can voluntarily and with confidence share and reuse data in a federated manner [6]. For the architecture, engineering, construction and operations industry, digiGO has worked with the sector on a system for federated data sharing (DSGO).

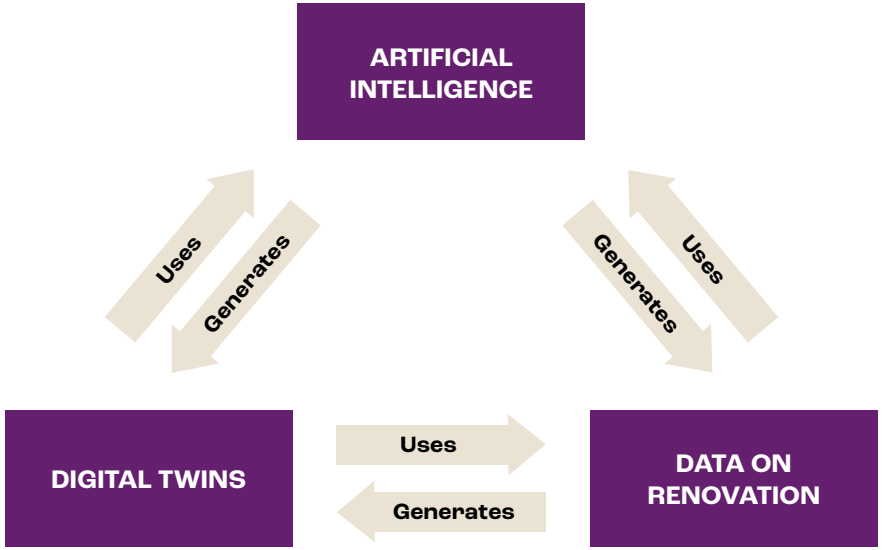


FIGURE 4: relationships between artificial intelligence, digital twins and data

Enabling technologies

In addition to data and digital twins, a number of other technologies play an important role in artificial intelligence. It is therefore important to understand the relationships between these technologies.

For example, the increasing availability of computing power and the significantly lower costs of sensors to obtain information, leads to more data and makes more complex forms of artificial intelligence possible and affordable.

Successful application of artificial intelligence is depending on the extent to which these technologies reinforce another. These dependencies between technologies also lead to risks for the development of artificial intelligence. For example, if the technology is only available from a limited number of providers, such as is currently happening with cloud providers.

Figure 5 shows several relevant technologies for the renovation challenge. The technologies on the left enable artificial intelligence, the technologies on the right are actually created by artificial intelligence (partly). It should be noted that relationships can also be reciprocal in many cases: increase in digital twins (and therefore more structured information about, for example an existing building) also offers opportunities for the broader application of artificial intelligence.

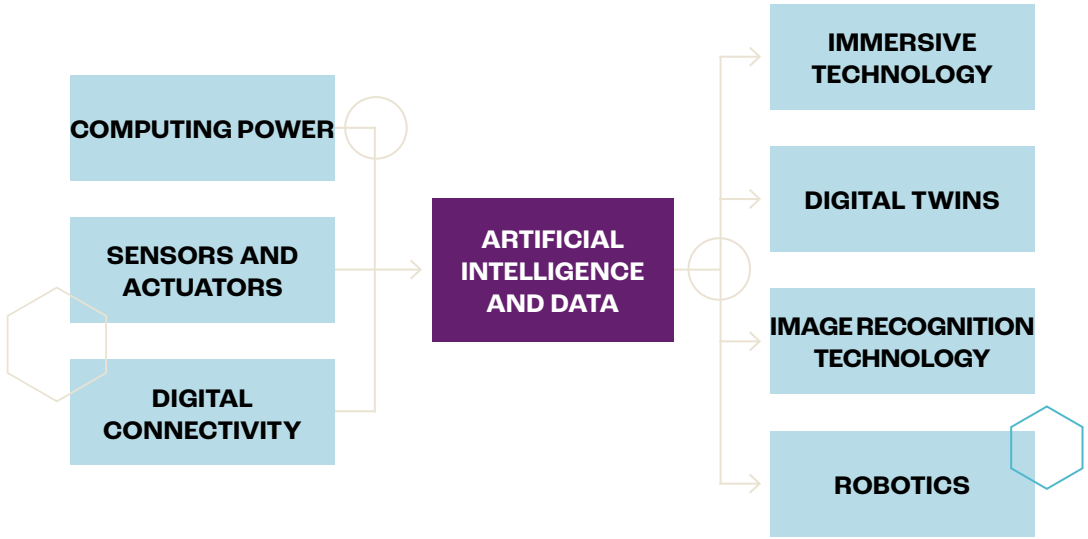


FIGURE 5: technologies with a relationship to artifical intelligence

3 APPLYING ARTIFICIAL INTELLIGENCE FOR THE RENOVATION CHALLENGE

To make clear how artificial intelligence actually creates value for the renovation challenge, we have broken down the renovation challenge mission in four innovation perspectives.

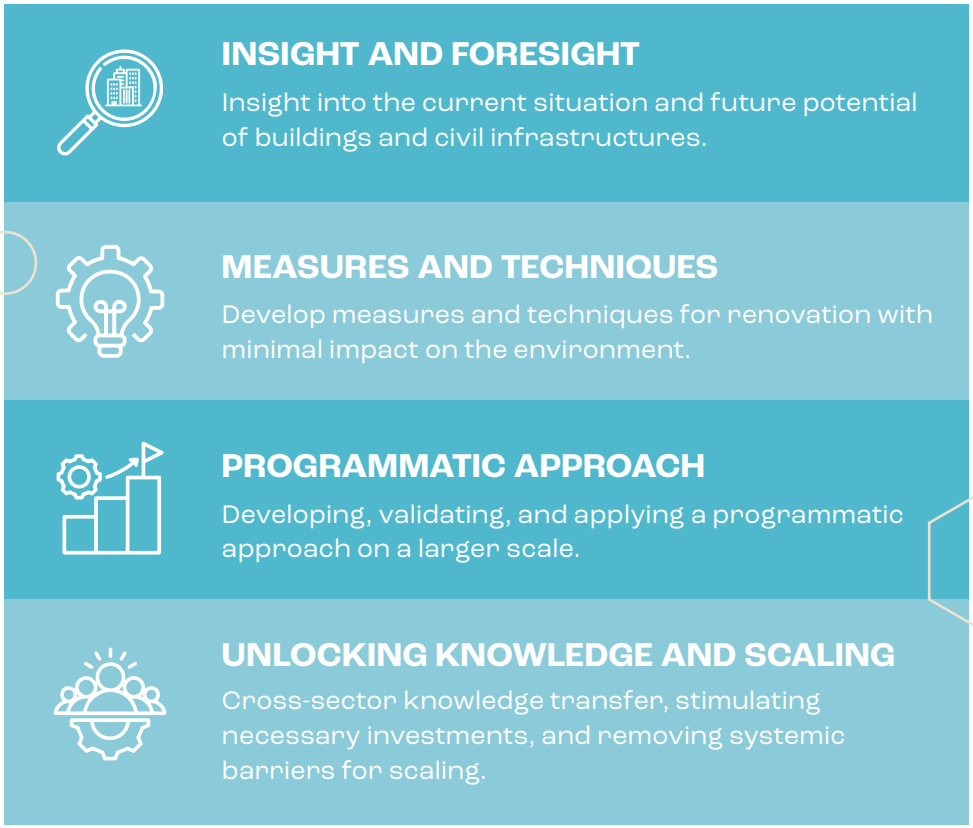


FIGURE 6: innovation perspectives for the renovation challenge

Following these four areas, we identified various objectives, use cases and impacts for artificial intelligence.

INNOVATION PERSPECTIVE	GOALS ARTIFICIAL INTELLIGENCE	POTENTIAL USE CASES
 Insight and foresight	· Better insights in existing built asset · Better decision making in prioritizing the renovation challenge	· Automated analysis (machine learning / computer vision) · Generation of synthetic data using artificial intelligence to create missing data (for example to get insights about the crack in a beam or to generate missing data points in energy data) · Simulation and optimization empowered by artificial intelligence to better predict behaviour of structures over time · Decision support systems enabled by artificial intelligence to facilitate better decision making
 Measures and techniques	· Automated generation and validation of design solutions · Integrate artificial intelligence in measures and techniques (e.g. robotics)	· Hybrid artificial intelligence systems to support in identification and development of design solutions · Combine generative design with artificial intelligence to optimize design decision on multiple criteria · Autonomous and self-learning robots in production and during construction · Virtual commissioning with artificial intelligence, optimization the design and execution approach before actual delivery
 Programmatic approach	· Reduce time of planning, design and delivery of renovations	· Optimize project and logistic schedules with many variables and uncertainties · Generative artificial intelligence to develop and validate documents (tender documents, validate design to rules and regulations) · Use computer vision to improve safety at the construction site and to optimize logistics on site
 Unlocking knowledge and scaling	· Use self learning and expontetial power of artifical intelligence to make sectorwide impact	· Share and make developed knowledge around the renovation challenge better accessible using artificial intelligence systems · Share learnings with applying artificial intelligence in the industry with professionals in the sector

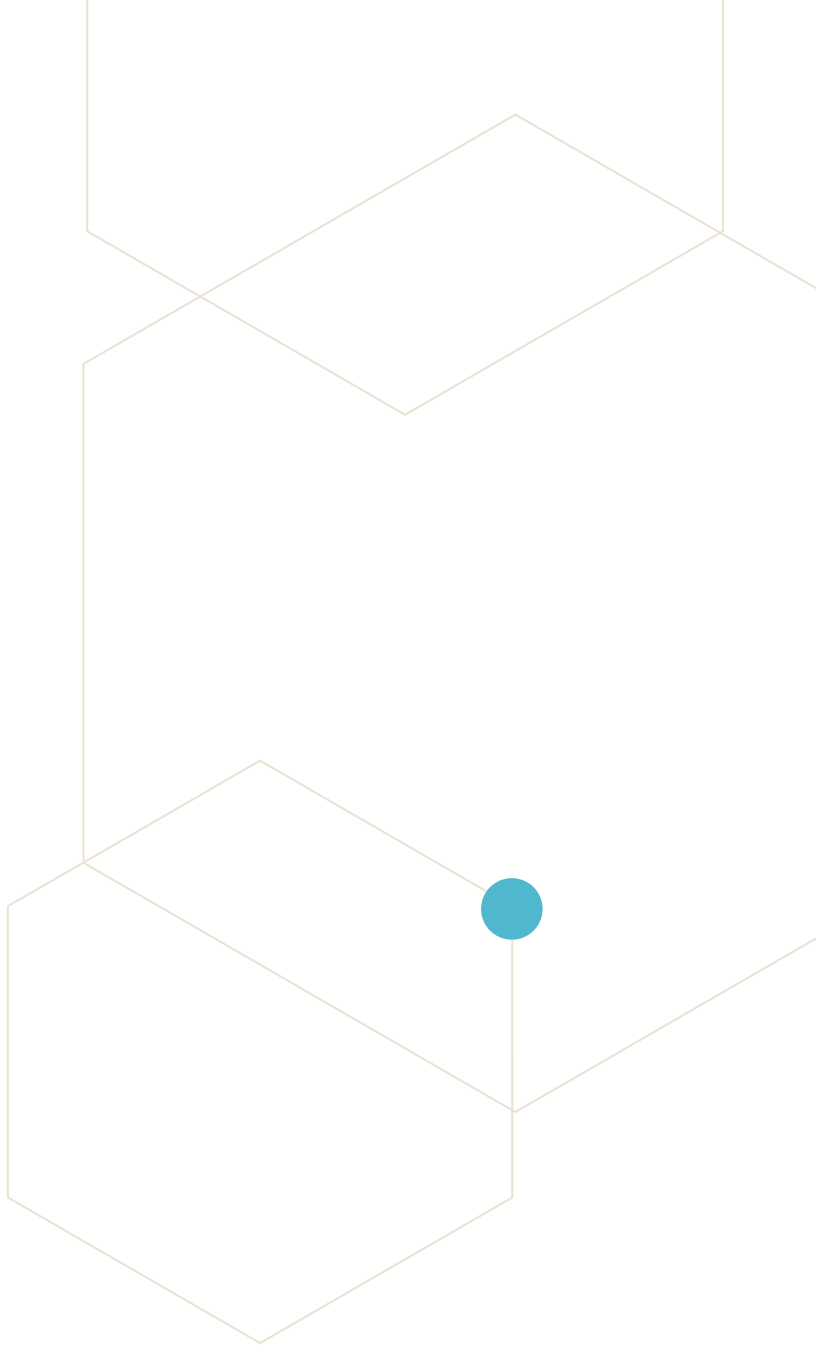
IMPACT OF ARTIFICIAL INTELLIGENCE USE CASES FOR THE RENOVATION CHALLENGE
- Grow labour productivity: (partly) automate repetitive tasks
- Grow capital productivity: cyber physical system widely applied due to artificial intelligence
- Accelerate execution due to better and faster learning at system level
- Grow international position around applying artificial intelligence for the renovation challenge

TABLE 1: goials, use cases and impact of artificial intelligence for the renovation challenge

In summary we notice that applications for artifical intelligence fall in two categories.

Some applications are automating and accelerating part of the delivery (efficiency). Often these applications can be implemented fast (like using generative design in tenders).

Other applications are helping to make better decisions for better outcomes (effectiveness). Not just on the level of a built assets, but also on the wider system they are part of. These artificial intelligence systems take much more effort and time to develop and optimize. However, the impacts of these systems can be large given their ability to learn over time.



4 KEY CONSIDERATIONS AND ENABLERS

When starting to work on artificial intelligence, we need to take multiple topics into account.

First of all, we need to raise our overall **digital maturity and knowledge** about artificial intelligence. Especially within the architecture, engineering, construction and operations industry, the digital maturity is relatively low [8]. Due to low barriers for usage, especially due to generative artificial intelligence and platforms like ChatGPT, this creates significant risks for the sector: without proper understanding about what artificial intelligence is and how it should and could be used, there is significant risks on wrong assumptions and conclusions.

Artificial intelligence is highly **dependent on data**. Although the volume of data is increasing significantly, the quality of data in the built environment is extremely fragmented and siloed, unstructured and on average of low quality. Without more attention to the quality of data and applying processes and techniques to improve it at scale, artificial intelligence won't make impact.

Next to the quality of data, data needs to be also accessible, often referred to **interoperability**. Especially to apply artificial intelligence across the value chain or across a portfolio of multiple assets this interoperability of data is crucial. This requires that various agreements, as defined in data spaces, are in place and are being used sector wide.

Artificial intelligence also comes with various **ethical dilemmas and security risks.** This could go about using artificial intelligence without human oversight, biases in algorithms and unauthorised use of data. Increasingly legislation is focussing on these risks.
But also on an organisational or individual level the risks and dilemma's require attention. This governance of artificial intelligence needs to be established and promoted; execution need to be monitored.

It is important to have a **clear goal in mind** where you want us artificial intelligence for. A use case driven approach will help to focus on the right data sets and development of the right artificial intelligence models.
In practice we however see still too often focus on just collecting as much data as possible without a proper use case in mind.

Finally, we need to be aware that **specific characteristics of our industry** make the application of artificial intelligence challenging. Construction sites are dynamic, often unstructured, environments with external factors, like the weather. But also the nature of working in projects with every time new teams, different parties and new contracts, makes the collection of larger volumes of data across a portfolio of projects and thus the application of artificial intelligence, challenging.

5 ACTION!

To make next steps in developing and deploying artificial intelligence for the renovation mission, we identified five key areas.

More on a architecture, engineering, construction and operations systems level, we need to raise the digital maturity of our sector. This requires for example a basis understanding of machine learning, the skills to work with laptops and smartphones, but also more generic competences like analytical thinking and problem solving, and ability to communicate and collaborate in a fast-changing environment.
But it goes beyond just skills, we need to create a digital mindset for all involved like policy makers, asset owners and experts. Sharing best practices widely supports building this mindset.

Within our national mission for renovation, we work within consortia from across public sector, asset owners, academia and the wider industry in innovation programs. It is important that artificial intelligence becomes much better integrated in these programs. To do so, it all starts by putting it on the agenda as early as possible and collectively identify the most promising use cases. Having sufficient digital mindset and understanding of artificial intelligence present in the consortium is a prerequisite.

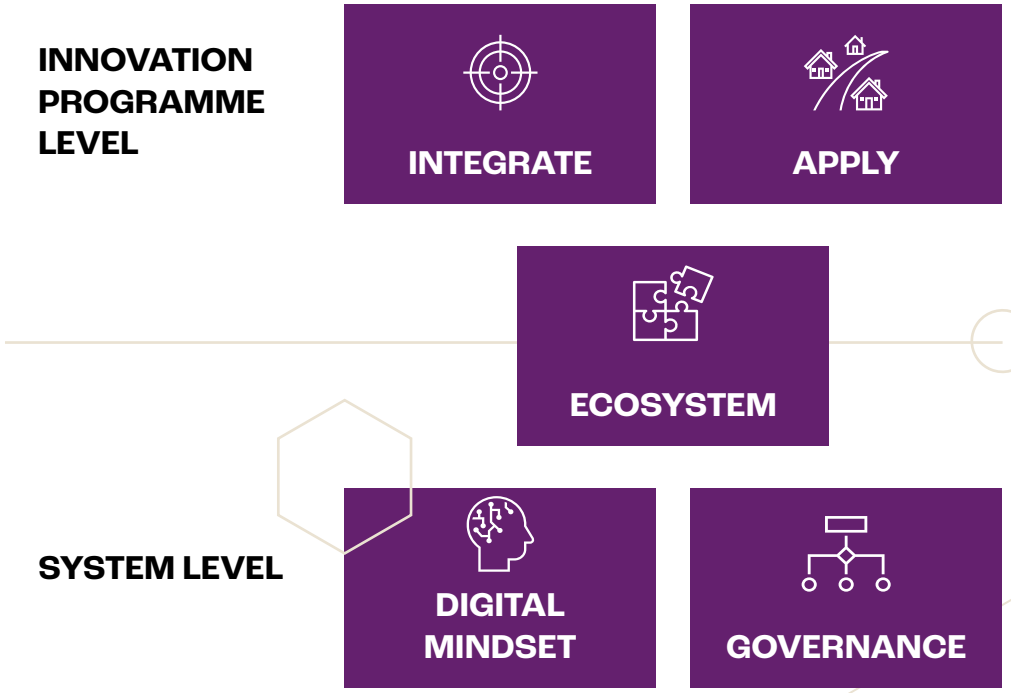


FIGURE 7: Five key areas to apply artificial intelligence

When we actually start developing the use cases there are various success criteria: right mix of participants, both from a domain and technology perspective, explicit choices to re-use existing models and tools or develop new ones, incorporate interoperability, open standards and security by design and create a sandbox to enable sufficient experimentation before moving into production and scaling.

Although there is a huge potential for artificial intelligence, the risks are also significant. Therefore a proper governance for applying artificial intelligence is essential. This needs to be organised at multiple levels: within the project, within in the organisation and at the national sector level. From a wider perspective we see that artificial intelligence becomes more regulated, for example via legislation at European level like the AIact. But at sector level also guidance and policies need to be developed and implemented. For example, around applying models in public environments, applying good practices towards responsible artificial intelligence, implement decentral data sharing and incorporating open standards in procurement policies.

Finally, we need to better bring together the whole ecosystem around applying artificial intelligence at sector level. Currently learning and applying happens in silos: within companies and within universities, or within specific project contexts. Bringing together the front runners on artificial intelligence in our sector at national level, will help us to more collectively learn with our sector, but also make connections to other parts of the emerging artificial intelligence ecosystems in other sectors, like logistics and industry.

Therefore as TKI Bouw en Techniek we started a development of national program for artificial intelligence and the renovation challenge. This program will help in raising awareness and sharing best practices, work on a couple of value chain wide use cases for the renovation challenges and will help in developing guiding principles and policies to apply artificial intelligence for the renovation challenge.

6 IN SUMMARY: POTENTIAL IMPACT

SCOPE NETHERLANDS

8 million | 1 million | 87.000

Renovate, decarbonize and upgrade

PRODUCTIVITY GAP

3X

From €8.1 billion to €18.1 billion

APPLYING ARTIFICIAL INTELLIGENCE IN PRACTICE

- insight and foresight
- programmatic approach
- measures and techniques
- unlocking knowledge and scaling

IMPACT OF ARTIFICIAL INTELLIGENCE ON THE RENOVATION CHALLENGE

€1 BILLION
added value per annum

- labour productivity
- capital productivity
- accelerate implementation
- international position

CONDITIONS

- digital mindset
- ecosystem
- governance

FIGURE 8: overvieuw artificial intelligence for the renovation challenge

7 ABOUT TKI BOUW EN TECHNIEK

TKI Bouw en Techniek is the Top Consortium for Knowledge and Innovation in building design, construction and technology aimed at a CO2-free and future-proof built environment. TKI Bouw en Techniek leads three national missions: circular buildings, the renovation challenge and climate adaptation.

See also: https://tki-bouwentechniek.nl/english/

About the author

Bart Brink is as senior program manager at TKI Bouw en Techniek leading the national mission for renovation. Bart has an engineering and business background. He has been working in the national and internation sector for almost twenty years on sustainability, innovation, digital transformation and technologies like digital twins and artificial intelligence.

Given the relationship between the mission and potential for artificial intelligence, Bart has taken the initiative to write this paper.

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