Digital transformation to improve quality, efficiency and safety in construction of roads incorporating recycled materials

I Widyatmoko1,2
1Transportation and Infrastructure Materials R&D, AECOM, Chetwynd Business Park, Nottingham NG9 6RZ, UK
2Civil Engineering Department, Universitas Pertamina, Simprug, Jakarta Selatan 12220, Indonesia
E-mail: daru.widyatmoko@aecom.com

Abstract. Raw materials and supplies have been subjected to much increased pressure due to the recent boom in infrastructure construction. These activities have caused more severe environmental damage. The construction and demolition of infrastructure assets accounts for around 30 per cent of global material consumption and waste generation. There are many benefits associated with recycling end of life materials and waste from these construction works. Recycling reduces disposal costs and carbon emissions. It also helps complying with environmental legislation and restrictions on what can be sent to landfill. It is expected that reliable recycling methods in the future should make efficient use of comprehensive catalogue and databases of materials currently used in construction. Greater challenges when dealing with end of life infrastructure assets are often associated with the lack of, or incomplete, records about the materials used in the assets, such as since the design and construction phases, and throughout their serviceable lives. The increasing use of Big Data, smart sensors and automation open ways to build banks of material database into BIM (building information modelling) and other similar methods. This will provide detailed records of existing materials and their in-service history ahead of any future recycling, thus better informed during the design stage, and helps improving the effectiveness and quality of recycled products. Furthermore, road construction industry has been adopting the latest advancement in digitalization of pavement assessment technology. This new approach was aimed at obtaining substantial improvement in the productivity levels, quality and safety of the construction industry and minimizing impact on the environment. A new concept called “Construction 4.0” was subsequently introduced to implement this approach. This concept is often associated with key components such as smart automation, predictive intelligent, real-time data exchange, 4D/5D executions and immediate field-to-office stakeholder communication. These components are currently at early stages however, it has been evidenced that some of these components are being realized. This paper discusses the opportunity and potential benefits associated with the digital transformation in construction industry, specifically as means to promote quality, efficiency and safety in future recycling.

1. Introduction
In line with the improvement in world’s economy and the consequent increase in public spending in infrastructure construction, there have been increasing pressure to consume raw materials and supplies for these projects. The impact from these activities to the environment can be severely damaging.
Furthermore, the construction and demolition of infrastructure assets accounts for around 30 per cent of global material consumption and waste generation. To minimize carbon emissions and waste during the construction and maintenance of road networks, smarter use of data and efficient reuse of materials will become very important. Given they account for 70 per cent of global greenhouse gas emissions, infrastructure construction and operations have an important role to play in helping the international community mitigate the risks from climate change [1].

In 2017, the sustainability advisory body of the UK Green Building Council released a statement that: “There is a need for the infrastructure sector to reduce carbon emissions from the operation, maintenance and decommissioning of infrastructure assets, as well as from the construction of new assets or modification of existing asset systems” [2]. Consequently, the roads industry has been seeking new ways of working to minimize reliance on raw materials, find or develop new methods and improve recycling rates. It should also look at new methods of managing asset deterioration caused by severe climate change such as increased temperatures and higher rain intensities.

2. The Future of Road Recycling

Recycling has been widely acknowledged as playing a very important role in managing and reducing waste from end of life infrastructure assets [3]. Recycling is also a necessary component of a circular economy; it should only be considered when there are no other alternatives for re-use, repair or reprocess. This is the basic premise of the waste hierarchy, which ranks first as the most effective solutions to waste management.

A 2016 survey of the Dutch construction sector found that while it generated the highest volume of waste, it also used half of all recycled materials [4]. Many materials employed in the process of building roads can be recycled. Reclaimed asphalt materials, including their residual binders, can be reused through a variety of techniques developed over the last decade. However, there are a long process to be considered before carrying out a rehabilitation technique which incorporates waste from end of life infrastructure assets for recycling [5, 6]. As illustrated in Figure 1, a road rehabilitation process may comprise several stages:

1) It starts with identifying the existing condition of the infrastructure assets. This stage often includes carrying several surveys such as visual assessment of the assets and in situ testing to assess the structural and functional capacity of the assets. Where available, review of the original design and as-build documents can provide good understanding of the properties expected from the existing pavement, however, these documents are often not readily accessible after 10 – 15 years since the construction. Also, maintenance records can provide in depth information on how the assets have been performing in service.

2) The next stage is determining the cause(s) of pavement distress. This stage is particularly essential to ensure that the rehabilitation work can effectively address the current issues while anticipating the future requirements.

3) Rehabilitation options can subsequently be explored by considering available budget, resources and construction methods. The new design should account for new requirements on geometrics, future traffic and the target level of mechanical and environmental performance (including air and ride quality). For publicly financed assets, it is mostly mandatory to consult with local regulatory requirements and political constraints.

4) Optimization is often required in order to obtain the best design recommendation. The details will be project specific such as whether there is any incentive in the contract to allow for sustainable design or if the procurement will be mainly based on the initial construction cost. The former can be demonstrated by carrying out life-cycle cost analysis of the proposed design.

The above process can be iterative and may require interrogation into extensive database of track records. These may imply a prolonged and time-consuming process. Historically these have become the barriers and/or challenges faced by the material suppliers, designers and specifiers which often discouraged and/or prevented them from incorporating waste from end of life infrastructure assets for recycling [7]. These challenges are often associated with the lack of, or incomplete, records about the
materials used in the assets, such as since the design and construction phases, and throughout their serviceable lives. In this context, recent advancement in technologies can help streamline and manage the whole design for rehabilitation process in a more effective and efficiency manner.

Figure 1. Rehabilitation technique selection process

3. Construction 4.0 and the use of BIM
As recently as a decade ago, it was rare to record construction details such as materials, layer composition and methods of construction beyond the project’s handover. Lost in local archives, there was little or no information to guide what could be recycled after demolition. In such cases, recycling experts are forced to play detective. Cross-contamination, increased costs, more waste to landfill and reduced recycling rates are often the result.

In line with the adoption of Industry Revolution 4.0, the construction industry has also employed a considerable shift from analogue to digital transactions and improved real-time connectivity. This new revolution, calledConstruction 4.0, is expected to radically improve productivity levels, quality and safety of the industry and help minimize impacts on the environment [8]. Some of the key components include smart automation, predictive intelligent, real-time data exchange, four to five dimensional (4D/5D) executions and immediate field-to-office stakeholder communication. In this context, the Big Data and ‘Internet of Things’ (IoT) [9] have been utilized to integrate information collated from different platforms. The latest gadgets such as laser scanning and smart sensors are also used with the prospect of enhancing the ability to monitor various stages in construction projects from design to construction,
and in service. In addition to this, BIM (Building Information Modelling, also referred as Building Information Management) was also employed and is often regarded as one of the most important steps towards digital transformation. This is a process of moving industry to ‘fully’ collaborative working using a harmonized system of digital tools which will be progressive, with distinct and recognizable milestones being defined within that process. This process has been defined in the form of ‘levels’ 0 to 3 by the Bew-Richards maturity model [10, 11]. Figure 2 summarizes the different BIM levels whilst Figure 3 illustrates the implementation of Construction 4.0 in some trials and road construction projects in England [12].

Note 1: Some standards (BS 1192, BS 8536 and PAS 1192 series) are publicly available to support the industry in the adoption of BIM Level 2, outlining the processes and information management practices required to perform at this maturity level. Note 2: This level will expand from 3D modelling to genuine collaboration; from design and construction into operations; from individual buildings to cities and their systems; and will include a feedback loop where lessons learnt on one project can be applied on the next. Additional information about scheduling, cost, sustainability, operations and maintenance of the assets can also be incorporated.

Figure 2. Schematic illustration of Bew-Richards’ BIM maturity model [9]

Figure 3. Automated data gathering and compliance monitoring during road construction [13]

Trials and implementation of Construction 4.0, by the digitalization in road construction in the UK, together with the use of BIM, have started around 5 years ago. These works reported improve productivity levels, quality and safety of the construction [13]. As illustrated by Figure 4, Norfolk County Council in England has estimated reduction in testing costs and increase their replacement cycle period from 25 to 30 years through the benefit of implementing automated quality assurance (AQA) data monitoring [14]. Furthermore, the use of smart sensors and automation during the construction have substantially reduced the need for technicians on site; this minimized the risk for site incidents and consequently improved the safety on site.
Increased rate of adoption of digitalization and successful implementation of the mentioned Construction 4.0 will help facilitating successful implementation of digital twin programme in the infrastructure projects. Furthermore, these developments can offer greater potential to minimize impact on the environment, which is being discussed later in this paper.

4. Adoption of digital twin technologies to help future recycling

A digital twin is a realistic digital representation of something physical such as road and building infrastructure, or even a city. In July 2018, HM Treasury introduced the Centre for Digital Built Britain (CDBB)’s National Digital Twin programme to help unlock an additional £7 billion per year of benefits across the UK infrastructure sector [15]. The scope of the UK Government digital agenda for managing information over the whole lifecycle of a built asset is further explained in BS EN ISO 19650 standards [16]. These developments have consequently accelerated the adoption of digital twins by many road asset managers, where a live digital twin of a physical asset responds and behaves like its real-world counterpart.

Adopting digital twin technology right at the start of a project can future-proof against inefficiencies from the stages of design, construction and maintenance towards the end of life infrastructure assets. A digital twin provides asset owners with clear and specific digital data and modelling, making it much easier to determine how the end of life assets are to be reclaimed and the materials recycled when the time comes. For this to work, it is essential that project managers are extremely diligent in keeping track of all the data involved in construction, both in terms of what is being used on site, and where.

The latest development in machine learning (artificial intelligence) can improve analyses of road design in holistic view (from the design stage, construction and operation/maintenance), bringing specific material knowledge to each road project and sourcing intelligence access from multiple road design databased to fit in the specific project constraints. The automated processing offered by machine learning can help identifying the available assets and, using multi-scale aerial imagery, understanding the surrounding environment. The processing system will support scenario planning and strategic decision-making by prioritizing improvement sites and reporting network wide sustainability and biodiversity metrics. It will allow monitoring environmental parameters in greater detail, more often and more cost-effectively, while improving environmental performance and delivering benefits to those living near the network by ensuring targeted investment to the areas that need it most.

It was reported that by augmenting design practices, digital platform may lead to smart consumption of raw material resources. It has been suggested that the selection and sourcing of materials as well as design can affect up to 85 per cent of a project’s overall greenhouse gas emissions, and up to 60 per cent of the cost [17]. An illustration how the concept of digital platform can be implemented to achieve zero waste landfill, by adopting holistic design, construction and operation of infrastructure assets, can be seen from Figure 5. Digital twins can facilitate this process. However, there has been very slow adoption of digital processes in the road sector. This should change if recycling should become easier for future engineers.
The use of smart sensors for smart operation

Road pavements deteriorate with time as a result of traffic loading and environmental variations, and rehabilitation is required to maintain serviceability throughout their life. Typically, the condition of road pavements is monitored using visual inspection and annual surveys to assess surface defects, skid resistance and bearing capacity. This approach is reactive, however, highlighting visible surface defects rather than predicting deterioration to aid maintenance planning. Smart sensors have been increasingly used to monitor the condition of bridges and roads, in real-time. According to a report by Deloitte, the global smart sensor market is growing at an annual rate of 19 per cent and is expected to reach $60 billion by 2022 [18]. These sensors can either be embedded under the surface of the road or can be vehicle-mounted. Measurements as well as detecting distresses and faults can be taken and recorded in real-time and can be seamlessly fed into the central data server for subsequent analysis; an illustrative example is presented in Figure 6. These sensors become indispensable assets in smart operation and maintenance of the infrastructure assets, providing information about what is happening below the surface, and how the structure is ageing.

When used together with data captured from construction, smart sensors can inform engineers on how individual assets are behaving so that they can assess the performance of these assets. This approach can be used to make informed decisions prior to devising maintenance schedule of the assets, such as explaining why two seemingly similar roads constructed only a few months apart but behaving so differently? Data from these sensors can also help engineers decide whether a material should be recycled based on the Big Data of performance and track records.
6. Concluding Remarks

Not much has changed in the last few decades regarding materials in the field of road engineering. However, the drive to develop and adopt new technologies and materials to minimize impact to environment and reduce the sector’s carbon footprint needs to pick up speed. The industry has a golden opportunity to increase efficiencies and meet ambitious emissions targets. The deployment of our present-day arsenal of smart tools such as digital twin is essential to meeting that goal. These smart tools can facilitate site specific evidence-based design and help engineers gaining better confidence in incorporating end of life infrastructure assets in their rehabilitation projects while maintaining high quality and good efficiency with improved safety. This will also ultimately contribute to realizing zero waste in construction works.

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