DII

Automated understanding of engineering drawings

White paper

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Summary

This document explains an innovative approach developed by Dii.ai for the automated creation of computer-aided design (CAD) models by processing scanned engineering drawings. In this paper, we discuss the need for such innovation from the wider strategic context. We address a global challenge of digitising legacy assets and supporting automation technology potential for industrial and built environments.

Key findings of the paper:

1. *Digitally built environment, as well as digitally run equipment and facilities, are the major strategic trends. They define a great part of our future.*
2. *All applications for the digital management of physical assets require CAD models. CAD models become central to the respective product lifecycle.*
3. *The problem is that most of the existing assets do not have CAD models.*
4. *Conversion of the old drawings into CAD has been mostly manual. That requires substantial time and resources and slows down the adoption of technology for pre-built assets.*
5. *The solution lies in the automation of conversion, which has been an unresolved technical challenge for years.*
6. *We at Dii.ai believe that we have developed the solution. We also believe it will become an enabler of a wider spread of digital asset management technologies. The solution is an AI-based software we called The Reader.*
7. *We currently use The Reader in-house and provide the drawings conversion service. With further development, we plan to reach the stage when The Reader can work as SaaS (software-as-a-service).*

Digitally-run objects

A key assumption of the paper and our work is that digitally-run industrial operations and digitally built environments will largely define the future of humanity[1]. All industrial operations and facilities, buildings, and infrastructure objects will be created and operated with a wide selection of digital tools and methods. For a great many of them, it is already the case but this trend will soon become dominating both for new assets and the assets built in the past.

We are certain that digital transformation leads to the widest possible adoption of cutting-edge technologies for industrial and built environment. Those include technologies for creating, improving, and operating physical assets. They have significantly changed various traditional disciplines such as architecture, engineering, construction, manufacturing, etc., creating massive impact and multiple new business opportunities. And they profoundly impact basic human activities such as urban development, transportation, energy, maritime, manufacturing, and many others.

The effects resulting from those technologies became possible due to the combined application of well-known innovations such as the internet of things, machine learning, increasing processing power at lower costs, high-speed data transmission, affordable sensors collecting data, processing 'at the edge', image recognition, enhanced CAD software, data science, etc.

The most well-known applications include:

- Digital prototyping – an application of sophisticated design solutions providing an ability to validate the design without building a physical prototype[2].
- Building information modelling (BIM) – an enhanced CAD application, which allows to model exact copies of the objects of built environment[3].
- Smart facilities (building automation) – the infrastructure objects equipped with multiple sensors, data transmission, and processing, providing their better management[4].
- Smart cities (and living spaces) – automation of a wide array of urban management functions[5].
- Digital manufacturing/construction – various applications for automation of the manufacturing/construction processes leading to higher efficiency[6].
- Digital twins – a digital representation of the connected physical object, allowing a complete mirroring of all object's activities[7].
- Connected places (conceptual name) – a network of the assets and "a network of networks" allowing direct exchange of data between physical objects[8].

Those and other physical asset management technologies, we believe, will play a very substantial role in the near future. They bring material benefits to the asset operators and influence infrastructure management at various levels: personal, corporate, municipal, industrial, national, etc. The leading analysts' reports constantly mention those technologies among the top strategic global trends[9].

However, we have identified an important obstacle to the mass adoption of those technologies, which we address in this paper.

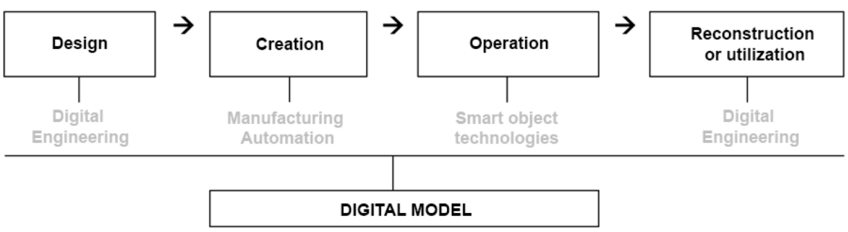
Digital models

Something that all of the above-mentioned technologies have in common is a requirement for a digital model of the asset. A *digital model,* in this paper, is an engineering design package contained in the CAD file. CAD is well-known in all engineering disciplines since it became a dominant global instrument for architecture, engineering, and design some decades ago in the 1980s and 1990s. All of the above-mentioned modern technologies require digital models as necessary input or components. They either use CAD models for engineering or planning; or as a product's digital replica, a core element for many of those applications.

One of the most common effects of the mentioned trends is the utilisation of the digital CAD models of the assets during all lifecycle stages. We can observe this effect by going through each stage of the lifecycle:

- <u>Design</u> – the CAD model is created at the design stage.
- <u>Construction/manufacturing</u> – CAD is used in various construction software (including BIM) and digital construction packages use the information from BIM throughout the construction process. In manufacturing, the traditional use of a CAD model pertains to CNC machines, robotic welding, and assembly, etc.
- <u>Useful life</u> – the stage where all *smart* products' technologies are implemented. They collect all data from the products, processes the data, and aids in the efficient operation of the assets.
- <u>Remodelling, modernisation</u> – at this stage when the object needs capital repair, upgrades, or remodelling, those processes include engineering work, which is based on using design software utilising the object's CAD models.
- <u>Decommissioning/demolition</u> – when the complex equipment is decommissioned (demolished) at the end of its useful life, this stage includes engineering work, again, requiring the object's data in the CAD model.

The CAD model, thus 'travels' with a product throughout its lifetime and becomes central to all stages of its lifecycle.



Some software developers have introduced so-called *product lifecycle management* (*PLM*) *products* – integrated digital packages, helping to manage products throughout their lifecycle[10].

Examples of modern trends requiring CAD models in various stages of the lifecycle

Sustainability and CAD models. The general trend of sustainable management requires companies to manage waste and be responsible for assets and their impact on the environment. This includes not only the impact during operations (such as emissions or industrial waste) but also the impact of the operational assets themselves – buildings, equipment, property, and infrastructure, including redundant or written-off equipment. One of the best ways to reduce or manage this impact is ensuring an ability to recycle, reuse, or otherwise dispose of the assets with minimum environmental impact[11].

Circular economy[12] is a promising and globally endorsed concept, assuming the systemic re-use of existing assets for future applications thus decreasing useless waste. For large objects, the typical examples of the re-use include remodelling the old infrastructure for different purposes (ex: industrial buildings to residential) or using the waste materials for other products (ex: utilising scrap metal for future products)[13]. If a large object's remodelling involves an engineering phase, the CAD model of the old assets becomes required again.

Use of autonomous objects. One of the most promising global technology trends is autonomy, which includes self-guided machinery, such as robots, UAVs, self-driving vehicles, boats, and other equipment. Understanding the operational environment is critical for planning and control. That creates a substantial need for precise models of the respective areas or premises[14].

Infrastructure resource management. The modern approach requires the responsible and predictable use of resources, including water, fuel/energy, and raw materials. Conventional smart infrastructure applications allow users to monitor the use of resources, collect data, and develop efficient informed decisions. Any infrastructure management application must be engineered and thus requires some digital modelling with an asset[15].

Preventive maintenance (PM). PM is one of the typical ways of saving resources and increasing the stability of operations. PM is particularly effective with data collection and forecasting technologies (smart objects, PLM solutions, digital twins, etc.), which all need engineering data on the objects in digital form[16].

Automated and remote inspections. PM requires regular inspections, which aids in forecasting risks of breakdowns. Many modern inspections are done remotely by applying sensors and autonomous inspection devices. These include working with engineering data of the objects in digital form[17].

Objects' safety and security. Operating in secure and safe conditions is a key requirement for modern life. The key requirement for security is situational awareness, which requires information and data about the real-time environment around the object. Multiple sensors are used to ensure the information is timely collected and delivered (ex: CCTV cameras, alarms), while access management systems (ex: controlled access, fences, etc.), and situational emergency systems (ex: fire extinguishers) maintain a controlled environment. Planning and installation of those systems require an engineering phase and thus, the object's CAD model[18].

Law enforcement and defence. Various security and defence agencies widely use technologies to enhance their capabilities. Preventive measures ensuring the security of the specific objects/areas require a rigorous planning and engineering phase. Planning is also paramount in operations. Planning and conducting an operation require much detailed knowledge and maintaining situational awareness in the operational zone. Both require digital data for fast and thorough planning[19].

Industrial decommissioning. Decommissioning of large objects such as industrial facilities, large buildings, offshore rigs, nuclear plants, and other large equipment become labour intensive and expensive projects, each having an engineering stage. Understanding the object, the process of its dismantling, and transportation of the pieces must be designed knowing its exact engineering parameters. Since any engineering is based around CAD, they require CAD models[20].

(The list is not complete; we aimed to show a variety of the industries and stages requiring CAD models).

Legacy assets problem

Legacy assets digitisation – this problem is a roadblock for technology adoption.

Now we come to an actual problem, which is also common to all of the above-mentioned solutions. The problem is that CAD models are not available for a clear majority of existing assets. The so-called *legacy assets*, which were created before the digital revolution and in most cases, are over 90% of the total assets, have their engineering information usually in printed paper drawings. Sometimes the owners scan them for safe storage purposes, but that does not change the situation.

Unless the legacy assets are *digitised* (engineering information transferred to CAD files) they keep data in an outdated form. This is true for all assets created in pre-CAD times but also for more recent decades. Despite that CAD has been a dominant technology in engineering since the 1980s, in most cases, the asset owner probably received paper drawings. The use of CAD technology after the design stage of the lifecycle was very limited. Most of the design firms have only provided printed drawings for construction or manufacturing. When the final product or object was passed to the ultimate customer, another copy of the drawings was provided as a client’s set of drawings. Thus, the digital file most often ‘stayed’ with the original design firm.

Only in recent decades, it became more common for asset owners to obtain the working CAD files. Of course, many asset owners have already adopted the digital solutions described above. But still, the paper drawings constitute most of the engineering data for the assets available.

The absence of the original drawings in CAD is the biggest but not the only problem. In many cases, particularly with buildings and large industrial facilities, the actual product is different from its original design. The *as-built* drawings often are not properly completed and stored, let alone digitised.

Digitising legacy assets is a major problem for the wide adoption of the large-scale industrial and digital built environment technologies, while some innovation research agencies call it the biggest problem, in that respect[21].

Digitising legacy assets now

Today, anyone who needs CAD files for legacy assets needs to *digitise them*. The digitisation for any large asset currently involves a huge amount of manual labour. Generally, the paper drawings are scanned and then transformed into CAD software. To maintain document control and traceability, the first outputs of the conversion must exactly match the original drawing's content sheet by sheet. Later they can be adjusted, corrected, or joined together into assembly models, including in 3D. The drawings are usually saved in formats readable by all CAD software. However, the automation of this conversion is rather primitive. For example, AutoCAD's *raster to vector* convertor is very basic, and it does not create a proper CAD model automatically. It does not recognise layers, does not do attribution of the lines or symbols. Other *pdf-to-cad* or *image-to-cad* convertors available online are similarly basic as well. So, most of the work is done manually, which implies time and resources[22].

Digitising the asset also needs to account for the difference between the original design and the actual object. The object can be photographed, and it can be scanned by laser 3D scanning devices. Scanning provides precise information on surface dimensions, but nothing else. Transforming scans to CAD is also largely manual. Finally, there is a physical inspection of the object with manual adjustments to the engineering files.

So, the automation level of these processes is at the very minimum. Assuming our original statements that 1) digital built environment and digitally run equipment and infrastructure play a big role in the future, and 2) digitising legacy assets is one of the major roadblocks to this future, we cannot imagine how it can be overcome with such basic tools.

Thus, we can confirm that: *existing asset digitisation tools are not enough and much more automation is required.*

Practical examples of missing CAD models (from the actual cases observed by paper authors)

- Offshore decommissioning in the North Sea includes many large oil platforms being removed with all supporting infrastructure. Some of these oil platforms were built in the 1960s to the 1980s and for most of them, the CAD models are not available. Decommissioning requires detailed engineering planning, which requires CAD. So, the models are reconstructed from paper drawings mostly manually. It takes time and effort, which contributes to increasing budgets, underestimated time and costs, and a long time for this work. Sophisticated CAD models of the extremely complex installations are re-created only to enable their removal and demolition.
- Situational emergencies with infrastructure objects require engineering work as well. We know the case of New York's old apartment building that has been evacuated for a long time after a fire and residents could not move back to their building while engineers planned the repairs. A huge amount of time and funds went into

converting old drawings to CAD.

- Building a new object in an existing area, like a house in a block group requires an engineering effort of placing it among the pre-built structures and communications. If those pre-built objects are not digitised, a massive amount of work is required to digitise the surrounding area to include in the building project.
- The CNC machining factory requires CAD files for its work, but many clients have only paper drawings. That requires an entire engineering department dedicated to making CAD files from scanned drawings.
- A developer of the digital facility management solutions in the US has lots of rejections or long delays with new contracts when it turns out that its prospective customers (schools, hotels, hospitals, factories, etc.) have no CAD model of their building and the conversion is so labour intensive and costly.
- Law enforcement agencies need CAD to plan complex operations. Naturally, they are time-constrained, which puts them in a difficult situation when only old, complicated paper drawings are available.

What is the solution?

Searching for the solution began around the same time when CAD was brought to the main market. Publications are dating back to the 1980s about drawings automatic 'recognition'. The articles continued to be published through the 1990s. Unfortunately, there still has not been a practical solution[23].

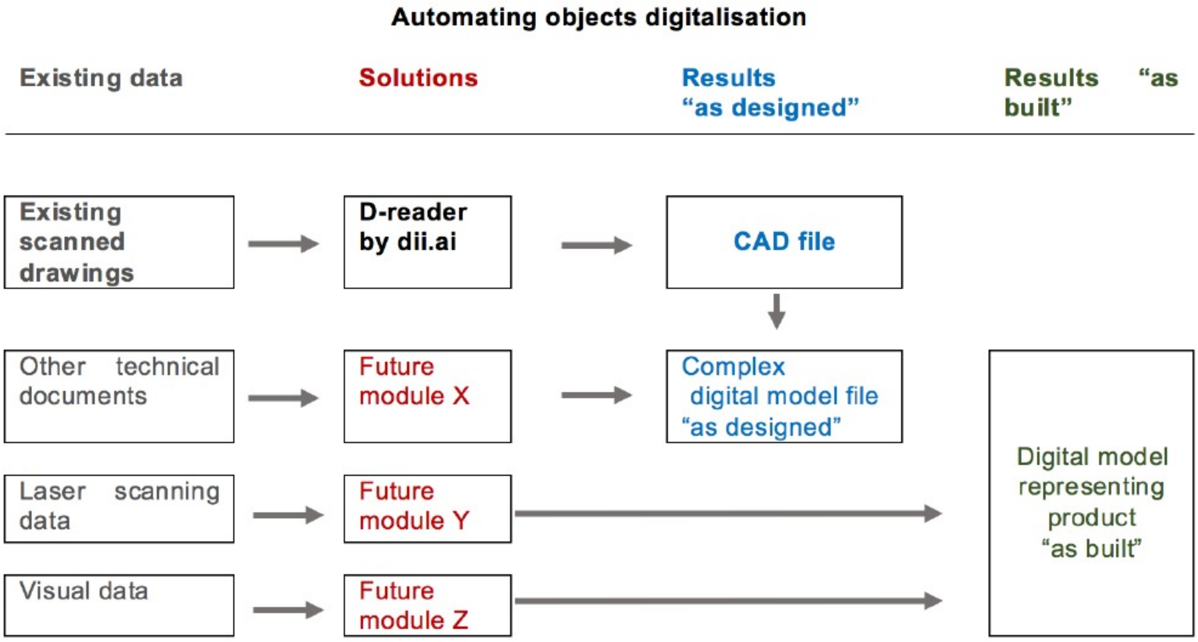
We believe that modern computational power, image recognition, and machine learning allow us an opportunity to finally bring forward the solution. It allows us to detect the key areas of the drawings using the commonalities and standards and identify the key elements of the objects and determine the number of layers.

We also may notice that the automatic conversion of the scanned drawings appears in line with the wider popular process called *document understanding*. Document understanding is a process of the automatic determination and classification of the content of the document. It often is a part of *robotic process automation* (*RPA*), a widely adopted technology of replacing organisational administrative manual tasks with automation. Document understanding also normally involves AI. That's why in some of our presentation materials, we call our method *engineering drawings understanding*, highlighting its connection to document understanding. Document understanding is a relatively new field and is very close to a similar activity called *Intelligent documents processing*. Several organisations provide their services in this field enhanced with AI-based software[24].

Paper drawing → Product → Digital model

The drawings conversion is only a first phase. To reach maximum automation of the assets digitisation, we need to address missing *as-built data* as mentioned above. That solution takes the complete 3D CAD model of the object based on its originally converted drawings and compares it with the surface scanning and photos. Any differences are flagged and addressed.

We have developed a simple solution tree for the creation of digital copies of existing assets. Where the input would be scanned drawings, laser 3D scanning data, and photos. The output would be a complete 3D as-built model of the object



It must be noted that it would be difficult to create complete automation for complex objects. There will be always a need for some manual input – correcting mistakes, addressing conflicting data, ensuring the missing information is completed, etc. But if currently, the average level of automation around the industry is 10%, we believe we can reach over 80%.

We also realise that not every practical technology requires a complete digital copy of the asset with every little detail included in the model. Some applications may require basic information on the object. For instance, we do not need a complete detailed BIM for every building (ex: including details on flooring and power sockets) for a smart city project.

STEPS	Level of automation	Service delivery
0. Current market offering. Scan-to-CAD conversion is mostly manual.	10%	Result is delivered as an engineering service.
1. Dii Reader. Manual work is still required but for most of the drawings* automation is much higher.	50%	Result is delivered as engineering service but much quicker and cheaper enhanced by software.
2. Dii Reader is trained on various types of drawings, has consumed large dataset and is released as product available for mass market.	70%	Result is delivered as SaaS with supportive service.
3. Dii Reader passed the learning curve and is commonly used by various industries as a standard solution.	90%	SaaS

Higher automation will enable quick and inexpensive digitisation of engineering data for large and complex objects. For example, now, only a few cities have made their digital twins; projects that are difficult to implement. Smart infrastructure projects may become quite attractive if we enable digitisation of the cities and factories in a matter of weeks or even days? We believe it will help to unlock the true potential of digital assets management technologies by making them more affordable with a faster implementation that will help to boost a new phase of the digital revolution.

Where we are with the solution now?

Dii started researching this subject over two years ago. Since the summer of 2020, we have been exploring possible tools and methods to address that challenge. By August 2021, we have completed a working version (v.0.1) of our product, the *Reader* (working name), which reads, recognises, and understands the scanned drawings and produces a standard CAD file, in .dxf format compatible with most CAD software. The software still makes a few mistakes (incorrect reading) with complex drawings. The complex drawings require manual completion. Also, it recognises mainly the drawings of the mechanical parts and various structures since that has been our focus for the beginning phase. Architectural drawings are much more complex to understand and will be addressed later. Nevertheless, the results confirm the correctness of our algorithm and the approach. For simpler drawings, the software can do most of the work automatically and for some, it did not need any manual intrusion. The level of intrusion depends on complexity, mistakes, style, etc. We have also tried the automatic creation of 3D assemblies for drawings. The typical drawing conversion is demonstrated in a demo video in the link below[*].

So, currently, we at Dii define the key areas of the drawings, key symbols, classify them, and attribute them to each other. That allows us to determine the service areas, break down the drawing into layers, and identify the lines and symbols finally comprising an actual product. A significant number of computer visions and other machine learning methods are

[*] The Reader demo video: https://www.youtube.com/watch?v=R58Xoo7jsAo&t=6s

employed.

Ahead is the process of collecting drawings, and teaching the software new standards, symbols, and combinations. Various drawings standards depend on geography, industry, and time. Learning each factor is required for recognition via computer vision.

For the time being, we are offering our drawings conversion service, with manual input, however, it is already substantially faster due to advanced automation. The software helps our engineers do a large portion of the work with automation and dramatically reduces time and manual effort. We follow all popular products currently available on the market and observe Dii's level of automation substantially more advanced than any alternative.

Thus, we believe we have developed a working algorithm, which allows the effective automation of scanned drawing conversion to CAD. That triggers a chain of events:

1) *Offering conversion services with manual input but reduced time/cost due to automation.*
2) *Later, offering Dii software as a SaaS (software as a service) without any manual element.*
3) *Thus, making the conversion much simpler, cheaper, and faster.*
4) *Adding elements to Dii software – integrating laser scanning and photo to CAD models.*
5) *Thus, substantially simplifying the digitisation of legacy assets.*
6) *And helping the next wave of the mass adoption of digital asset management technologies: smart facilities, cities, and digital twins.*
7) *Building a platform that enables third-party data services built on CAD & BIM models.*

Dii invites all interested parties involved in similar activities, such as applied AI for infrastructure and industrial engineering, document understanding, drawings conversion, digital twin related technologies, digitally built environment automation technologies, etc., to communicate about our research. We can be reached anytime via LinkedIn messaging or our website feedback form.

https://www.linkedin.com/company/diisocial

https://dii.ai/

References and additional reading

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We constantly are looking for the past and current research papers and information. The latest report (30 page as of time of publication of this paper) can be found in this folder on Google drive:
https://drive.google.com/drive/folders/1WEkLb-SczjiEDFKnYS0KNnGB8C8ur4qZ?usp=sharing

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