TATA CONSULTING ENGINEERS LIMITED

Overcoming Post COVID19 Challenges through Design Alternatives

The Construction Industry

Introduction

The construction industry requires physical presence of workforce at the site for myriad activities, involving both skilled and unskilled workers, working in proximity to each other, in concentrated groups. The construction work itself happens in relay fashion with strong interdependencies between precedent and antecedent activities. Currently, the level of technology intervention in the field tasks is low even in projects with good construction practices and lower for public sector projects. Multiple levels of controls are needed to handle the workforce for quality, safety and progress monitoring requiring the deployment of supervision staff at the field and consultants specialised in project management. COVID19 has now brought in additional challenges and complexity to this labour-intensive industry.

Several documents on 'Restarting Construction Site Operations' are being released based on current understanding and available knowledge on the pandemic across the industry. However, availability of labour, labour productivity and safety measures adopted will govern how well the work gets performed post-lockdown and how well the projects progress at the site. It is a known fact that the situation will never be 'normal' as it was pre-COVID19, and the 'new normal' will get established. This article is an attempt to describe how design alternatives and technology options can help enhance site productivity and project progress. Various technologies and suggested work guidelines explained here may help strengthen the ability to meet a committed schedule in new or ongoing projects working under constrained epidemic scenarios.

During this epidemic situation, construction sites are to work amidst several risks such as but not limited to, the following:

1. Migratory labour force may not be available in the required numbers
2. Seasonal variation in workforce availability – low turnout during peak agricultural season
3. Supply of equipment and materials may get impacted due to transportation hurdles
4. The health-related uncertainties resulting in lower productivity
5. Reduced productivity due to on-site health and safety measures (e.g., social distancing, staggering of work, working in shifts, enhanced sanitary measures, etc.)
6. Increase in workload, longer shifts and reduced rest periods for the available workforce that may result in additional stress and psycho-social issues
7. Inadequate safety and quality supervision leading to poor quality and reduced safety score
8. Slowing down of work due to less workforce, unavailability of materials leading to schedule delays and cost overrun

The following sections privides perspective and describes and compares design alternatives to the traditional construction methods concerning the identified risks as above and labour productivity.

Traditional Construction Methods

The conventional construction method called "brick-and-mortar" or "stick by stick" is a hands-on method where the process is executed sequentially in a series of steps. The steps in the entire process are constructed primarily 'on-site', and predecessor activity needs to be completed before the next activity can be taken up.

This process has scope for accommodating modifications and changes during execution, especially in brownfield situations and can also achieve uniqueness of design. However, the disadvantages associated with this method of construction are the involvement of large numbers of on-field activities, the requirement of higher-skilled workers, more vigilant on-field quality and safety supervision and greater time involved in a serial execution process. All this substantially adds to the cost of construction from the perspective of both materials and labour.

The conventional concrete construction technology involves estimation of material, site preparation including excavation, levelling, compaction, building formwork, placing reinforcement, mixing, pouring, finishing and curing of concrete. In the traditional methods, a large workforce is required to work in close contact zones on interlinked activities.

The erection of structural steelwork consists of the assembly of steel components into a frame on-site. The components of the structure are fabricated from rolled shapes or plates usually in a fabrication yard with a large number of skilled and unskilled workforce or in some cases are factory-fabricated. The processes then involve lifting and placing components into position, aligning the assembled frames and connecting them through bolting or site welding, performed exclusively by workmen at the site.

The significant steps involved after the foundation has been readied, typically include - installation of the temporary structures, transportation of material from the shop and temporarily stacking them, fixing of base plates, lifting of columns, girders and trusses by crane, preparation of the structural joints, bracing, painting, cladding and enclosures and finally, disassembly of temporary structures.

In India, there is a higher degree of dependency on the workforce for most projects as against technology infusion. Therefore labour productivity impacts the progress of projects to a large extent.

Workforce Productivity

Productivity measures the efficiency of resources, both workforce and materials to be converted into goods or services. The productivity of the workforce, besides land and capital, determine, the outcome of the project and economic growth and is the most powerful engine driving and sustaining industrial growth, especially in the construction industry with a very strong dependence on the workforce. Level of skills, technology employed, and quality of materials determine, the productivity of the workforce. Globally, labour productivity growth accounts for about two-thirds of growth of gross domestic product (GDP), with the balance one-third coming from employment growth.

The following data shows that labour productivity level in India is below that of many developed and emerging economies.

Country	Labour Productivity (PPP) (GDP per person employed per hour, US $)
Hong Kong	44.68
India	6.46
Indonesia	10.21
Japan	36.22
Korea	28.70
Malaysia	26.43
Philippines	7.55
Singapore	59.76
Thailand	10.71
China	10.64
USA	59.77

According to an analysis of India Ratings and Research (Ind-Ra), labour productivity in India has gone down significantly over the last eight years from average of 7.4% between 2010-11 and 2014-15 to a low of average 3.7% during the fiscal year 2015-16 to 2017-18.

According to Ind-Ra, sustainable labour productivity growth are dependent on investments in innovation, knowledge, and intangible capital by businesses, and governments' commitments towards structural reforms. Ind-Ra suggests changes in policies both at the government level and at the industry level by those using this workforce. In the absence of technology infusion and quickly adapting to available alternatives, this low productivity may go down further and negatively impact not only the progress but even the viability of ongoing projects.

The construction labour costs in India is 3 to 4 times lesser than the costs in developed economies. Labour productivity is poor despite labour costs being much lesser as compared to developed economies where productivity is higher despite high labour costs due to technology infusion. The present COVID19 situation has resulted in the scarcity of labour which may increase the labour rates (1.5~2 times) and further impact project schedules (1.5~2 times) thereby making it imperative for technology infusion to ensure that the project remains viable. Technologies such as precast construction, prefabricated structures, pre-engineered buildings, modular construction, 3D printing etc. will enhance productivity levels and BIM / 4D construction simulations will help plan construction activities and resource utilisation much better at design phase itself ensuring higher controls and commitments to planned schedules. The same is discussed in the following sections.

New Technologies

The prevailing low productivity level of labour in India and the added current health concerns of social distancing, reduced availability of workforce and absence of key workers (skilled and unskilled) due to COVID19, are going to negatively impact the construction industry, which is already suffering from slowdown due to other factors such as lowering of demand, lack of funds, land procurement issues, and environmental concerns. Therefore, it is essential to study how new technologies, including digital technologies, can help manage the current situation and sustain the progress in the construction industry.

In this section, a description is made of some of the existing and newer design-driven technologies that may be employed to execute construction projects with lesser time and reduced efforts, even working under COVID19 guidelines.

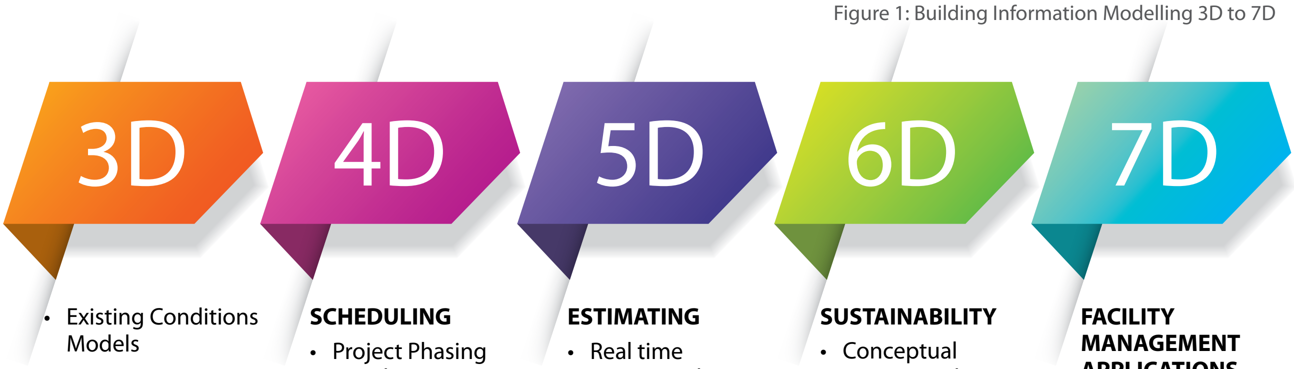
Building Information Modeling (BIM) is a product from Autodesk for creating an intelligent and integrated 3D model of the complete design, construction, operation and management processes for buildings and infrastructures. This tool gives architects, engineers and construction functions useful insights to more efficiently perform all the tasks throughout the life cycle of the structure.

BIM tools are used to design and document all features and details of the building. The model is used for exploring design options, creating visualisations before actual construction and then generating standard construction documents. Post-construction, the digital model can be used to manage building operations by integrating all the operation processes.

BIM usage helps professionals, by enabling them to cast the design against real site settings, for better visualisation, putting intelligence into the components for complete data capture to avoid design miss-outs and clashes. It also helps keep control on changes to design, enables better collaboration amongst the various design and construction functions, creates submodules according to construction sequence, and provides all details in construction document forms. BIM acts as a single repository of all project information.

The level of detailing (LOD) in BIM refers to stages right from concepts (LOD 100) to As-Built (LOD 500) and further into operations and maintenance. The technology is available to extend a 3D BIM to further dimensions that include schedule (4D), costing (5D), sustainability (6D) and facility management (7D), as indicated in Figure 1. Figure 2 shows the various benefits of BIM that include better site coordination, quality, cost and schedule control, and safety. Adopting BIM will certainly enhance productivity at the site during the current challenging times.

Figure 1: Building Information Modelling 3D to 7D



3D

- Existing Conditions Models
  - Laser Scanning
  - Ground Penetration Radar (GPR) conversions
- Safety & Logistics Models
- Animations, renderings, walkthroughs
- BIM driven prefabrication
- Laser accurate BIM driven field layout

4D – SCHEDULING

- Project Phasing Simulations
- Lean Scheduling
  - Last Planner
  - Just In Time (JIT) Equipment Deliveries
  - Detailed Simulation Installation
- Visual Validation for Payment Approval

5D – ESTIMATING

- Real time conceptual modeling and cost planning (DProfiler)
- Quantity extraction to support detailed cost estimates
- Trade Verifications from Fabrication Models
  - Structural Steel
  - Rebar
  - Mechanical / Plumbing
  - Electrical
- Value Engineering
  - What-if scenarios
  - Visualisations
  - Quantity Extractions
- Prefabrication Solutions
  - Equipment rooms
  - MEP systems
  - Multi-Trade Prefabrication
  - Unique architectural and structural elements

6D – SUSTAINABILITY

- Conceptual energy analysis via Dprofiler
- Detailed energy analysis via EcoTech
- Sustainable element tracking
- LEED tracking

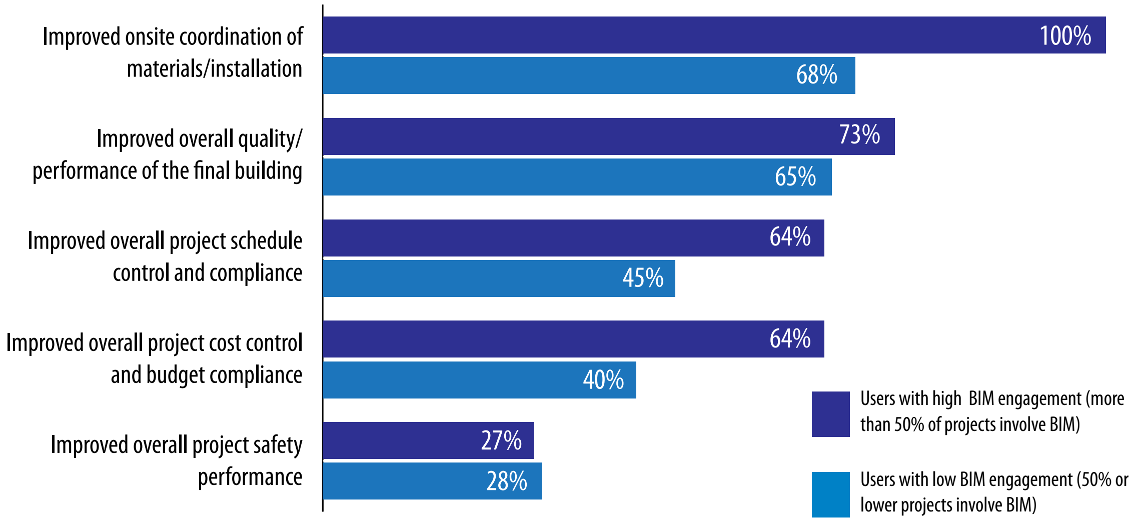
7D – FACILITY MANAGEMENT APPLICATIONS

- Life Cycle BIM strategies
- BIM As-Builts
- BIM embedded O&M manuals
- COBie data population and extraction
- BIM Maintenance Plans and Technical Support
- BIM file hosting on Lend Lease's Digital Exchange System

Benefits of BIM

Percentage of highly engaged BIM users who cite each of five benefits generated by having other key team members engaged with BIM

Figure 2: Benefits of BIM (high Engagement: Users Only)



4D Modelling and Construction Simulation

As discussed, briefly under BIM, 4D modelling elevates the design engineering process from out of desk into the real world of construction. Merely creating a 3D model of the project in software is a static process though integrating the separate discipline works together creates a model incorporating individual teams' details for a combined model free of interferences. However, with the 4D simulation through BIM, this static 3D model can be visualised in each step of implementation by adding the time dimension to the activities. 4D models prevent the loss of planning the work during translation from design to field as each step is connected in time sequence to the others. 4D models also help in project planning and monitoring integrally with the digital version of the structure.

The benefits of 4D modelling are cost-saving in time spent by engineering resources in the separate worlds of design and project management, better visualisation of resource planning, optimisation of resource deployment, enhanced visualisation of safety, accurate project monitoring and better control on project timelines, creating opportunities for innovative construction methods and adding value to all stakeholders.

Since the technique is purely digital-driven, there are no challenges other than adopting the necessary tools, skilling the personnel to maximise the benefits and building a work culture of embracing the technology in the organisation. The technology has been successfully used in all types of construction projects in the industrial and infrastructure development sectors.

It may be noted that 4D simulation is not to be seen in isolation – it is applicable not only to conventional methods but to all methods or design alternatives that are discussed in the following sections. The current challenge of COVID19 can be minimised by utilising construction simulation through simulation of various scenarios in 4D that aids better planning and managing of available resources. Hence, this appears to be the best solution irrespective of the type of design adopted.

Pre-cast Construction

A high degree of repeatability of design and potential reduction in human involvement would also reduce contagion related risks and will turn the benefit ratio favourable for adoption.

Precast Construction Technology is a system of casting concrete in a reusable mould or "form" which is then treated in a controlled environment, conveyed to the construction site and lifted into position.

The benefits of adopting this practice are factory-controlled production of concrete structural elements reducing workforce needed at the site; carrying out casting at ground level, eliminating safety challenges at difficult site locations, especially working at heights; carrying out manufacturing in a controlled environment with better control on material quality and workmanship; repeatability of use of forms, better surface finishes, reduced wastages, enhanced safety at the site and reduced construction time.

However, joint construction and equipment to handle large components are the challenges to adoption of pre-cast construction that need technology intervention. A high degree of repeatability of design and potential reduction in human involvement would also reduce contagion related risks and turn the benefit ratio favourable for adoption. Pre-cast elements that can be easily adopted in construction include slabs, beams, columns, walls, footings, staircase, box culverts, maintenance holes, trenches, poles and compound walls.

Figure 3: Precast Construction in one of TCE's project

Pre-Fabricated Structures and Equipment

Pre-fabricated structures are made at the factory in pieces and assembled at the construction site. Prefabricated structures may be portable or non-portable (permanently fixed to the foundation). The term pre-fabricated structure is generic and can include both structural steel and concrete elements that have been manufactured under factory conditions.

Pre-fabricated construction will help reduce wastage of time and materials and can be carried out under difficult weather conditions. This technique has all the advantages discussed under pre-cast concrete construction techniques. It avoids the need to transport raw material and fabrication teams to the construction site, thus reducing risks associated with large workforce presence. However, this advantage comes with the additional cost of transporting prefabricated sections and lifting them into position, and these are usually larger, more fragile and more difficult to handle than the materials and components of which they are made.

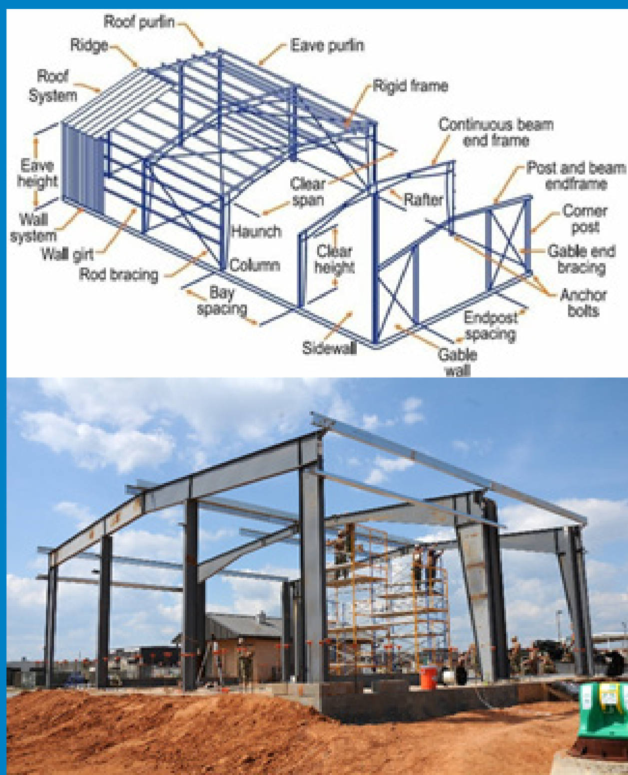
Beyond the realm of structures, prefabrication can also be applied to the fabrication of parts of machines that are site assembled and erected. Equipment like tanks and vessels other than skid-mounted items are often assembled at site in pieces. Such prefabricated items are called sub-assemblies and considerable reduction in site activities would be possible by prefabricating the subassemblies and assembling the pieces at the site in correct sequence and alignment.

Pre-Engineered Buildings (PEBs)

Pre-engineered buildings are designed and engineered at a factory according to pre-set specifications and assembled at site. The term generally refers to metal buildings using steel structure framing and metal sheet roof and wall cladding. The most significant benefit of adopting pre-engineered buildings can be realised by using standard details and predefined specifications for layout, materials, loads and performance requirements.

Efficiently designed steel buildings can be lighter than conventional designed buildings by about 30%. The advantages of PEB construction include better quality control in factory fabrication, design economy, minimum construction time and lower maintenance requirements due to fewer site activities and finally, PEB suppliers provide warranty on the building for a specified contractual period. Figure 4 displays a PEB under construction.

Figure 4: Details of PEB framing arrangement and construction



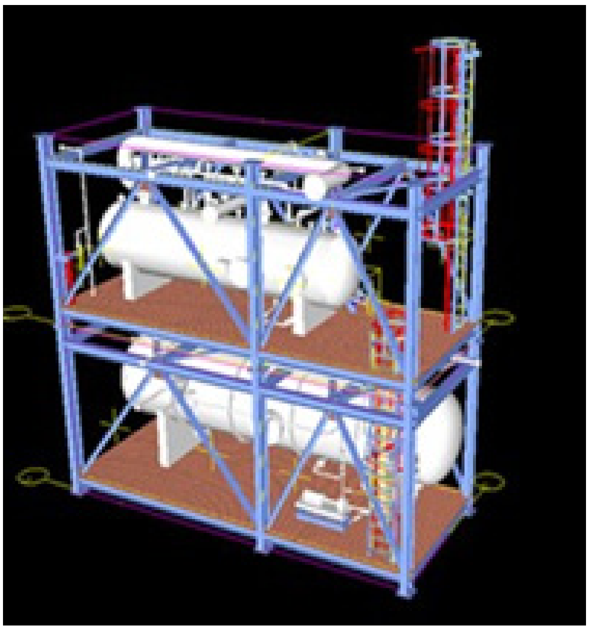
Modular Construction

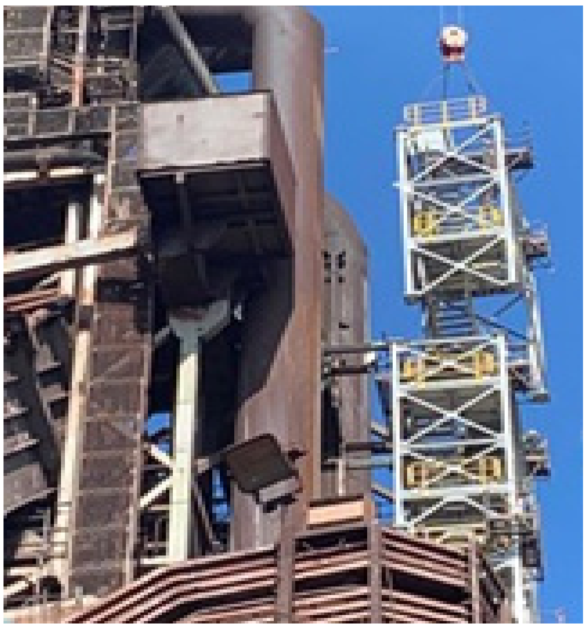
Modular plant concept is the construction of an actual plant carried off the actual site in such a way that after completion, it can be easily transported, erected and integrated with other required utility facilities. Modular plant concept allows for project engineering and construction activities to be carried out in parallel. While site infrastructure development and site construction are under progress, modules can be built in parallel, away from the site. Compared to the sequential activities associated with conventional stick-built approach, parallel activities result in a significant reduction in the project schedule.

The entire plant is split into various modules so that individual modules can be separately fabricated, erected and transported to the site. The number of modules for the given plant depends on size limitations of transportation mode (logistics). Modules are complete with all equipment installed with its associated internal piping, cabling and necessary instrumentation with minimum work requirements at the actual site inside the module. The modules can also be internally tested offsite for ensuring proper functioning of the components and local control systems. Modules are built to minimise site work which now typically includes placement on foundation base, final interfacing or hook up with central utility systems and integration with a site pipe network, interface with electrical and instrumentation wiring, and integration with central control systems. Potential to complete projects in shorter time spans and with shop ensured quality are the major drivers for modularisation. Modular construction concepts also offer the flexibility of adding to plant capacity for both construction and operation stages. Modular construction concept can also be used for steel structures that are of repetitive design such as pipe and cable racks and conveyor galleries.

Limitations to the adoption of modular plants and structures are posed by transportation and handling facilities, a fixed design that cannot be customised for unknown site conditions, upfront finalisation of input data and design, and the relatively larger quantity of steel structure required to cater for the additional stresses of handling and transportation. Figure 5 indicates a modular construction.

Figure 5: Modular Construction





Additive Manufacturing / 3D Printing

Figure 6: 3D Printed structures

The terms Construction 3D Printing (c3Dp) or 3D Construction Printing (3DCP) are used to describe technologies that employ 3D printing for construction of buildings or its components. The basic process of concrete extrusion is also defined by other terms like Additive Construction, Autonomous Robotic Construction System (ARCS), Large Scale Additive Manufacturing (LSAM), or Freeform Construction (FC).

Some of the 3D printing methods suitable for use in building construction include extrusion (concrete/cement, wax, foam, polymers), powder bonding (polymer bond, reactive bond, sintering) and additive welding. It enables faster construction, low labour cost, little wastage and ability to produce complex shapes. Further development of applications in construction projects will see an extensive application for various private, industrial and public project sectors.

3D concrete printing at the site is effected through industrial-scale robots, gantry systems and tethered autonomous vehicles. Examples of constructed structures include private homes, cladding components, structure panels, pedestrian bridges and sculptures. Figure 6 indicates examples of 3D printed structures. A promising use of 3D printing can be for the construction of cheap houses for the displaced population and for creating complex shapes. The technology at present is still not mature or scaled for large scale construction projects but is suitable for faster construction of small homes and structures with very low waste generation making it sustainable and economical.

There are reports by Texas-based company ICON of a 3D printed 350-square-foot house costing $10,000. They are also working towards printing 600-800 square feet homes in El Salvador at the cost of $4,000, partnering with the non-profit organisation New Story.

The construction chemical company Sika has already come out with an industrial solution for 3D concrete printing as part of digitalising the construction industry. In India, IIT Madras has developed a solution for 3D concrete printing and along with a manufacturer are working to promote this technology. They claim to be able to construct a 350 sq ft house in one week at less than the cost for construction of a traditional house. These techniques could be put to use to handle quick construction of quarantine facilities, ICUs, etc., in the COVID19 times.

Comparison of Design Alternatives – Our Perspective

In the preceding discussions, we have reviewed the risks and challenges to the construction industry in restarting operations in post COVID19 scenario amidst the stringent regulations and the low workforce productivity in the country. We have also studied the various available design stage interventions which can enable the construction sites to continue project work or start new projects and achieve targeted progress. Table 2 summarises the effectiveness of these design alternatives in mitigating the risks and challenges for successful business continuity in construction projects.

Table 2 indicates the following:

1. Execution of construction by conventional methods is at the highest risk of failure due to the requirement of a large workforce at the site. However, this large workforce is not effectively managed in most cases, and idling of resources is a commonly observed phenomenon at work sites.

2. The use of BIM and 4D construction simulation tools can help plan effective use of resources – men, materials and equipment helping construction sites perform optimally. These tools can be used, even with conventional projects, since most current project designs are available in digital platforms either directly in 3D format or can be quickly upgraded from 2D to 3D formats for integrated modelling and adding construction sequence planning dimension to it. It should be deployed in all new projects and is agnostic to the design technology adopted; it can be successfully applied to all methods of construction.

3. Modular construction takes the prefabrication technique to the next level. It further reduces workforce-related risks by prefabricating the complete unit offsite. However, it requires more upfront closure of complete engineering. There is also an increase in structure cost and greater demand for logistics. This technique would be more suitable for large new projects designed on modular principles and is not ideal for ongoing projects.

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4. Pre-cast construction, Prefabricated designs and Pre-engineered building construction can all be successfully designed and implemented at construction sites with consequent lowering of workforce-related risks. These solutions can be applied in new and ongoing projects where the designs that are yet to be constructed can be changed into these forms. There is some associated cost increase, but this can be negated to a large extent through optimised designs and innovative solutions. The other challenge is in the logistics of moving large items both on public roads and at the site which can also be overcome by the use of appropriate equipment, optimised through proper construction planning and sequencing using BIM/ 4D tools.

Modular construction takes the prefabrication technique to the next level. It further reduces workforce-related risks by prefabricating the complete unit offsite. However, it requires more upfront closure of complete engineering.

5. 3D concrete printing technology is still in field trial stage and has been tried out on small scale pilots only. With the present status of this technology, it is still not suitable for adoption in large projects. It is a digitally enabled technology with potential for achieving fully mechanised site work with minimal workforce and does not require large parts to be transported.

Risk	Conventional	BIM *	4D*	Pre-cast	Prefab	PEB	Modular	3D Printing
Migratory Labour	--	+	+	-	-	+	+	++
Seasonal Variation in Labour	--	+	+	-	-	+	+	++
Transportation Hurdles	+	+	+	-	-	-	--	+
Health Uncertainties	--	+	+	+	+	+	+	++
Reduced Productivity (due to COVID19 guidelines)	--	+	+	+	+	+	++	++
Inadequate supervision	--	++	++	+	+	+	++	++
Increased work (labour availability)	--	++	++	+	+	+	++	++
Schedule delays	--	+	+	+	+	+	+	++
Quality of Work	--	+	+	++	++	++	++	++
Overall Cost	++	++	++	-	-	+	-	--
Complexity of Technology	++	++	++	+	+	+	-	--
Maturity of Technology	++	+	+	+	+	++	-	--

Legend: -- Insignificant risk mitigation - Marginal risk mitigation NA; No effect / Neutral + Moderate risk mitigation
++ Substantial risk mitigation

*Note: BIM and 4D are applicable to all stated methods but this comparison is with respect to conventional method only and is to be seen in that context.

Smart Applications: Go Paperless

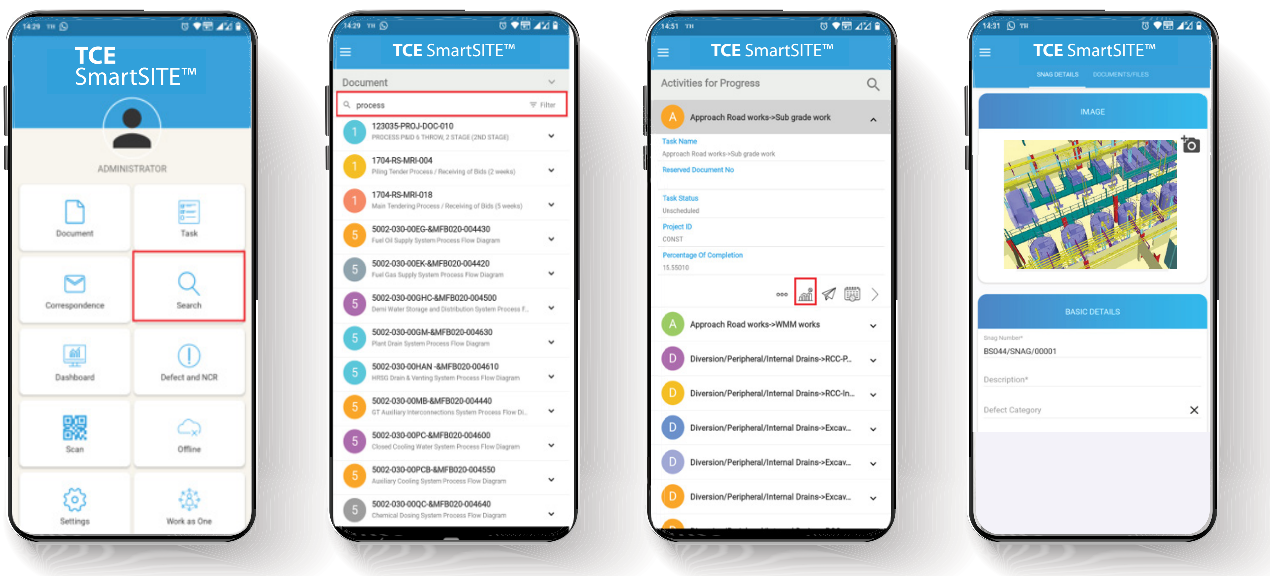
At Tata Consulting Engineers (TCE) we have promoted the use of smart project management applications that help reduce the exchange of paper and stop the spread of infection in COVID19 times. With the help of the following apps we have managed to go paperless to a large extent:

1. Suraksha App for daily tracking of site safety indicators.

2. Increased use of drones and fixed point photography to reduce the need for manual inspection

3. Use of mobile based TCE SmartSITE™ App to

   - Manage and track engineering drawings and documents across their lifecycles.
   - Bring all stakeholders together on the same platform, having built-in quality management processes.
   - Ensure that everyone works on the most up-to-date information with complete traceability.
   - Collaborate digitally through electronic reviews, comments, approvals, RFI's, correspondences and transmittals
   - Work as a team and make sure everyone is held accountable for their responsibilities and action items.
   - Ensure better visibility through real-time dashboard and reports.



Summary

In the post COVID19 scenario, the construction industry in India which has traditionally employed large workforce at the site is facing challenges in reviving the projects while maintaining the social distancing, labour availability and low labour productivity standards. Deployment of available technologies such as BIM and 4D / construction simulations, pre-cast construction, prefabricated structures, pre-engineered buildings, modular designs, additive manufacturing would help face the current challenges.

Studies also show that the construction industry, in general, is the least digitised sector globally. While other industries have begun to adopt new technologies, digital practices and to the changed working conditions, the construction industry needs to move forward through proper planning, adoption of new technologies and an appropriate framework of policy for better utilisation.

Of the various technologies evaluated, BIM and 4D simulation have the highest potential for immediate deployment in existing as well as new projects. The other techniques, barring 3D concrete printing can also be adapted easily with alterations of the design in new as well as ongoing projects.

TCE has experience in all technologies described and opines that adoption of these technologies would result in reduced delays and ensure better commitment to quality and schedule in ongoing projects as well as any new CAPEX investments. Further, TCE promotes use of Smart Project Management Apps that helps reduce exchange of paper and the spread of infection in these times.

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The Company

Delivering Aspirations, Achieving Scale

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1. Design & Engineering
2. Project Management & Safety
3. Procurement Management
4. Digital & Advanced Technologies

Useful Links

1. SOP for Restarting Office post Lockdown
2. SOP for Restarting Construction Sites post Lockdown

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