K4D | Knowledge, evidence and learning for development

Applications of digital and innovative construction techniques in lower-income countries

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Question

Assess the extent to which new digital and innovative construction techniques are being used in lower-income countries (LICs), with a focus on DFID priority countries, and identify the potential opportunities (if any) that have already been identified in published literature.

Contents

1. Overview

Construction technology has experienced rapid changes in recent years associated with the growing use of computers, software development, automation and offsite construction. These advances are helping to address two common problems associated with the industry, namely project delay and safety. A lack of communication between stakeholders and the uncertainties associated with construction sites and processes have been identified as the main causes of construction delays for a number of years. However, recent developments in information and communications technologies (ICT), new cutting-edge technologies (NCETs) and modern methods of construction (MMC) are helping the construction industry to complete projects on time and to budget by improving communications between stakeholders and their pre-engagement with a project. This report reviews examples of successful adoption of digital and innovative construction technologies in low-income countries in the three areas of 1) Building Information Modelling (BIM), 2) Offsite construction, and 3) New cutting-edge technologies (NCETs).

The use of **Building Information Modelling** (BIM) in the last few years has been a particularly striking innovation. BIM has been shown to be useful in visualising construction processes and has helped risk managers foresee potential hazards to inform risk assessment and mitigation measures, reducing construction accidents and improving the safety of working environments. The literature reviewed on BIM reveals growing interest in developing countries (e.g. Adzroe, 2015; Monko and Roider, 2014), highlighting potential benefits that include reducing environmental impacts (Marzouk *et al.*, 2017), providing a sharing information platform and accelerating the use of ICT (Chileshe and Kikwasi, 2014), and cost savings (Benrós *et al.*, 2011).

In the time available for this review, we found few studies demonstrating the use of BIM in low-income countries, suggesting that there has been limited uptake of this technology.   This conclusion is supported by other studies (Kuittinen and Kaipainen, 2011; Monko and Roider, 2014). However, it has been suggested by Aboushady and Elbarkouky (2015) and Monko and Roider (2014) that capacity building and training to introduce BIM technology to staff and provide the necessary facilities (i.e. software) may help increase its utilisation.

Modern methods of construction (MMC) and in particular **offsite construction** (the process of manufacturing a structure offsite in a factory under controlled conditions and thereafter transporting it to be assembled onsite) have the potential to transform the construction industry in LICs. Offsite construction provides a quality-assured process that can be completed quickly and safely and to budget to meet tight deadlines. The installation process presents less risk than traditional onsite approaches, is safer, has less environmental impact and reduces disruption on the site and can be subject to less corruption.

The literature on offsite construction, albeit from a relatively small number of studies identified in this review (n=6) demonstrates potential benefits including the rapid provision of affordable mass housing (Cherian et al., 2017), time saving (Gunawardena et al., 2014), quality control, and advantage of manufacture and transition to a country under trauma (e.g. post-earthquake) Benrós et al. (2011). There is a perception that mass production ignores individual needs, but when used in conjunction with BIM, offsite construction can help to overcome this issue by engaging end users in the design phase to include individual and cultural needs (Vieira et al. (2017); Pour Rahimian et al., 2017).

The literature also shows potential for utilisation of some other '**new cutting edge technologies**', such as the capture and use of big data (Monroe, 2017), image analysis for landslide detection (e.g. by processing images obtained by satellite and UAV) (Greenwood *et al.*, 2016) and condition assessment of the roads and structures (Paal *et al.*, 2014; World Bank, 2016). These approaches use state-of-the-art hardware and software to enable rapid, inexpensive, real time, repeatable and reproducible data capture and analysis. These technologies can provide additional benefit when used in combination. For instance, where satellite and/or aerial images might be out of date and not including updated information, using UAVs offers the opportunity to capture real-time data. Furthermore, data infusion and automation can make it possible to deal with big data and to make efficient decisions.

Unmanned aerial vehicles (UAVs) are increasingly being utilised by the construction industry to assist with quality control in construction, the measurement of asset inventory and periodic condition assessment. UAVs are particularly useful for accessing confined spaces, e.g. bridge bearing, and/or high buildings, and for assessing assets which occupy large areas (such as transport networks). They provide a bird's eye view enabling additional information through aerial images to be captured and analysed relatively rapidly. Advanced image-processing techniques, machine learning and associated automation also allow rapid automated, real time, data analysis of the images and thereby enhanced decision making. Further recent approaches to analysing large data sets, such as those obtained from UAVs, for example over a road network, are assisting with inferring network level information multiple assets.

Of the countries identified in this search, Haiti and Nepal show particular potential for more advanced technologies application, due to the experience these countries have in dealing with post-disaster earthquakes. However, other countries may also benefit from schemes to raise the awareness of the potential uses and benefits of these technologies and capacity building programmes which equip LICs with the knowledge and wherewithal to uptake the technologies. A starting point can be the evidence provided by the uptake of the technologies in wealthier countries such as India, Nigeria and Egypt with regard to the drivers for the adoption of technologies, such as offsite construction and BIM.

The review question lends itself to an unbiased aggregation approach where the aim is to identify a sufficient number of studies which demonstrate the use of the three identified technologies in different contexts. Given sufficient resources, such an approach would ideally seek to identify all relevant literature. However, because of the resource constraints of this report, careful consideration was given to locating a sample of studies most pertinent to addressing the research question. This was achieved by carrying out a keyword search of titles and abstracts of studies via Internet search engines and accessing academic journal databases and the websites of specific organisations. Following the initial screening process, the full text of candidate studies were retrieved for further scrutiny.

2. Building Information Modelling (BIM)

BIM is a 3D model-based process that gives stakeholders visual tools to plan, design, construct, and maintain infrastructure more efficiently, by providing a platform for data integration and analysis (Autodesk, 2017; Eastman *et al.*, 2011). Our review found eight studies associated with the uptake of BIM in the DAC ODA supported countries, which are summarised in Table 1.

Figure 1: Example of a BIM model

Source: Middlesex University, 2017

Table 1: Summary of the literature on BIM

Author	Year	Key findings	Country
Aboushady and Elbarkouky	2015	Identification of recommendations including wider distribution of the associated software and capacity building among stakeholders.	Egypt
Marzouk et al.	2017	Identification of the potential of different application of BIM for assessing the environmental impacts of road construction projects in Egypt.	Egypt
Matar et al.	2010	Identification of potential benefits of adopting BIM in the Egyptian construction industry.	Egypt
Adzroe	2015	BIM was ranked as the most preferred technology by the interviewees and participants in the study.	Ghana
Benrós et al.	2011	Alternative BIM driven processes for post-disaster housing can produce financial benefits if associated with mass production, and also reduces time of housing delivery where there is a requirement for a large number of houses	Haiti
Kuittinen and Kaipainen	2011	Low usage of BIM by Haitian construction companies.	Haiti
Chileshe and Kikwasi	2014	BIM adaptation can accelerate the currently slow ICT uptake in Tanzanian construction industry by providing a sharing information	Tanzania

		platform.	
Monko and Roider	2014	Despite the lack of both knowledge and adaptation, 81% of the survey participants indicated that wider adaptation of BIM will improve the Tanzanian construction industry.	Tanzania

Adzroe (2015) investigated the benefits of e-business technology take-up (including BIM and Cloud Computing) in the Ghanaian construction industry through foreign direct investment. The study adopted a mixed-mode approach which utilized a questionnaire and interviews with local companies. The study identified barriers to the wide adaptation of the technology associated with limited awareness of the technology within local firms, a lack of information and communications technology (ICT) skills and limited national e-technology infrastructure. On the other hand, the study revealed the potential improvement in communication as well as cost saving opportunities, through adopting e-business technologies in Ghana, and BIM was ranked as the most preferred technology by the interviewees and respondents to the questionnaires.

Sustainable construction in Egypt using BIM was investigated by Matar *et al.* (2010), who developed a BIM-oriented data model that included three elements: environment, construction facility, and construction system. The developed framework was not tested on a construction site, but the potential benefits of adopting BIM in the Egyptian construction industry were discussed. Aboushady and Elbarkouky (2015) reported the utilisation of BIM in ten construction projects in Egypt, where only three projects had a clear maintenance plan. With the aid of a literature review and interviews the authors made a number of recommendations, including wider distribution of the associated software, as well as capacity building among the stakeholders to appreciate the benefits of utilising BIM.

Marzouk *et al.* (2017) reported an application of BIM for assessing the environmental impacts of road construction projects in Egypt. The application made use of a number of software platforms (Autodesk Revit 2015™, Copert 4™ and Athena Impact Estimator™) so that it is capable of calculating project elapsed time, life cycle cost, environmental impacts, and primary energy needs associated with road construction processes. The potential usage of such a model for other types of construction projects in other developing countries was also suggested.

A study by Kuittinen and Kaipainen (2011) of a school reconstruction project in Haiti reported that the lack of uptake of BIM in Haiti was a barrier to the wider use of BIM. Benrós et al. (2011) presented an automated design and delivery approach for relief housing in post-earthquake Haiti which utilized BIM in a way which considered user needs and site-specific contexts. Their model incorporating BIM, which they termed a mass customisation approach, is an alternative to the traditional process followed after such a disaster where a 'one size fits all' approach is often adopted which does not necessarily satisfy the end-users as it fails to meet their individual and cultural needs. The proposed mass customisation approach on the other hand, combines the financial benefit associated with scale of mass production and the functional qualities of customisation. Benrós *et al.* (2011) model also accommodates prefabrication and modular construction to allow offsite construction to meet a post-disaster situation, i.e. large numbers construction in a relatively short period. The use of automated techniques as an energy reduction measure was identified in their study as a source of potential future research.

Chileshe and Kikwasi (2014) investigated the barriers to the implementation of risk management processes in the Tanzanian construction industry by means of a survey of professionals allied to

a literature review. One of their main findings was that ICT uptake was slow in Tanzania construction industry and that this was a potential impediment to uptake of risk management within the industry. BIM was suggested as a potential solution as it would provide a suitable ICT platform for sharing data and information across the industry.

Monko and Roider (2014) conducted a study to investigate the appreciation and application of BIM in the Tanzanian construction industry by means of questionnaires aimed at practitioners, finding that there was a lack of knowledge and adaptation of the method throughout the country. However, the study showed an overall positive indication of interest and need for its adoption, as 81% of the participants agreed that BIM wider adaptation would improve the efficiency of the Tanzanian construction industry. Achieving a more efficient project documentation process was identified as the parameter which would provide the greatest utility from the adaptation of BIM. The main reasons for not adopting BIM in Tanzania were identified as inadequate training, low demand, and inadequate time for assessing the technology. A Public-Private-Academic Partnership was suggested as an effective mechanism to enable the wider adaptation of BIM.

Sahil (2016) in his phenomenological study of building information modelling in developing countries found that when adopted in the construction industry, BIM can help to reduce one of the main issues facing that industry, that of project overrun.

3. Offsite construction

Offsite construction is regarded as a modern method of construction (MMC) and is sometimes referred to as manufacturing in construction, prefabrication, preassembly and construction standardisation (Arif *et al.*, 2012).

Offsite construction has been advocated as a potential solution to face the problem of housing delivery affecting developing countries. Three useful summaries of the literature on the use of offsite construction in Nigeria (Kolo *et al.*, 2014; Pour Rahimian *et al.*, 2017) and India (Arif *et al.*, 2012) show that offsite construction has a number of advantages:

- reduced time for construction and consequent product delivery;
- improved quality of cost;
- improved product consistency
- reduced environmental impact and achieved sustainable constructions;
- reduced lifecycle cost, and
- improved site logistics.

Our review found six studies associated with the use of MMC in DAC ODA supported countries. These are summarised inTable 1.

Table 2: Summary of the literature on offsite construction and automation

Author	Year	Key findings	Country
Vieira et al.	2017	Development of adaptive modular housing is a solution for addressing the lack of adequate housing in Cape Verde.	Cape Verde

Gunawardena et al.	2014	Modular and prefabricated constructions are effective solutions for post-disaster housing, reconstruction and reduced time for construction.	Haiti
Arif et al.	2012	Identification of advantages, barriers, and driving factors for the implementation of offsite constructions in India.	India
Cherian et al.	2017	Use of GFRG panels can provide a rapid and affordable mass housing solution in India, compared to the traditional construction system.	India
Kolo et al.	2014	Identification of advantages, barriers, and driving factors for the implementation of offsite constructions in Nigeria.	Nigeria
Pour Rahimian et al.	2017	Identification of advantages, barriers, and driving factors for the implementation of offsite construction in Nigeria.	Nigeria

One of the main benefits of offside construction is the reduced time needed for construction. Because of this, modular and prefabricated construction can be considered an important solution for post-disaster housing reconstruction. Gunawardena *et al.* (2014) investigated this approach in a number of recent post-disaster interventions (e.g. the installation of 46 modular housing units following the earthquake in Haiti), confirming that modular and prefabricated construction can provide significantly faster construction times and is an effective solution for post-disaster permanent housing. Moreover, the ability to manufacture prefabricated components in a quality controlled environment, and the potential integration with techniques such as BIM, can allow high quality standards and consequently good conditions for the dwellers.

However, there are still a variety of limitations that affect the adoption of this construction method by LICs. Barriers highlighted by Pour Rahimian *et al.* (2017) and Arif *et al.* (2012) include the lack of construction standards, planning systems, guidance and availability of information on the process, as well as limited design flexibility, shortage of local skills and knowledge, and the perceived negative nature of the industry, stakeholder and clients.

Cherian *et al.* (2017) investigated the use of glass fibre reinforced gypsum (GFRG) panels for rapid and affordable mass housing in India. Also known as Rapidwall™, GFRG panels are manufactured from any type of recycled industrial waste gypsum (flue gas gypsum, mineral gypsum, phosphogypsum or marine gypsum). The panels are prefabricated in 3m × 12m sizes with cellular cavities inside, to allow concrete reinforcement wherever required. A peculiarity of the GFRG application in India is the use of these panels not only for walls, but also for floors. The panels were designed to be earthquake resistant as more than 50% of the Indian population lives in seismically active areas. A two-storey building model was first constructed and tested, followed by a mass housing construction at Nellore, comprising of 40 units of housing in five two-storeyed blocks (Figure 2). The GFRG building system revealed a number of advantages compared to the traditional construction system: (a) high speed of construction; (b) reduced 'built-up' area for the

same carpet area; (c) recycling of industrial waste gypsum results in less embodied energy and carbon footprint; (d) significant reduction in the use of cement, sand, steel and water; (e) excellent finishes of prefabricated GFRG panels for all the walls, floors and staircases, eliminating the need for additional plastering; (f) lower cost of structures due to savings in materials; (g) lower energy consumption for heat-regulation of interior of buildings; (h) lower CO_2 emission, compared to other conventional building materials, and (i) significantly lower building weight, contributing to savings in foundation and reduction in earthquake loading in multi-storeyed construction.

Figure 2 Construction of GFRG demo building

Source: Arif *et al.* (2012)

Vieira *et al.* (2017) explored the use of modular construction as a solution for addressing the lack of adequate housing in Cape Verde. The approach used in this case consisted of developing prefabricated modules designed according to environmental parameters, e.g. temperature and humidity, which allow the production of economic and quickly built houses which are in keeping with the traditional concept of habitation in the country. The development of the framework for the modular construction consisted of analysing the hydrothermal, acoustic, mechanical and waterproofing requirements of wall panels, in addition to the availability of local material. Also, the framework focused on the composition of the housing module by addressing dimension requirements, geometry of the prefabricated module and its elements. The proposed solution allows the production of adaptive modular housing based on semi-modules that can be added or subtracted to the house, giving the opportunity to modify the dimension of the house based on necessity of increasing or reducing the dimension (Figure 3).

Figure 3 Schematic representation of the habitational module's assembling process and examples of different evolutions of the adaptive module
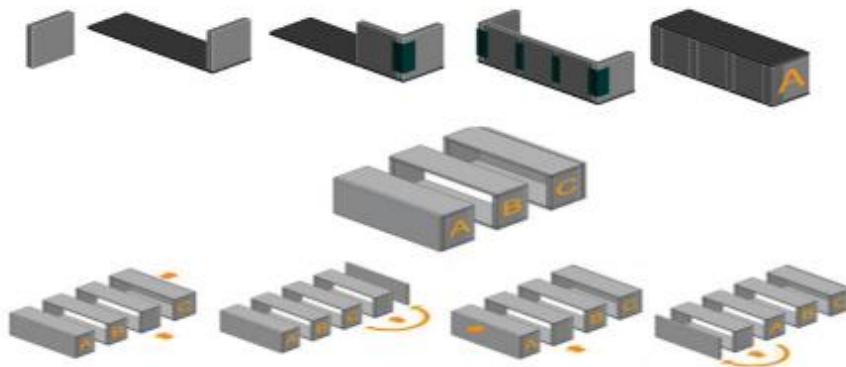
Source: Vieira *et al.* (2017)

Pour Rahimian *et al.* (2017) developed a framework (Figure 4) presenting the priorities and solutions for the implementation and adoption of offsite construction approach in Nigeria. The proposed framework can be used in other developing countries to promote the wider adaptation of the technology. Furthermore, as shown in the previous section, BIM can be utilised to engage with end-users at the design phase and to include cultural and/or environmental concerns within the overall design and build process.

Figure 4 Outline Roadmap for the Adoption of Offsite Manufacturing in the Nigerian Housing Sector
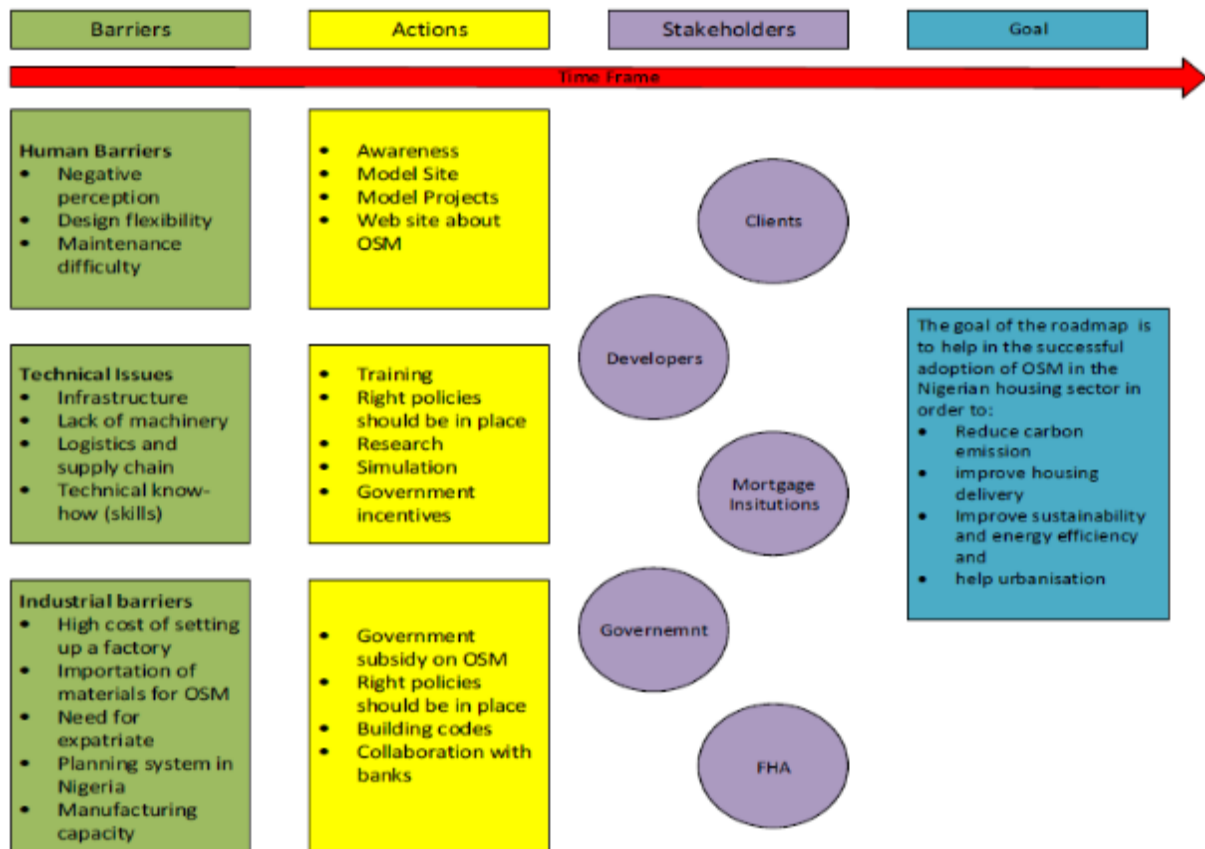
Source: Pour Rahimian *et al.* (2017)

4. New cutting-edge technologies (NCET)

In our literature search, we identified studies associated with the uptake of various other NCETs in DAC ODA supported countries, as summarised in Table 3.

Table 3: Summary of the literature on new cutting-edge technologies

Technology	Author	Year	Key findings	Country
Big data	Monroe	2017	Identification of potential applications of mobile phone call data for urban transportation, infrastructure maintenance strategy, transportation	Haiti and Tanzania

			managements, and land use planning.	
	World Bank	2016	Identification of potentialities of new technologies for data collection in remote rural areas through a developed spatial technique.	Ethiopia, Kenya, Mozambique, Tanzania, Uganda, Zambia, Bangladesh and Nepal
Laser scan	Mosalam et al.	2014	Laser scanner application can be an effective tool for assessing the condition of structures in post-earthquake situations.	Haiti
	Dhonju *et al.*	2017	Heritage documentation with application for structural model and condition assessment	Nepal
GIS and Satellite Image	Antos et al.	2016	Identification of potentialities for applications of the GIS and satellite imagery for evaluating population density of urban areas.	Ethiopia, Kenya, Rwanda, Tanzania and Senegal
	Pantha et al.	2010	The combination of GIS, satellite images and UAV can allow the development of a road maintenance prioritisation model that combines road and roadside slope stability conditions.	Nepal
Satellite image	Sharma et al.	2017	Detecting landslides.	Nepal
	Xiao	2017	Detecting landslides.	Nepal
	Gueguen et al.	2017	Achievement of 100% accuracy for detecting villages' boundaries on mapping application.	Nigeria, Somalia, Pakistan, and Afghanistan
	Ningombam et al.	2014	Detecting landslides.	Nepal

	Kayastha et al.	2012	Detecting landslides.	Nepal
Image processing	Cowgill et al.,	2010	LiDAR survey allows real-time assessment and rapid decision making in post-earthquake conditions.	Haiti
	Paal et al.	2015	Identification of concrete defects through the use of combined UAV and image processing.	Haiti
	Paal et al.	2014	Identification of concrete defects through the use of combined UAV and image processing.	Haiti
	Zhu et al.	2011	Identification of concrete defects through the use of combined UAV and image processing.	Haiti
UAVs	O'Driscoll	2017	Identification of UAV application for mapping.	Haiti and Tanzania
	Gevaert et al.	2017	Achievement of a 95 % accuracy using UAV images for automated mapping urban areas.	Rwanda
	Greenwood et al.	2016	Detecting landslides.	Nepal
	Soesilo et al.	2016	Identification of UAV application for mapping.	Haiti and Tanzania
Machine learning	Massawe et al.	2018	Identification of applications for machine learning for automatically learning programmes from multi-source datasets to make forecasts, and satellite images processing for classifying soil.	Tanzania

Big Data

'Big data' refers to massive data sets that can be analysed by computer algorithms to reveal patterns, trends and associations which provide useful information to the user and which may not have been otherwise be recognised.

Monroe (2017) in his study for the World Bank on innovations in analytics in the urban spaces context, found that in Haiti, mobile phone call data is used for urban transportation and land use planning, and has potential applications for disaster management. He also suggests that these

data can be used to inform infrastructure maintenance strategies, and traffic and transportation management, although these applications were not trialled in the study. Monroe (2017) also reported similar applications of mobile phone data and open-source software in Dar es Salaam, Tanzania, where a pilot programme is collecting the travel behaviour of 500 individuals to inform transportation policy and infrastructure development.

The World Bank (2016), in a collaboration project with DFID, assessed the potential of the use of modern technologies for data collection in remote rural areas as part of the development of a Revised Rural Accessibility Indicator (RRAI). The original Rural Access Index (RAI) measures the proportion of people who have access to an all-season road within an approximate 2-km walking distance and has been widely adopted as a global development indicator for transport accessibility (specifically as a Sustainable Development Goal indicator). The proposed RRAI would be based on spatial data and IT techniques whilst maintaining the original definition. The new method was developed with the aim of establishing a sustainable, consistent and operationally relevant method to measure rural access, using newly available data and spatial data collecting technologies. These include assessing road ride quality (i.e. roughness) by means of data captured from a smartphone during driving and high-resolution satellite imagery to assess road inventory (number of culverts, road length) and aspects of road infrastructure condition. Trials of this approach have been undertaken successfully in Ethiopia, Kenya, Mozambique, Tanzania, Uganda, Zambia, Bangladesh and Nepal.

Laser Scanners

Mosalam *et al.* (2014) reported the application of laser scanners for assessing the condition of structures. A case study was conducted in post-earthquake Haiti where the result of high-definition laser scans with 4mm accuracy were compared with visual inspection results. An example of the survey conducted in Haiti is presented in Figure 5, which shows the identified deformed members (beams and columns) of the structures. The system application as a quality assessment tool after any new construction was discussed. The 3D reconstruction of an as-built asset can be used within a BIM system to identify differences between what has been built and what was designed. The reconstruction can also provide a realistic record of the structure.

Figure 5: Condition assessment using laser scanning technique, healthy top beams and columns (top right image) and deformed ground columns (bottom right image).


Source: Mosalam *et al.* (2014)

The potential benefits of combining laser scanning and images captured by UAVs are discussed by Dhonju *et al.* (2017) as part of a heritage documentation project in Nepal, where condition assessment of the structures was also conducted by using generated 3D models to detect cracks in the structure.

Image Processing

Pantha *et al.* (2010) developed a Geographic Information Systems (GIS)-based road maintenance prioritisation model for Nepal, which combines road and roadside slope stability conditions. Road condition is assessed by its surface roughness, i.e. International Roughness Index (IRI) and the roadside evaluation is conducted by analysing aerial images and topographical maps to detect landslides. However, the aerial images used were taken in 1992, and therefore might not include some recent landslides or new earth movement. This issue could be resolved by utilising new technologies such as images obtained by unmanned aerial vehicles (UAVs).

UAVs have also been used in geotechnical investigation projects in LICs, for instance Greenwood *et al.* (2016) successfully utilised images obtained by drones for detecting landslides in Nepal (Figure 6). Satellite images were similarly used by Kayastha *et al.* (2012); Ningombam *et al.* (2014); Sharma *et al.* (2017); and Xiao (2017) for landslide detection in Nepal.

Figure 6: Example of utilising drones (a) for landslide detection (b) in Nepal
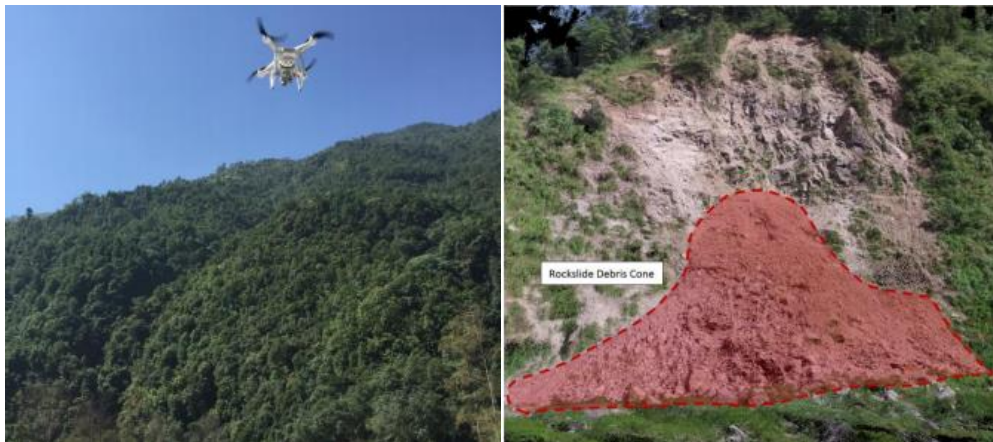
Source: Greenwood *et al.* (2016)

A more advanced technology, virtual-reality visualization using LiDAR[1], has been deployed in Haiti for surface mapping and post-earthquake assessment, allowing real-time assessment and rapid decision making (Cowgill *et al.*, 2010).

Automated image processing has been also used for condition assessment of concrete structures in Haiti (Paal *et al.*, 2014; Paal *et al.*, 2015; Zhu *et al.*, 2011) and in particular to detect

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[1] Light Detecting and Ranging. Also called LIDAR and LADAR.

defects in concrete (i.e. spalling). Automated image processing combined with UAV technologies can further improve the decision-making process.

Unmanned Aerial Vehicles (UAVs)

Both O'Driscoll (2017) and Soesilo *et al.* (2016) reported applications of UAVs related to construction including mapping densely populated urban areas in Haiti and assessing flood risk in Tanzania. Having accurate and reliable datasets for rural areas and populations is vital for managing infrastructure including access roads and locations of amenities. Gueguen *et al.* (2017) used satellite images for automated mapping of rural and urban populations in Nigeria, Somalia, Pakistan, and Afghanistan, where a 100% accuracy for detecting village boundaries was claimed. Furthermore, Antos *et al.* (2016) reported applications of the GIS and satellite imagery for evaluating population density of urban areas through case studies in Ethiopia, Kenya, Rwanda, Tanzania, and Senegal. Gevaert *et al.* (2017) utilised UAV images for automated mapping urban areas in Rwanda using a developed model, achieving 95% accuracy.

Machine learning

A recent study reported by Massawe *et al.* (2018) in Tanzania utilised machine learning, a type of artificial intelligence (AI) which uses ability of computers to automatically learn programmes from multi-source datasets to make forecasts, and satellite images processing for classifying soil. The focus of the study was on land management from an agricultural point of view, however this showed great potential for construction applications including detecting local construction materials and carrying out primarily geotechnical and geophysical assessments for new construction sites.

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About this report

This report is based on five days of desk-based research. The K4D research helpdesk provides rapid syntheses of a selection of recent relevant literature and international expert thinking in response to specific questions relating to international development. For any enquiries, contact helpdesk@k4d.info.