TOWARDS DIGITAL DELIVERY OF METRO-RAIL PROJECTS IN INDIA

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ABSTRACT

There is a large programme of metro-rail construction in India, upgrading public transportation systems to provide rapid transit to millions of people in major Indian cities. The scale of this development makes it important to innovate as improvements in design, construction and operations can have a significant impact on built asset sustainability. As integrated digital delivery approaches are becoming used internationally in infrastructure projects, new questions arise about their application and suitability in these Indian metro-rail projects. This paper is based on a research collaboration involving desk-based study, site visits, and a hosted workshop with 40 participants including client representatives of six major Indian metro-rail projects along with technology providers and delivery teams. Findings are that - while Nagpur Metro project is most advanced in implemented Building Information Modelling (BIM) in its planning and design phase, translating practices from Crossrail in London into the Indian context - there are significant challenges in adopting digital practices in the delivery of new transportation schemes in Indian cities. These challenges include stakeholder awareness and education; integration and interoperability; standardization; cost implications and BIM strategy. The paper concludes with some potential directions for future research and discusses the potential for India to 'leapfrog' a generation of technology to implement low-cost effective digital solutions.

Keywords:*Digitisation; Infrastructure; Innovation; Metro-rail Projects.*

1. INTRODUCTION

There is a large programme of metro-rail construction in India, upgrading public transportation systems to provide rapid transit to millions of people in major Indian cities. At present, India is experiencing a sustained period of rapid economic growth nearing 9% per year between 2003/04 and 2010/11 (Brahmbhatt & Kathuria, 2014). This pace has also contributed to an unprecedented decrease in the poverty rate (from 37% in 2004/05 to 22% in 2011/12); an extraordinary decline over so short a period. The segment of population which overcame poverty corresponds to the middle-class families. On one hand, the present forms of public transport in Indian cities (including buses, suburban trains, and other private vehicles) and the road/rail infrastructure cannot cope with such rapidly increasing demand. On the other hand, around 20-40% of India's emissions are due to the above transport forms. Metro-rail systems are an option that can improve the quality of transportation infrastructure in Indian cities considering that a single four-car metro-rail rake per trip is expected to remove 16 buses/300 cars/600 two-wheelers from the road (Bundhun, 2015). This reduces both traffic congestion and pollution.

India has built around 324 km of metro rail mostly in the last decade, with another 520 km currently under construction in various cities including Delhi and NCR, Kolkata, Chennai, Jaipur, Mumbai, Kochi, Ahmedabad, Nagpur and Lucknow (Metrorailnews, 2016). Additionally, another 553 km is under consideration (Shah, 2016). The Indian government aims to build metros in at least 50 cities across India within

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the next 10-15 years (Kochhar, 2016). Sankhe et al., (2010) at McKinsey estimates that around 7,400 kilometres of metros and railways will be constructed during this period. This will lead to an unprecedented era of construction activity, which is part of the $1.2 trillion in planned capital investment for meeting the demand of India's growing cities.

The scale of this development makes it important as improvements in design, construction and operations can have a significant impact on built asset sustainability. The current practices of project execution and maintenance generate substantial waste at the behest of the client's preferences and local existing laws that are often loosely enforced (Arif et al., 2012). The construction sites in India are typically congested and located in heavily built-up areas with no provisions for alternate storage or staging location for materials. Often, construction wastes are not and cannot be taken ownership for due to the presence of multiple contractors on site and lack of awareness and education among the construction workforce. Also, waste is transported by open trucks and often scattered in nearby areas (Kaushik, 2016). Debris is frequently dumped along the road-side without provisions for proper disposal. Worse, the lack of waste management programs often leads to waste burning, which is the largest uncertainty in India's emissions inventory. Beyond material waste there are other inefficiencies that lead to time and cost overruns on a majority of Indian infrastructure projects – non-availability of resources on time and poor planning to name a few (Project Management Institute and KPMG, 2014). These are but a few of the symptoms of a less than advanced approach to sustainable development. The United Nations Environment Programme suggests that achieving sustainable design and construction practices in India requires a) bridging the knowledge gap on sustainable building strategies, which exists at various levels within the industry; b) enforcing implementation of strategies to encourage adoption of sustainable, green and energy efficient infrastructure; and c) conducting research and development on technology for lowering costs (Kochhar, 2016).

In order to improve project performance and overcome these challenges, project organizations are now embracing digital tools. While the first generation of digital tools allowed for the digitization and sharing of information (CAD files, spreadsheets), later generations allow for the creation of digital models with shared, embedded information which can be used for enhanced coordination across the project team. Building Information Models (BIM) for instance represent one such paradigm that promises to increase throughput on projects by enabling greater, and earlier visibility of information with a view towards allowing project leaders to optimize decisions (Eastman et al., 2008). Tools such as BIM have been embraced by the international construction community. Several countries such as the UK and the USA have mandated the use of BIM on key projects and iconic structures such as the Disney Concert Hall in the USA and Heathrow Terminal 5, to name a few have used a variety of digital tools in their development (Bryde et al., 2013). As integrated digital delivery approaches are becoming used internationally in infrastructure projects, new questions arise about their application and suitability in these Indian metro-rail projects. To what extent have Indian Metro Rail projects embraced Digitalization in project delivery? How applicable is Digitalization in the Indian Infrastructure context? What pathways can be charted for a digital expansion in infrastructure delivery? This paper seeks to address some of these issues.

2. BACKGROUND

2.1. OVERVIEW OF THE INDIAN METRO-RAIL PROJECTS

Based on the perceived success of the Delhi Metro-rail Project, which revolutionized transport for the 17 million residents of that city, many other cities in India initiated metro rail projects. On 11 August 2014, India's Union Government announced that all Indian cities having a population of more than 1 million would be eligible for financial assistance to implement a metro rail transit system (Elets Technomedia Pvt Ltd., 2014; Indo Asian News Service, 2014; Wikipedia contributors, 2018). Following this, in May 2015, Union Urban Development Ministry's proposal to introduce metro rail systems in 50 cities was approved by the Union Government. Most of these planned projects will be realised through special purpose vehicles, established as equal partnership joint ventures between the Union and the respective State Government. An estimated ₹5 lakh crore (5 trillion rupees, ~US$77 billion) would be invested by the Union Government (Rail News Media India Ltd, 2015; Wikipedia contributors, 2018). As of November 2017, there are 11 operational metros in ten cities (Kolkata, Delhi, Bangalore, Gurgaon, Mumbai, Jaipur, Chennai, Kochi, Lucknow and Hyderabad) in India and has 324 km of operational metro lines (Metrorailnews, 2016; Wikipedia contributors, 2018). Existing metros and the metros under construction and planning are shown in Figure 1.However, many of these metro rail projects are facing cost overruns, schedule delays and safety incidents (Indo-Asian News Service, 2017; Staff Reporter, 2017; Menezes, 2018; Rawal, 2018).

2.2. BIM, LEAN AND BUILT ASSET SUSTAINABILITY

The construction sector has taken active steps to reduce its carbon footprint by minimizing its key sources; construction waste and process inefficiencies. This has been achieved through adopting lean construction principles, moving towards mechanized off-site manufacturing and exploiting recent IT waves, such as Building Information Modelling. In the UK, for example, the use of BIM is predominant and expected to rise to 95% by 2018. Many governments internationally (e.g, Germany, UK, Singapore, Korea and China) promote the use of BIM and related forms of integrated digital delivery in building and infrastructure projects. There is substantial work on standard development, with a new suite of standards (ISO 19650) being developed. The World Economic Forum has recently brought out its own plan to accelerate BIM (World Economic Forum and The Boston Consulting Group, 2018), building on recent work on the future of construction, that articulates the different digital technologies that are available across the lifecycle. Projects like Crossrail and High Speed 2 in the UK have put significant effort into developing information management strategies during delivery.

India has yet to make significant advances in lean adoption and off-site manufacturing and lags significantly behind in the exploitation of recent IT waves. For example, only 22% of India's construction professionals use BIM (Sawhney, 2014). The result is that construction activities in India account for the highest direct and indirect CO2 across all Indian industries at 266 MT/year (24% of the total), while Delhi alone produces 5,000 tonnes of construction material waste every day. This carbon footprint is about to get even worse, as the Indian government is in the process of planning and building metros and railways for 50 cities over the next 10-15 years, which is 20 times the capacity added in the past decade. It is unlikely that existing IT tools and adoption mechanisms in India will manage to change this trend and substantially contribute to reducing the carbon footprint anytime soon: what will make a big enough difference?

2.3. TOWARDS DIGITAL DELIVERY AND LEAN

Hence, this project's primary motivation is that India's construction sector is not ready yet to exploit the ongoing BIM wave to its full potential for sustainable development due to the lack of tools that cater to the needs of a developing country. The second motivation is that there is a parallel gap in the range of technology developments being considered to maximize the benefits of a BIM-enabled digital worksite. To date, research efforts have focused mostly on data models for smart cities, refining BIM standards and applications, data security and sharing, integrating BIM with the cloud and the smart infrastructure; complementary to this is the possibility that worksite models can be generated (or as-designed models updated) throughout construction to help provide the rich data backbone needed for sustainable construction practices, such as workflow automation and quality assurance, and create a resilient, as-is digital record of India's built environment.

A shift towards the use of digital information about assets in rail, which has been enabled through developments in Building Information Modelling and its use on major projects. While integrated digital delivery approaches become used in globally-leading transportation projects, there is a shift in the locus of new transportation projects to developing contexts such as India, raising new questions about how the delivery of transportation systems can benefit from innovation across a broader range of institutional contexts.

BIM is not widely used in the Indian context (Mahalingam et al., 2015). A starting hypothesis, which motivated the international research team to work together, is that if it is affordable to digitize and interact with the digital version of the construction project and the infrastructure systems it affects, more of India's stakeholders will be likely to take advantage of digital technologies, leading to a significant reduction in upfront design costs and design uncertainties, which in turn will lead to better change order and rework control during construction. Objectives are to articulate the mechanisms for and barriers to innovation in the context of Indian metro-rail projects; and to identify opportunities for digital delivery.

Research on BIM in the context of the Chennai Metro indicates that a station that first implemented last planner had better success in its use of BIM than one that started with the use of BIM, perhaps because the lean processes associated with last planner required collaboration that was useful in using BIM (Mahalingam et al., 2015). BIM has resulted in benefits in such isolated cases. Why then have BIM applications not been scaled up and across Indian infrastructure?

Figure 1: Map of India Showing Statuses of Metro-Rail Projects

Previous research has determined that the key factors influencing the lag in construction technology adoption in India are: a) lack of awareness on client side and hence no requirement in contracts to adopt technology; b) no impetus from the government for a phased adoption plan; c) lack of industry wide standards (unlike the UK); d) dependence on international software tools with inadequate local technical support from vendors e) inadequate basic research and development capability by Indian IT industry to develop required platforms; e) focus by construction organizations on short-term ROI; f) little investment in training employees to adapt to new technologies; g) challenge in reengineering workflows to enable digital standards, and h) challenge in customising tools to support existing workflows. The developed world also suffers to some extent from some of the factors above. Yet, technological and procurement solutions and standards have been developed to address most of them, while a stronger focus on innovation and R&D has created a culture of innovation acceptance. The investigators and their peers have made preliminary attempts to address this technological gap through methods for generating and visualising rich Building Information Models (BIM) of existing facilities. The resulting prototypes are robust for practical use and provide early insights on the technical challenges that must be addressed. Yet, these tools are not built for worksites or metro/railway infrastructure. A key research gap, therefore, is to understand the kinds of mechanisms and strategies that can overcome these barriers and lead to greater adoption of Digital Technologies in the context of Indian Metro Rail projects. While we do not claim to comprehensively answer this question in this paper, we hope to understand the state of digital adoption, drivers and barriers and future pathways towards digitalization in the Indian metro context.

3. METHODS

Method steps associated with the data collection and analysis include:

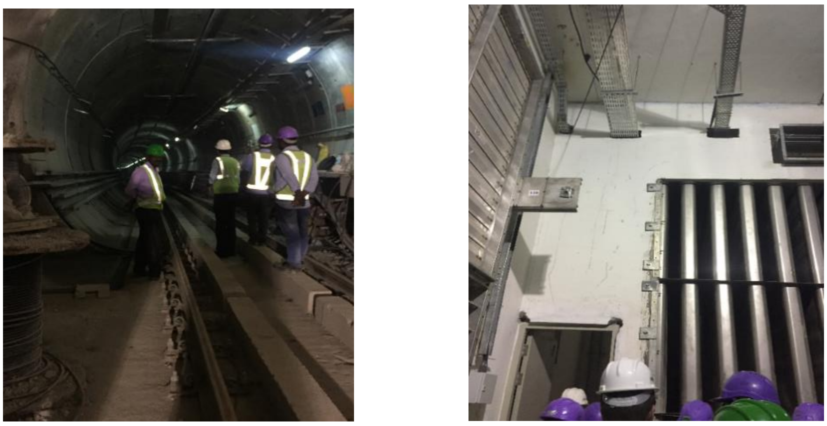
1. Preparatory desk-based research – initial work was done to understand the Indian construction context; and the potential for developing novel technological solutions in this context. The academic team has had many online meetings in shaping the research, proposing and planning for the co-located work in India.
2. Site visits – when co-located in Chennai, India, the team made two site visits, to the major contractor Larson and Toubro Ltd. (number 21 in the ENR's 2017 Top 250 Global Contractors) and to a metro-rail project. Four members of the team visited the contractor together; with five members of the team visiting the metro-rail project, giving shared familiarity with the context of metro-rail construction. The research team varied in their familiarity with the context enabling us both to ask simple open-ended questions, such as 'what was the main issue you faced on this project' and also to contextualise and interpret the answers given.
3. Workshop – this day-long workshop was hosted by members of the research team and attended by 40 participants including client representatives of six major Indian metro-rail projects along with technology providers and delivery teams. This workshop was organized to understand the challenges faced by the current metro projects in India, in adopting and implementing digital initiatives. The workshop also aimed at facilitating a common ground for exchange of ideas and gaps in pushing digitization in Indian metro construction. Leading practices in digital delivery and the potential for their adoption in digital metro rail construction in India were discussed. There were sessions to discuss digital practices in the six Indian metros that were represented; and the key challenges in their adoption of digital tools and methods. Based on the identified challenges, participants were divided into four groups and concentrated discussion on these topics was done and each group presented an outline of their discussion and how the challenges could be tackled. Detailed notes were taken throughout the workshop and audio was recorded. A report of the workshop was written up and distributed to industrial participants.

While collecting and analysing data from the site, the team also read recent research literature, to ground findings in the existing literature and to show where our work extends this existing work to make a contribution to understandings of transportation systems policy and practice.

4. RESULTS

4.1. PRACTICES ON THE CONSTRUCTION SITE

On the site visited by the research team, there had been 1300 people working in total (400 skilled and 900 unskilled). There is transient labour and high construction activity, such that the project managers felt they were short of 300 people. Labour is recruited through a specialist labour subcontractor, which takes responsibility for recruitment, and for managing the accommodation for site labourers. Evidence of the use of digitalization practices on site was virtually non-existent.



(a) (b)

Figure 2: (a) Metro-Rail tunnel in the 'fit-out' phase; and (b) A detail of the station showing the drilling of holes in the wall for high-level cables

4.2. WORKSHOP DISCUSSION

Indian metro projects are in the very early stages of adoption of digital initiatives. Most of the projects under construction have no digital initiatives in place. However, the projects going into the next phases are planning to include digital initiatives on its agenda. Considering that there is no official mandate by the government for implementation of BIM/digital technologies for any phase in a construction project, usually, client or general contractors drive the initiatives. However, there are isolated digital initiatives followed among the metros for automating the workflows. E.g. Kochi Metro has implemented a digital workflow for submitting documents and managing them. Metros for which Larsen and Toubro is a contractor develop 3D models and use clash detection for identifying clashes between different engineering disciplines at an early stage. Also, Larsen and Toubro have enabled mobile platforms for performing inspections on site.

At present, in India, Nagpur Metro is the only metro rail project which has taken significant steps towards implementing BIM in its planning and design phase. While the client – Nagpur Metro Rail Corporation Limited (NMRCL) did not stipulate inclusion of digitization, private technology providers along with the general contractor took leadership for a BIM integrated project delivery. 3rd party BIM developers such oversaw modelling and process integrations for BIM at the Planning and Design stage and supply-chain management. RFID tags were used to manage the status of component tracking and installation.

The Nagpur Metro Project uses digital information management systems across the lifecycle of the project. Following the BIM strategy developed for the Crossrail project, the BIM strategy for the project was based on the guidelines from PAS1192 standards. The main areas of the use of digital platforms for information management are:

- Design review and approval process are carried out in a common data environment to improve transparency and to enable tracking. Drawings will be attached with placeholders. The document will be transmitted to document controller. Document controller acknowledges transmittal & forwards to Lead Reviewer to initiate approval process. Reports are generated to track the status of review and review process requiring attention are flagged.
- Building Information Model (BIM) is created from 2D drawings and associated data. The following information is mandated to be included in every component (e.g. Geometric data, material definitions, quantity take off, asset tags, links to related documents etc.). The BIM model is intended to be used for planning and clash detection, in addition to the value it has during the operation phase. The work order quantities from the BIM models were used to cross-check with the work order quantities supplied by the contractor.
- To enable visual progress monitoring and integrated cash flow management, building information is linked to SAP software for billing and finance. Also, the building information model is linked to the

Oracle Primavera P6 for integrating the schedule. RIB platform is used as a 5D visualization platform for integrating information form costing and planning. This has enabled them to visualize the progress of the project and detect deviations.

One of the major challenges in Nagpur metro was that BIM was not used beyond the above two stages. As a result, information encoded in BIM was not used to ease the downstream phases such as operation and maintenance. Hence, during subsequent expansions of the metro, verification is required to ensure the validity of Building Information Models.

5. INTRODUCING DIGITAL DELIVERY

Based on the discussions on how digitalization of infrastructure is carried out in the UK and where Metros in India are at in terms of digitalization, the participants were grouped into four categories to brainstorm on opportunities, key challenges during metro construction and how it can be addressed through digitalization as represented in Figure 3.

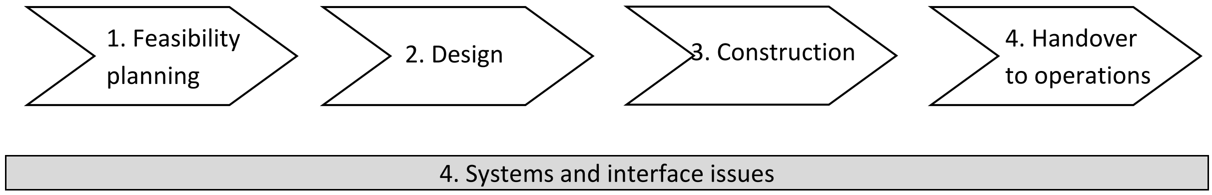


Figure 3: Issues considered at the workshop

5.1. FEASIBILITY PLANNING AND HANDOVER CHALLENGES

The problem of lack of land use maps along the alignment of the metros for decision making was discussed. This can be tackled through the use of city-based geographical information systems. One of the main challenges when it comes to digital information is the lack of data retrieval mechanisms over the lifecycle of

Figure 4: Discussions on the Challenges in Progress at the Workshop

the project. Information is embedded into the model at different stages with different tools and most of the data is locked within the tool and cannot be accessed easily.

Group 1 also discussed the lack of platforms for predictive analytics using real-time data and the need for those when it comes to digitalization of metros. The group also touched on the issues of stakeholder – technology management and the need for a proper strategy for stakeholder-technology management for successful digitalization of metros.

5.2. DESIGN CHALLENGES

Availability and reliability of design information were one of the key challenges in the construction of metros, particularly when this information comes from different sources. The group also discussed design automation for generic designs such as viaducts instead of manual designing using spreadsheets and the role of digital tools in enabling it. Lack of organization-level customization for digital design tools was identified as a challenge in the context of design automation. This leads to the need for high level ontologies for design flow-process mapping.

The group also discussed the classic problem of information loss and interoperability when digital tools are adopted. This reinforces the need for open standards for digital information. In the end, the group discussed about generative design which solves the time and cost problems arising due to redesigning when changes and revisions are brought forward.

5.3. CONSTRUCTION CHALLENGES

One of the main problems which came up during the discussion was regarding the uncertainties in the underground soil profile as well as lack of information on the underground utilities. This has both a cost and schedule impact, the schedule impact is particularly massive, and its derivative cost impact, because the utility owner takes forever to make a change. Utility risk is put on the contractor. If the time between inception of the project and construction can be used to divert the utilities or creating alternate alignment this problem could be solved. India needs an accurate geo-information system to map its utilities.

The second issue discussed this group was on Progress Monitoring methods of compiling the progress updates from different sub-contractors and reporting it as an aggregated report of the contractor. Also, updating the information across different levels of documents/models was discussed as an issue which can be tackled using automation. The next topic of the discussion was the lack of construction friendly models and tools. The use of specific schemas that allow users to load inspection tasks and the model automatically showing relevant objects and dependencies at the right LOD level for each object type and relationship type would help increase the use of model at a construction site. In addition, there is a concern on how to sense the construction data and link them back to the model.

5.4. SYSTEMS AND INTERFACES CHALLENGES

One of the key areas of discussion was the lack of contractual provisions to include digitalization as an agenda on projects. Following practices in the UK, Group 4 discussed on adding clauses mandating digitalization as additions or as an appendix to contracts for the projects whose contract is already made. Development and adaption of standards was the next point of discussion. Although PAS 1192 acts as a good base of standards for digitalization, whether it could be adopted by Indian construction industry or should it be customized for Indian context was discussed. The group concluded that there should be an element of customization when it comes to standards. Defining a technology strategy for a project was found as a necessity for digitalization, and organizational culture should also be altered to integrate digital processes and workflow. Education of key stakeholders on digitalization was another point brought forward by the group. It is necessary for the client to understand the potential and capability of BIM and the workforce has to be given awareness on BIM. The responsibility for providing awareness and training on BIM workflows should be taken up by contractors and owners as a part of their social responsibility by opening BIM academies. One such has already been opened by Nagpur Metro and Larsen and Toubro ECC.

6. CONCLUSIONS

The penetration of digital technologies on Indian metro rail projects today is minimal. Barring the Nagpur metro, the other metro rail projects currently underway in India have hardly scratched the surface of Digital technology. However, the discussions in the various groups indicate that there are several challenges that such projects face that can be addressed through digitalization. Digital land use maps can lead to better planning, automated or generative design can lead to swift generation of alternatives, 3D and 4D models can help ensure timely progress on the sites and so on. Furthermore, the discussants from the various metro rail projects showed awareness of digital technologies and indicated a willingness to adopt digital technologies for these needs. However, it was clear that a single solution such as BIM may not be a silver bullet in these cases. A bottoms-up construction of a holistic Digital System that integrates tools such as BIM with GIS and other workflows specific to a project will be necessary in order to ensure adoption by the project team and to improve project performance. Design-thinking based approaches may need to be brought to bear in designing such systems that will not only be useful but will also be used. These are potential directions for future R&D. The ambitious metro rail program in India has opened up a plethora of opportunities for digital technology. Practitioners are aware of these technologies and barriers to adoption, though significant, can be overcome. It is now up to technology providers, academics and practitioners to take advantage of this situation to combine tools in innovative ways to create context-based solutions that accelerate digital adoption and also improve project performance.

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