BUIIILDING INFORMATION MODELLING (BIM) FOR INFRASTRUCTURE – THINKING BEYOND TODAY

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Abstract: The prevalence of waste and rework in the Design & Construction industry are symptoms of ineffective practices and fragmented data. Thus, the industry suffers from poor productivity, high risk, and low profitability.

Building Information Modelling (BIM) has started to expand the opportunities for project contributors to collaborate and use technology to improve efficiencies. More and more benefits are gained with each BIM Level of Maturity (Level 0 to 3). The most advanced state, **BIM Level 3**, is achieved when building data is fully "transactable" across project contributors, not locked in proprietary systems.

BIM Level 3 is being implemented for **Extended Collaboration**, an end-to-end cooperative process designed to improve efficiency and reduce waste for designers, contractors, and owners.

As a significant portion of most nations' gross domestic product (GDP), the Construction industry has much to gain by applying lessons from more efficient manufacturing practices. In Manufacturing industries, **Product Lifecycle Management (PLM)** systems have been refined for decades, enabling Extended Collaboration principles to systematically improve productivity, reduce cost, improve sustainability, and maximize value. Various technology platforms are being widely adopted in Aerospace & defence, Industrial Equipment, Automotive, and many other Manufacturing industries offering world-class PLM applications designed to unlock the value of BIM.

In construction industry, BIM data combined with PLM capabilities and processes create "**Building Lifecycle Management**" (**BLM**), which can increase construction predictability, long-term value for project owners, and profitability for project contributors. BLM solutions help enhance collaboration and outcomes for the Architecture, Engineering & Construction (AEC) industry.

Intelligent-Model-Centric application of BIM has proved its benefits for vertical (high-rise) building projects and now its adoption for horizontal infrastructure projects is gaining momentum. Discussed herein are the basic concepts of BIM, maturity model of BIM, its short-term and long-term benefits, return on investment, and BIM applications on various types of infrastructure projects. The discussion is focused on understanding global scenario with the help of research statistics and application of BIM on various infrastructure projects. The intention is to learn how Engineering & Construction organizations and owners are benefited from BIM applications, and why Indian firms should timely adopt BIM and reap the competitive benefits.

Keywords: BIM, BLM, Infrastructure, Civil Construction, Collaborative Design

1.0 MATURATION OF THE DESIGN AND CONSTRUCTION INDUSTRY

Infrastructure engineering and construction companies are under great pressure to build faster, increase profits, create less waste, improve quality, and comply with environmental regulations. These conditions are forcing a change in the way the industry operates. In pursuit of improving construction delivery process, efforts are focussed on two main aspects:

- Industrialization of construction, and
- Extended collaboration

Industrialization of Construction

Industrialization techniques have been common in Manufacturing industries for decades, but applying these concepts to the Design & Construction industry is a revolutionary idea.

With traditional construction processes, projects are often over budget and behind schedule. "**Industrialized construction**" uses improved planning and data-driven simulation to move construction of structural elements off the job site, which lowers the chances that the countless complex interactions in the construction process will collide at the point of final assembly. This shift in construction delivery processes affords better quality control, optimized operations, lower labour costs, and greater safety.

Extended Collaboration

Infrastructure projects are complex in respect of design, constructability, and operations. Multi-disciplinary involvement is required at all the stages of projects. One of the major drawbacks of present day construction practice is lack of coordination between multidisciplinary teams of architects, engineers, contractors, suppliers, and service providers. Working on a single platform and streamlining of data flow is the solution. Considering the long lifespans of infrastructure projects, owners responsible for Operation & Maintenance (O&M) have a crucial role to play in collaborative process.

Building Information Modelling (BIM)

BIM has been the Design & Construction industry's answer to improve the flow of data through the building process, and, therefore, help to create efficiencies. Industrialized practices work well when design information is structured appropriately for downstream application by contractors, fabricators, and operators.

2.0 UNDERSTANDING BIM

In starting to think about BIM and what it is, let's consider the following definition of BIM based closely on the U.S. National BIM Standard (USNBIMS):

> Building Information Modelling is the digital representation of physical and functional characteristics of a facility creating a shared knowledge resource for information about it and forming a reliable basis for decisions during its lifecycle, from earliest conception to demolition.

From this definition, we can understand three important aspects:

- It mentions digital representation, sharing knowledge, reliability, decision making, and lifecycle.
- This is much more than a 3D geometry model. It is about all asset information around the asset lifecycle.
- There can be many kinds of models – Financial, Data, Planning, Logistics, Environment, and also Geometry / Graphical (3D)

Every project generates lot of information through all its four basic stages which is shared by the teams and other stakeholders. Information-flow and how teams engage with that information and data is a iterative process around the asset lifecycle.

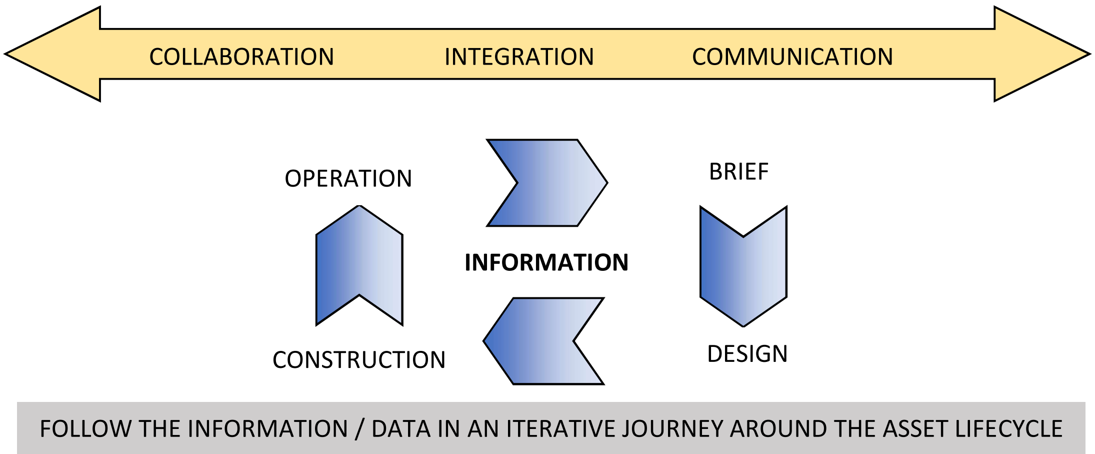


Fig. 2.1: BASIC STAGES OF PROJECT

The consistent and coordinated information flow help increasing efficiency, reduce rework, and increase reliability of decision making process. In BIM, all teams are sharing the same information source on the project – "A single source of Truth", the term often used in BIM, which makes BIM a model-centric process.

Building Information Modelling (BIM) is an innovative technology designed to aid Architects, Engineers, Contractors (AEC) community, owners, and stakeholders for efficient, collaborative design, construction and lifecycle management of projects. BIM offers single platform for all disciplines. The process of BIM begins with creating intelligent 3D model and then use that model to facilitate coordination, simulation, visualization, and management of construction projects. The components used to develop the model have parametric relationship with each other, so that whenever any change is made to any component or control level, other components and related views, drawings, and quantity schedules change automatically. BIM is called intelligent 3D modelling because it contains all the information like data, geometry, specifications, 2D drawings, 3D views & walkthroughs, quantity schedules, and cost schedules inside the model. BIM offers intelligence driven results using information integrated with the model. Figure 2.2 below graphically depicts BIM features.

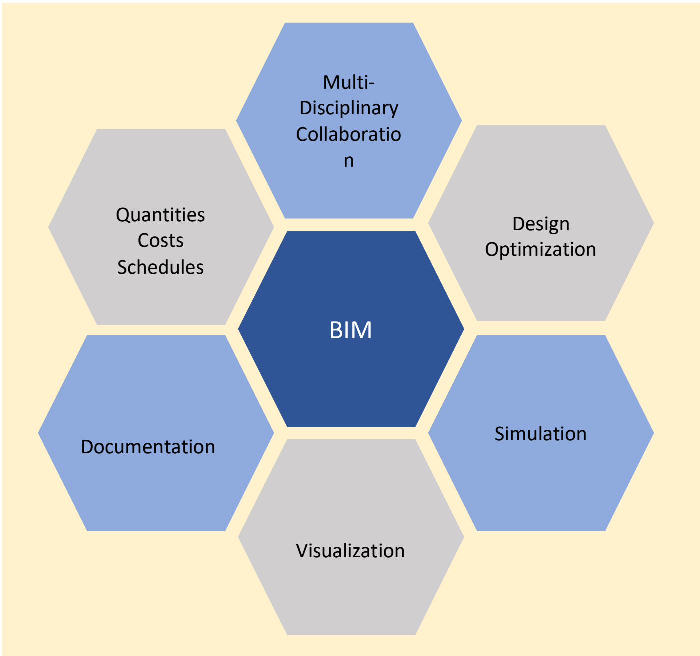


Fig. 2.2: PROMINENT FEATURES OF BIM

2.1 MISCONCEPTIONS ABOUT BIM

Having understood what is BIM, before we proceed further, it is important to clarify few misconceptions about BIM. It is true that BIM technology was originally developed for vertical building construction and, obviously, building construction industry adopted it quite early. However, in the horizontal world of infrastructure construction, use of BIM is just beginning. But the rate at which it is picking up is very impressive as seen from its applications in past few years. Despite that, there are some confusions, mainly due to word "BUILDING". For many, BIM is a confusing acronym, but now we are struck with it as it is the only universally recognized term for digital information modelling environments. So, few clarifications:

- BIM is not just about buildings; it takes in any kind of built, made or constructed asset, such as infrastructure, a power station, a metro station, a gas pipeline, an oil rig, a shop, an airplane, even a space station.
- Nor is it about the building stage; it covers the whole lifecycle of any made or constructed built asset.
- The model is not just 3D geometry; it is possible to have financial data model, maintenance information model, thermal environmental model, and so on.

The most notable recent example of BIM technologies in adjacent industry is the design, production and manufacture of the Boeing 777 airliner. Boeing assembled their supply chain in digital environment to design, test and construct the aircraft.

3.0 MATURITY OF BIM

It is interesting to understand how the BIM technology evolved and matured to present day high-end construction tool.

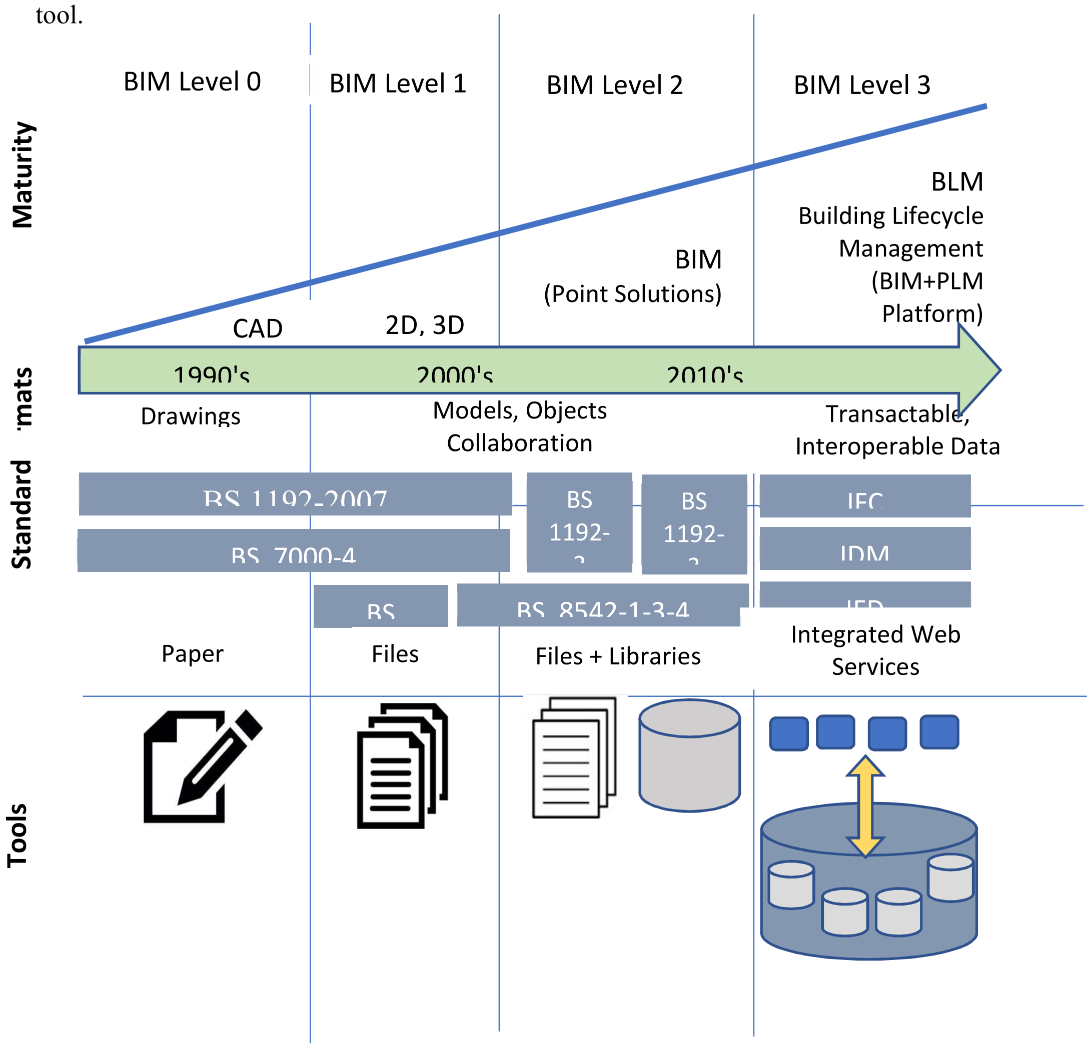


Fig. 3.1: AN UPDATED BIM MATURITY MODEL FROM COMPUTER-AIDED-DESIGN TO BUILDING LIFECYCLE MANAGEMENT

(The BIM Maturity Model by Mark Bew and Mervyn Richards adapted to reflect BLM's relationship to Level 3)

In late 1990's, Computer Aided Drafting (CAD) technology revolutionized working of engineering community. By 2000, drawing board drafting was fully replaced by computer aided drafting, enabling production of 2D drawings and 3D models. 3D modelling technology rapidly developed between 2000 and 2010.

The concept of Building Information Modelling (BIM) originated in early 1970's but the real parametric modelling tools development started in 1997 onwards. The software were intended to allow architects and other building professionals to design and document a building by creating a parametric three-dimensional model that included both the geometry and construction information. The term Parametric Building Model was adopted to reflect the fact that changes to parameters drove the whole building model and associated documentation, not just individual components.

After more research, development and improvement of the software, in 2005 structural component was introduced and, then in 2006 Mechanical – Electrical - Plumbing (MEP), making BIM software inclusive of almost all disciplines.

Much of the industry is now moving from BIM Level 1 to BIM Level 2. While some companies are trying to find efficiencies with BIM Level 2 processes, traditional workflows, and point solutions, industry innovators are rethinking collaboration and leveraging integrated BIM Level 3 technologies to become more competitive. Today, in 2017, in addition to parametric civil, structural, and MEP modelling, BIM software have much more advanced capabilities of analyses (structural, thermal, energy, etc.), point solutions, visualizations, reports generation, costing, and Interportability. Construction teams that successfully adopt BIM Level 3 processes benefit from strategic advantages: they create less waste, deliver in less time and produce a better outcome while retaining a healthy profit margin.

Before moving on to discussing BIM Level 3 process and its benefits to construction industry, it is important to understand where BIM Level 2 is falling short to support construction process.

4.0 BIM LEVEL 2 VS LEVEL 3

Governments of many countries (US, UK, Germany, France, etc.) are mandating that all government projects utilize BIM Level 2 in order to reduce information ambiguity. **While BIM Level 2 has indeed brought significant benefits to designers by focussing on design coordination problems, it does not maintain much of a role in construction processes.**

Models produced using Level 2 point solutions are ultimately exported and imported into disconnected systems. This handoff can create unintended consequences: data silos, errors, version control problems, and rework. Data produced by the design team at the beginning of the project does not flow seamlessly through the rest of the project delivery. Designers ultimately miss the opportunity to adjust for means and methods, lose control of their design intent, and are forced into a reactive process of responding to troubleshooting.

Under Level 2, with no integrated system to leverage data, contractors are removed from fully collaborating on the model and are left to absorb the cost of rework. BIM Level 2 results in siloed collaboration as shown below.

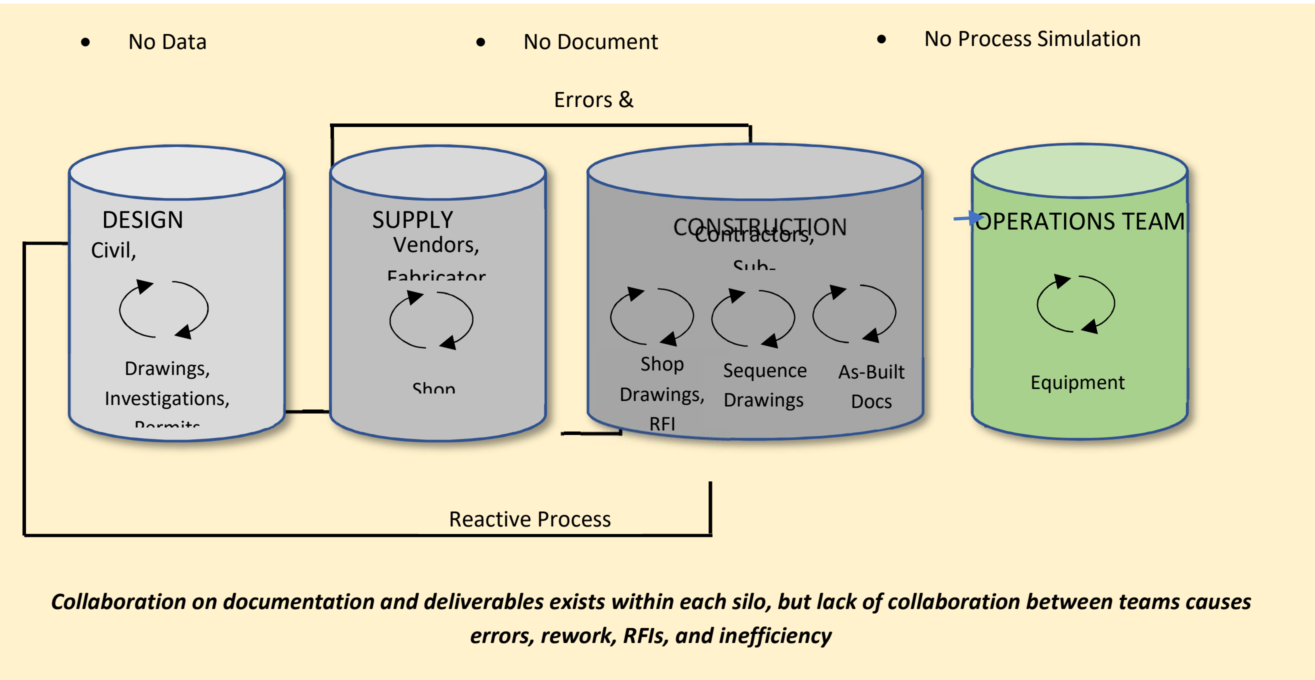


Fig. 4.1: TRADITIONAL DESIGN, CONSTRUCTION AND OPERATIONS PROCESS – BIM Level 2 Benefits are Locked in Silos

BIM Level 3 approach fully connects the data chain from start to finish, helping to create end-to-end efficiencies. In a Level 3 system, BIM data is not converted into files and emailed or sent via FTP sites to various parties. A Single Source of Truth is established, stored in a database on the cloud, and accessible by all project contributors through web services. BIM Level 3 allows data to be transactable for construction, fabrication, and even facility management purposes, enabling open collaboration and building lifecycle management.

A robust Product Lifecycle Management (PLM) system creates an efficient environment for coordinating complex Architectural, Engineering & Construction data. Adding BIM data to PLM system creates a Building Lifecycle Management (BLM) system, which enables BIM Level 3.

BIM + PLM = BLM

5.0 ADAPTING EXTENDED COLLABORATION ENABLED BY BIM LEVEL 3

An Extended Collaboration model synchronizes productive interactions between designers, suppliers, and contractors. Extended Collaboration proactively addresses errors and omissions, reduces rework, enables predictive process simulations to reduce risk, resolves issues in real-time to drastically reduce RFIs, and improves quality and safety.

Extended collaboration improves project outcomes.

Innovative projects delivered by industry-leading design and construction teams have shown that collaboratively planning and designing a project can provide significant productivity gains over siloed processes, which depend on RFIs to reconcile issues. A full-spectrum collaborative workflow ties all parties together (owners, designers, contractors, suppliers), such that each discipline can provide relevant data in the context of other disciplines' data.
Extended Collaboration in design, construction, and operations is made possible by BIM Level 3, where liberated data is transactable among authorized project contributors during each design, construction, and operations phase.

BIM Level 3 creates an environment where extended collaboration is possible.

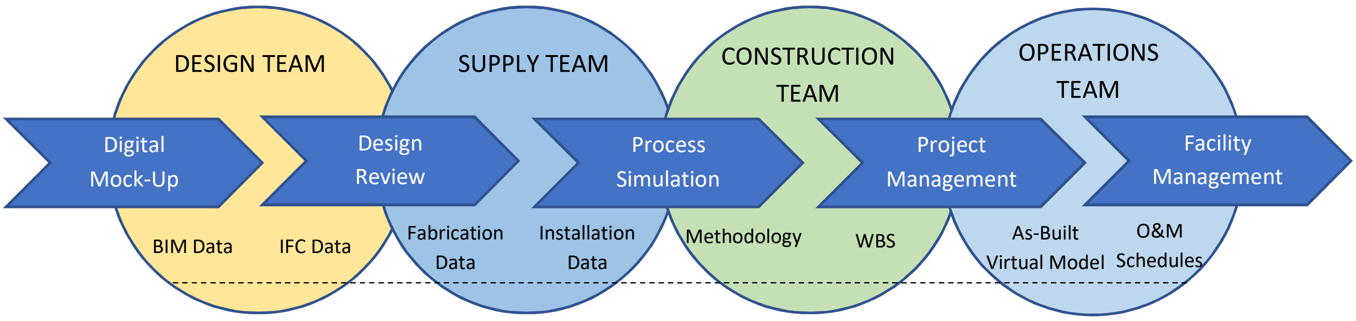


Fig. 5.1: EXTENDED COLLABORATION MODEL FOR DESIGN, CONSTRUCTION AND OPERATIONS – BIM Level 3 Benefits Are Realized Throughout The Project Lifecycle.

6.0 BIM CAPABILITIES THAT BENEFIT INFRASTRUCTURE PROJECTS

The specialized nature of infrastructure projects creates the opportunities for several benefits resulting from BIM technologies and processes. So, it is important to understand what BIM capabilities benefit infrastructure projects. Early clash detection is one major capability of BIM, which is unanimously accepted by vertical construction professionals, has special significance on infrastructure projects because conflicts tend to be much more expensive in heavy-nature infrastructure projects than in commercial work. Other BIM capabilities that benefit infrastructure projects are:

- **CIVIL CONDITIONS:** Infrastructure projects, due to its horizontal nature, are subject to every nuance of the complex realities of the geophysical environment. Many firms adopting BIM for civil projects believe in using a variety of reliable scientific inputs including GIS data, underground radar, laser scanning, test-borings, etc. to map real ground conditions for developing a complete-as-possible model. Once that model is in place, engineers can leverage it for nearly endless types of analysis, simulation and visualization to optimize design solutions.

- **SIMULATION:** Once surface and subsurface conditions are modelled, engineers can simulate and study the impact of their proposed design solutions. For example, by using Computational Flow Dynamic (CFD) analysis, engineers can assess flow conditions for hydraulic structures like dams and barrages. It is also possible to simulate the effect of a natural disaster on the built environment. This was done in Seattle to assess the impact of an earthquake to an elevated highway and the surrounding grade level improvements. To see video, go to http://www.youtube.com/watch?v=hos_ulKwC-c

- **ENGAGING COMMUNITY STAKEHOLDERS:** This factor is very important especially for complex public projects like large roadway or tunnel projects in urban areas or a dam project involving submergence and flooding issues. Such complex projects require choices between many alternative approaches before the final engineering solution is approved for implementation. This process is further complicated by required involvement from numerous stakeholder groups whose members are often non-technical and have difficulty understanding various options based technical drawings and documents. The best example is the Alaskan Way Viaduct and Seawall Replacement Project in Seattle, Washington. Coursing through the heart of the city's downtown business area, its impact was enormous. The project's engineering firm, Parsons Brinckerhoff, developed 98 different alternatives, from elevated highways to tunnels, which had to be comparatively evaluated and narrowed down to a final plan with the involvement of large array of parties. By modelling the existing surface and subsurface conditions of the entire downtown, PB could produce numerous highly descriptive and compelling animations that definitely accelerated the complex evaluation and approval process. To see an example go to http://www.youtube.com/watch?v=mWfwnkEbc4Q

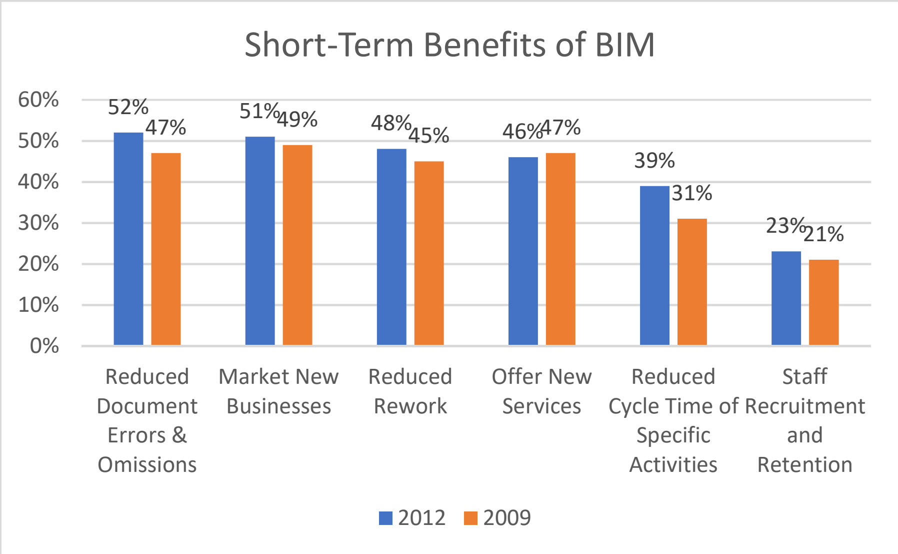
- **VISUALIZATION FOR BUSINESS DEVELOPMENT:** As reported by existing users of BIM, **m**arketing BIM capability is one of the top internal business benefits of BIM for infrastructure. Combining that goal with the power of visualization for highly complex engineering solutions, many firms are modelling proposed approaches to projects during the marketing phase. This allows them to demonstrate their BIM prowess, at the same time they impress the client with their understanding of the unique aspects of the project.

7.0 BENEFITS OF BIM

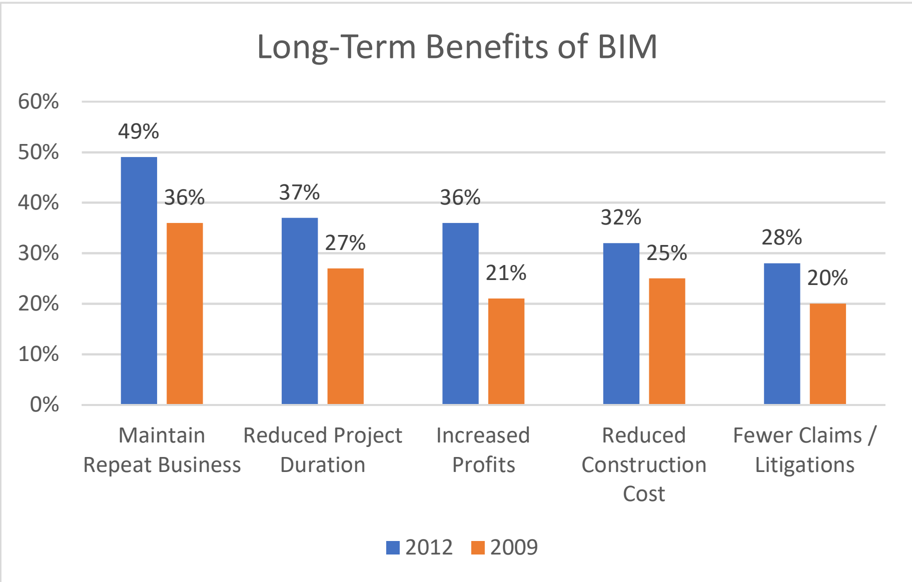
BIM for civil infrastructure is being applied widely across the globe for a variety of projects, with distinct advantages over traditional practices. The degree of advantage often depends on the ability to streamline workflows by having all players adopting a model-centric workflow.

Whenever any new technology is adopted in an organization as a business strategy, its implementation inevitably impact the business, processes, and technology toolset. The organization should be aware of how its business, processes, and technology might change. This awareness is very important so that organization can plan their business strategy to manage the change and reap the benefits of BIM.

Some benefits of BIM can be experienced on first few projects. Other benefits require longer timeframes to demonstrate their value. Thus, benefits of BIM can be categorized as short-term and long-term benefits McGraw-Hill Construction (MHC) conducted research on implementation of BIM in North America for a period 2009 to 2012 and published their findings in "**SmartMarket Report: The Business Value of BIM in North America**" The statistics of this research throws light on benefits of BIM for building construction industry.

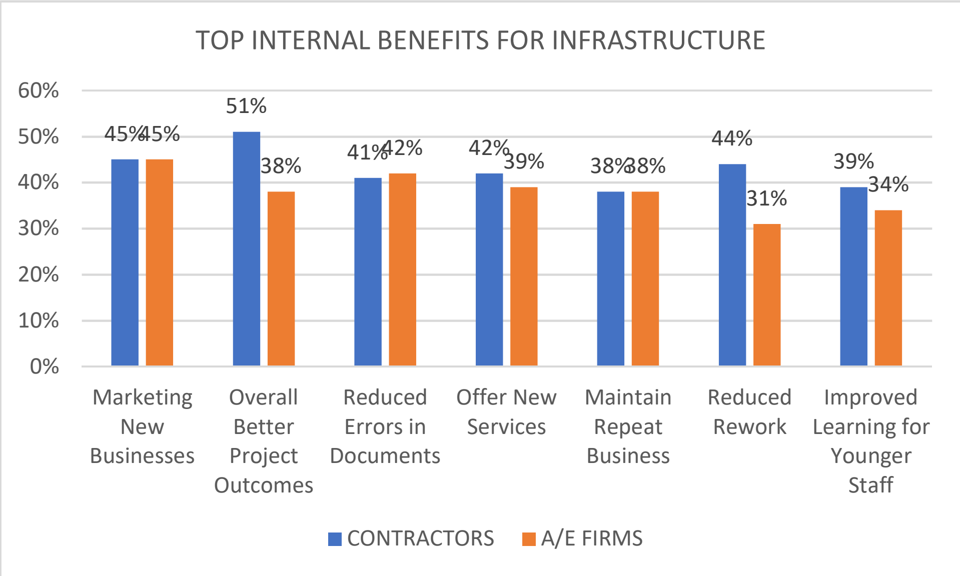


7.1 SHORT-TERM BENEFITS OF BIM FOR BUILDING PROJECTS (Source: McGraw-Hill Construction: SmartMarket Report)

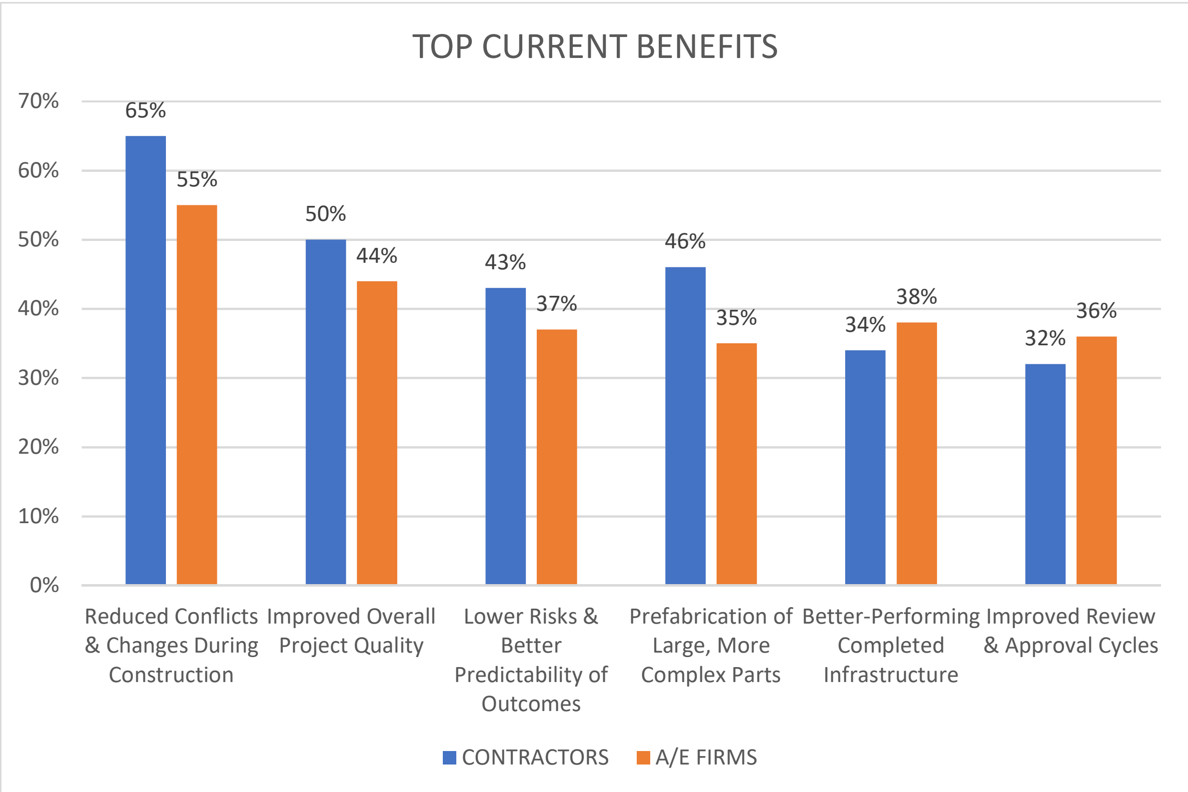


7.2 LONG-TERM BENEFITS OF BIM FOR BUILDING PROJECTS (Source: McGraw-Hill Construction: SmartMarket Report)

MHC published another SmartMarket Report in 2014 covering infrastructure construction industry (**SmartMarket Report: Business Value of BIM for infrastructure**). It is seen that benefits of BIM manifest in variety of ways. For the individual company that is deploying BIM, the benefits accrue directly in the form of improved productivity, profitability or efficiency. In other cases, the benefits are enjoyed by the entire team and often contribute directly to better overall projects. Additionally, each player involved experienced the value of BIM from its own perspective of needs, risks, rewards, and objectives. One common thread running through the findings is the positive impact on the business aspects of running organizations and designing, constructing and operating projects. The Figure 7.3, 7.4, and 7.5 below show Top Internal Benefits, Top Current Benefits, and Expected Benefits in Five Years respectively for A/E firms and contractors. **It's interesting to note that the top benefits noted by users of BIM for infrastructure are closely match with the top benefits noted for buildings in MHC's 2009 Business Benefits of BIM SmartMarket Report. This demonstrates the consistent results experienced from BIM irrespective of project types, especially to create new business and improve project outcomes.** Several other critical benefits hold equally strong appeal to BIM users AEC community.



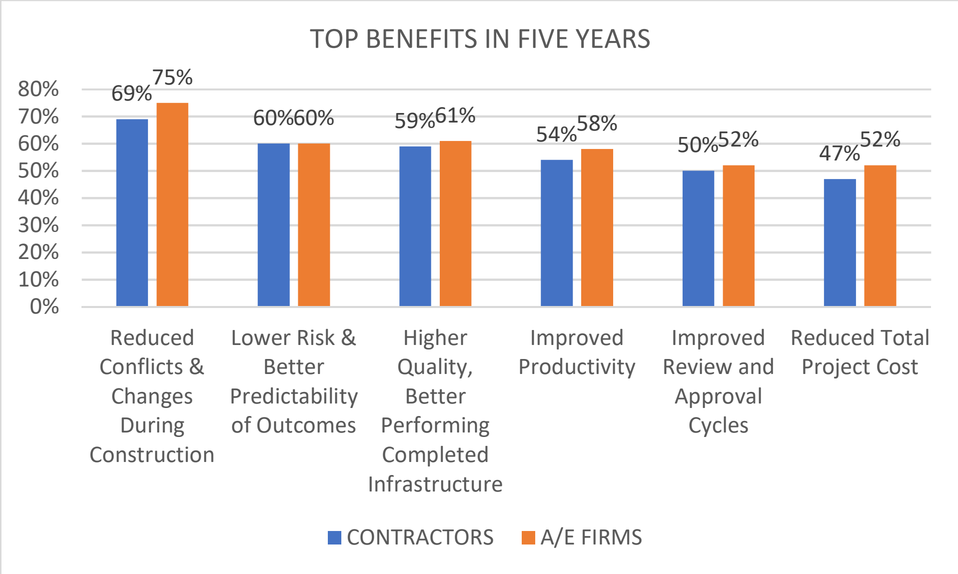
7.3 TOP INTERNAL BENEFITS OF BIM FOR INFRASTRUCTURE (Source: McGraw-Hill Construction)



7.4 TOP CURRENT BENEFITS OF BIM FOR INFRASTRUCTURE (Source: McGraw-Hill Construction)

65%, the highest percentage, of contractors cite reduced conflicts and changes during construction as important benefit, as early detection of conflicts results in reduced construction cost and time.

46% of contractors also give high marks to prefabrication of large and complex parts of projects, a BIM trend that is well established and growing.



7.5 TOP BIM BENEFITS IN FIVE YEARS (Source: McGraw-Hill Construction)

All players believe that reduced conflicts and changes during construction will be their top future benefit of using BIM for infrastructure. This benefit can have the greatest impact on improving project schedule and productivity and reducing the risk of cost and schedule overruns.

Lower risks and better predictability of outcomes is also an important benefit for contractors and A/E firms. A similar percentage (64%) considered this to be an important benefit of BIM for buildings in the future in MHC's 2009 report, which demonstrates how valuable it is across project sectors.

Reduced total project cost, though rated at lower than expected (47%) by contractors, is expected yield higher benefits as BIM applications in infrastructure grows and matures.

8.0 IMPACT OF PROJECT FACTORS ON BIM BENEFITS

It must be noted that BIM benefits will not be experienced at equal levels across all phases of the project. BIM, like many other strategic initiatives, takes time to mature. Value of benefits vary throughout the lifecycle of the project. Similarly, BIM generates varying degrees of value across different project processes.

The most important infrastructure project factors that impact BIM benefits are as below. The figures in brackets indicate percentage of contractors (Source: McGrawHill Construction).

- Project Complexity (63%)
- BIM Knowledgeable Design Professionals on The Project (54%)
- BIM Knowledgeable Firms on The Project (51%)
- Interportability Between Team Members' software (48%)
- Project Size (44%)
- Contract Form that Supports BIM / Collaboration (43%)
- BIM Knowledgeable Client (39%)
- Project Budget (27%)

While there is much variation among the value of project factors, one factor, Project Complexity, rates quite high (Total of 63%) among all firms. This strong result for infrastructure projects emphasizes the perceived value of BIM for managing large amounts of information among multiple participants more effectively than traditional approaches.

MHC's SmartMarket Report also indicates an interesting fact that a relatively small number (27%) of contractors assign high importance to project budget. This may indicate a belief that projects of any budget can benefit from BIM, not just the most expensive ones.

9.0 INVESTMENTS FOR INFRASTRUCTURE BIM

Investment for BIM implementation in AEC organization include investments in:

- Marketing BIM capability
- Software that supports BIM
- Developing collaborative BIM processes
- New / Upgraded hardware
- Developing custom libraries
- Training on BIM
- Customization / Interportability solutions

Of all the investments, the crucial investment in BIM for infrastructure projects by contractors is the ability to market new capabilities. This business development aspect convincing owners and other stakeholders of delivering overall better project performance, reduced construction time clashes and rework, reduced cost and duration, and reducing risks by collaborative predictive management is highly valued justification for investment.

BIM require specialized software. Though many BIM software available in market are quite capable of constructing 3D model, and 3D visualizations like rendered views and walkthroughs, sometime special 3D modelling and animation software are required for providing special effects for high quality views and animations.

BIM software require high configuration computer hardware, specifically bigger memory storage for handling large size files, higher RAM and high-end graphic hardware to handle graphics, and special network for collaborative working.

Training and education is an important aspect for understanding BIM and BIM related processes. It has been observed that bottom-up approach is advisable.

Customization and Interportability are important aspects for infrastructure BIM because of vast variety of elements required to be modelled, which are not readily available in software. Development of custom libraries is a continuous task as the demand grows on increasing as more types of projects are designed and managed using BIM.

The table below shows increase in focus of BIM investment over a period 2011 to 2016. (Source: McGrawHill Construction)

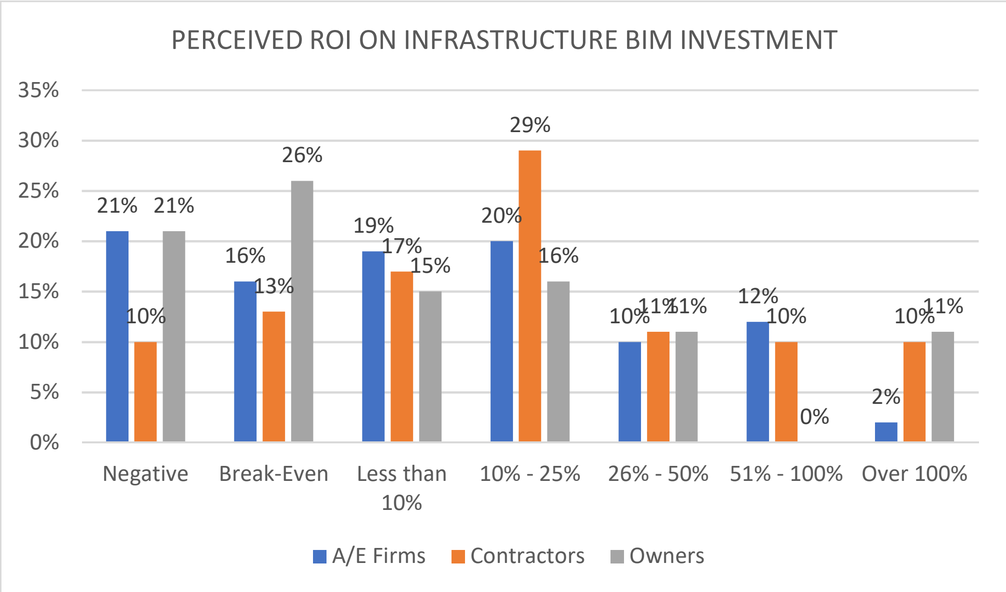
INVESTMENT	2011	2016
Marketing BIM Capability	38%	51%
Software that Supports BIM	35%	50%
Developing Collaborative BIM Processes	33%	49%
New / Upgraded Hardware	33%	46%
Developing Custom Libraries	31%	37%
Training on BIM	30%	42%
Customization / Interportability Solutions	29%	43%

10.0 RETURN ON INVESTMENTS OF BIM FOR INFRASTRUCTURE

Although there is no industry-standard method to calculate the return on investment (ROI) for BIM, the results presented here are based on the perception of the degree to which the BIM users are receiving value for the time, money, and efforts they have invested.

Perceived ROI on infrastructure BIM investment for AE firms, contractors, and owners is shown in Figure 7.1 below. Two main highlights of this statistics are:

- One third of the organizations currently using BIM for infrastructure work show negative or break-even ROI. Almost half (47%) owners fall into this category, followed by AE firms at 37%. Relatively, contractors are better placed at 23%.
- More than one quarter of all respondants report ROI of 25% or better with nearly one third of the contractors reporting that level.



10.1 PERCEIVED ROI ON INFRASTRUCTURE BIM INVESTMENT (Source: McGraw-Hill Construction: SmartMarket Report)

Existing users naturally improve their ROI over time as their skills and experience increases, and they amortize the initial costs over more projects. From the statistics shown in figure 10.2 below, **it is seen that nearly half (47%) of BIM beginners are experiencing negative or break-even ROI. At the other extreme, 43% of BIM experts claim high positive ROI (50% or Greater).**

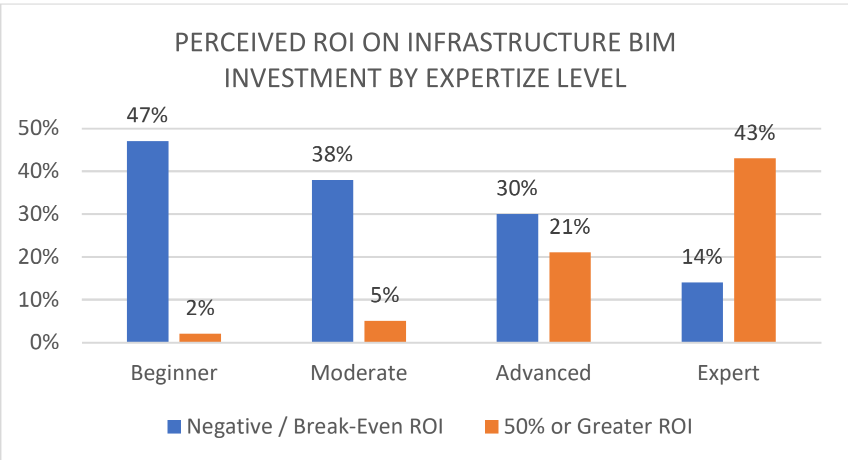


Fig. 10.2 Perceived ROI on Infrastructure BIM Investment by Expertize Level (Source: McGraw-Hill Construction: SmartMarket Report)

10.1 IMPORTANT FACTORS TO IMPROVE ROI

The factors considered as the most important means of improving ROI, grouped as project-oriented and project-based benefits, are shown in figure 10.3 below.

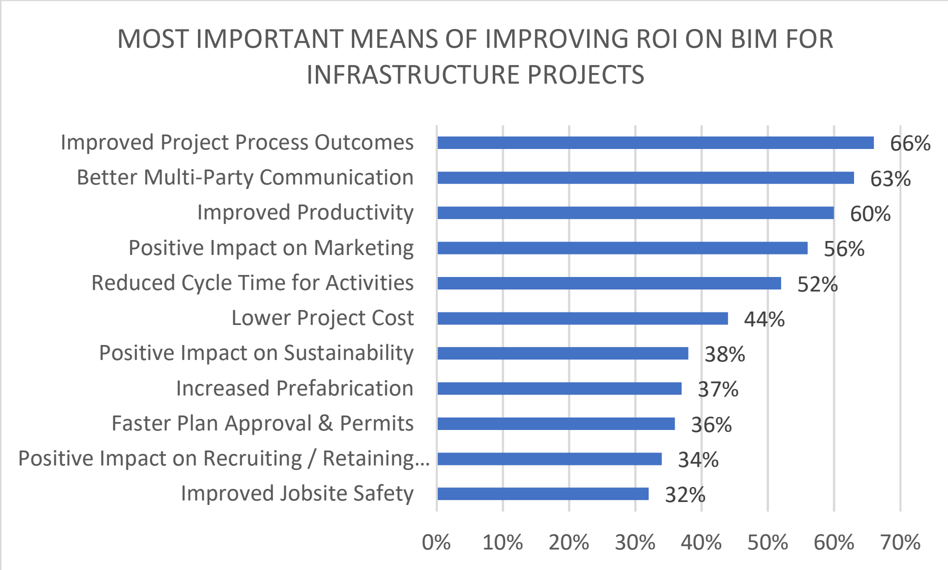


Fig. 10.3 MOST IMPORTANT MEANS OF IMPROVING ROI ON BIM FOR INFRASTRUCTURE (Source: McGraw-Hill Construction: SmartMarket Report)

From the above statistics, it can be noted that the top two factors that can raise the perception of ROI are project-oriented benefits, not internally focussed ones. **This is also a clear-cut indication that contractors are getting more benefits of BIM and higher ROI for infrastructure BIM.**

- At 66%, the leading factor is Improved Project Process Outcomes such as improved field coordination, and better understanding among all participants resulting in smoother and trouble-free projects. This was especially strongly felt by the contractors (66%).
- Better Multi-Party Communication, a close second at 63%, reflects that use of modelling can improve information exchange so effectively that each party will directly benefit.
- Internally focussed benefits are equally important which include Improved Productivity (60%) and Positive Impact on Marketing (56%).
- Positive Impact on Recruiting / Retaining Staff has been rated important factor by one third (34%) indicates value of recruiting and retaining BIM trained staff, which is going to be a tough challenge in near future.
- Remaining six factors considered the most important means of improving ROI by 30% to 52% are project-based factors.

11.0 BIM APPLICATIONS FOR TRANSPORTATION INFRASTRUCTURE

Though BIM is being applied to all types of infrastructure projects, transportation sector picked up with BIM quite early. Dodge partnered with Autodesk for conducting research focussed entirely on transportation infrastructure in US, UK, France and Germany, and published the findings in "**SmartMarket Report: Business Value of BIM for Infrastructure 2017**". The findings clearly indicate evolution in the use of BIM for transportation infrastructure projects. The most important findings are briefly discussed here.

11.1GROWTH OF BIM IMPLEMENTATION

- BIM users at a high level of implementation (on at least half of their projects) grew from 20% in 2015 to 52% in 2017.
- By 2019, 61% forecast that they will be at that high level of implementation.
- Between 2017 and 2019, the growth in BIM implementation is most dramatic among those deploying BIM on nearly all (75% or more) of their projects, with the percentage almost doubling from 17% to 32%.

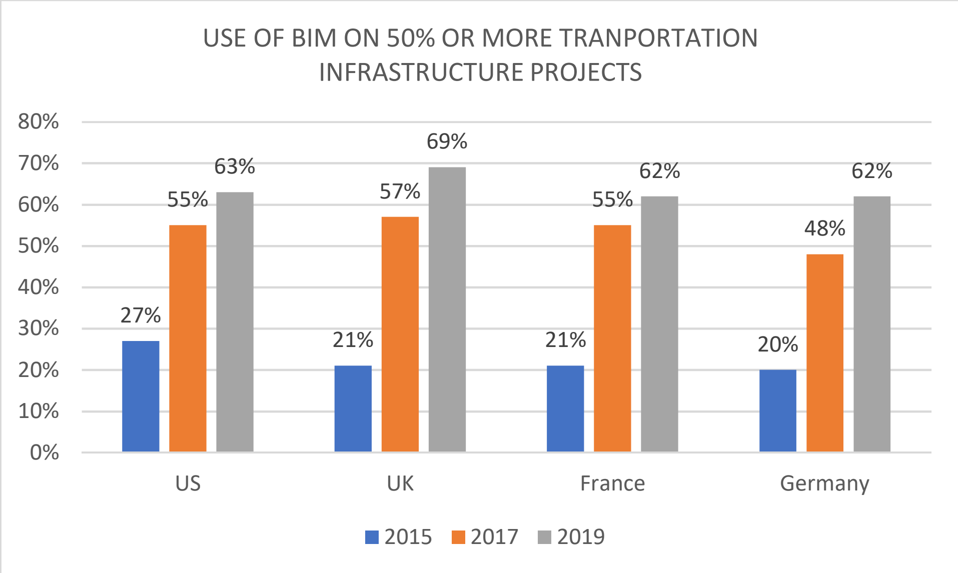


Fig.11.1 USE OF BIM ON TRANSPORTATION PROJECTS (Source: Dodge- Data & Analytics)

It is interesting to note that owners' demand for BIM use on transportation projects is equally important factor for growth of BIM implementation. It has been observed that in all four countries the owners demand BIM application on more than 50% transportation projects.

11.2 BENEFITS FROM USING BIM ON TRANSPORTATION INFRASTRUCTUR

While owner demand and mandates in the UK and Germany have been important to drive BIM use for transportation infrastructure, the internal business benefits that BIM users experience, and the improvements to project processes and outcomes that BIM generates are also key drivers for adoption and implementation. Most BIM users (87%) report positive value from their use of it, and 73% say they are yet to receive full potential value they believe BIM can provide. This finding reinforces the forecast for additional growth in BIM implementation as users gain experience, and the tools and processes advance to address more effectively the specific needs of the transportation infrastructure sector.
All of the nine business benefits included in the study were experienced at least at a moderate level by about three quarters or more, but five in particular were experienced at a high or very high level by 50% or more. Those benefits are shown in the chart below. All these five top benefits can be grouped in two categories.

- Those that help companies do business better (marked with *), and
- Those that help companies find more projects.

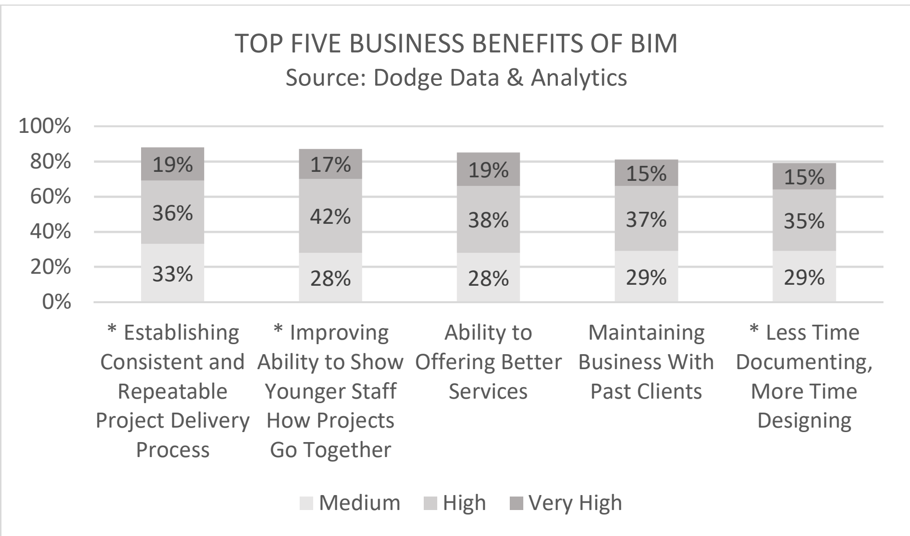


Fig.11.2 TOP FIVE BUSINESS BENEFITS OF BIM (Source: Dodge- Data & Analytics)

Other four benefits are shown in the chart below.

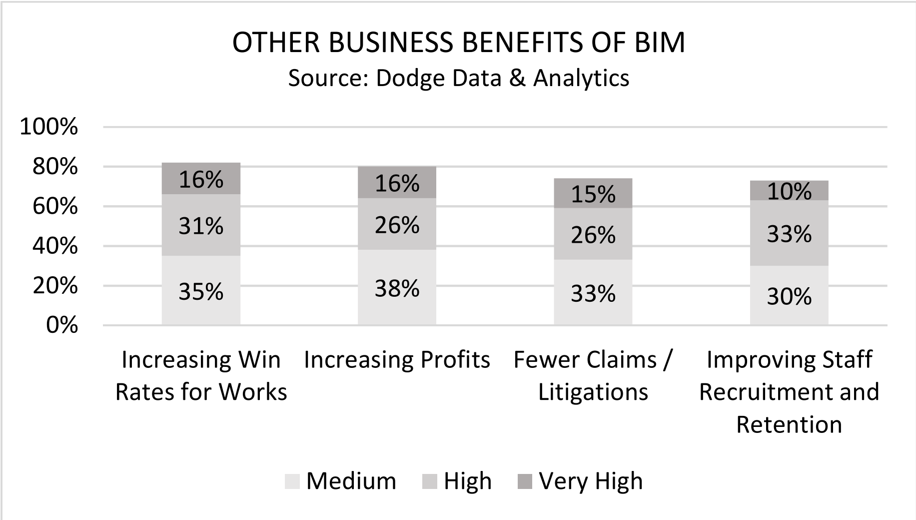


Fig.11.3 OTHER BENEFITS OF BIM (Source: Dodge- Data & Analytics)

11.3 TOP WAYS BIM IMPROVES PROJECT PROCESSES AND OUTCOMES OF TRANSPORTATION INFRASTRUCTURE

Top three benefits realized by Construction companies from a list of 13 benefits are organized into five categories as shown in the chart below.

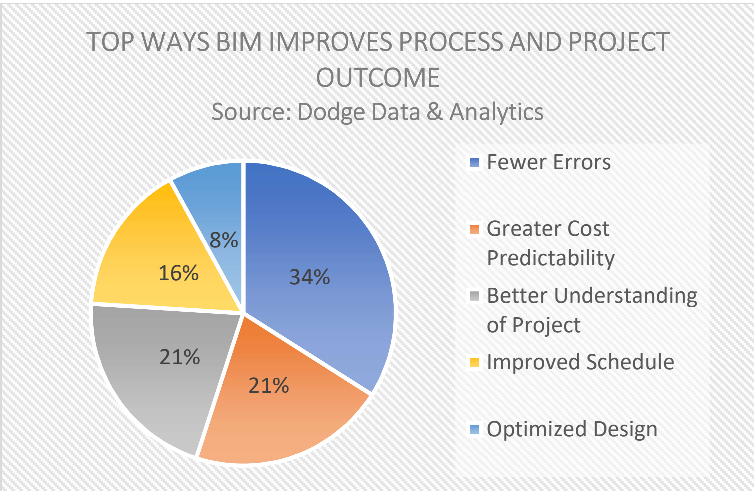
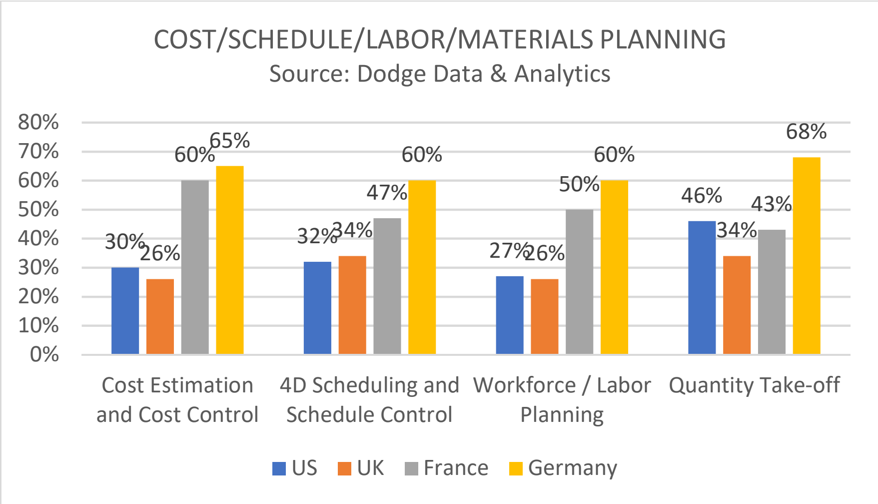


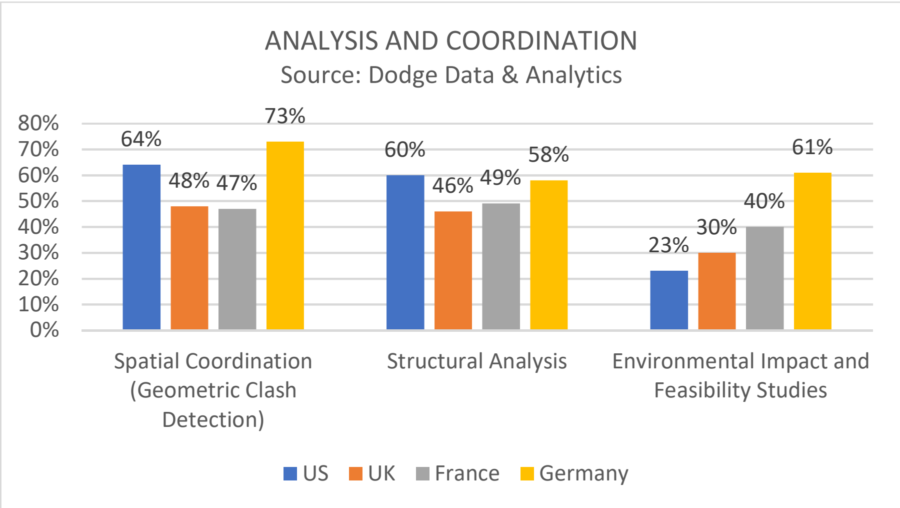
Fig 11.4 TOP IMPROVEMENTS OF BIM (Source: Dodge- Data & Analytics)

- Fewer Errors ranks highest among all respondents. This include benefits like:
    - Reduced conflicts / field coordination problems during construction
    - Reduced errors and omissions.
- A relatively high percentage also consider Greater Cost Predictability and Better Understanding of The Project among the top process and outcome benefits of BIM.
    - Better multi-party communication and understanding from 3d visualization is a critical contribution to better project understanding.
    - Better cost predictability not only includes reduced costs but also reduced rework.
- Also in the top five benefits are improved schedule performance and design optimization. Though, the percentage is low at present, it is expected to grow as the firms gain more experience.

11.4 HIGH VALUE EXPERIENCED FROM SPECIFIC BIM ACTIVITIES

The BIM users have rated the value of 10 specific BIM activities on a scale of one to five (no, low, medium, high, very high). The results are shown in the charts below; the activities are divided into three groups for easy comparison.





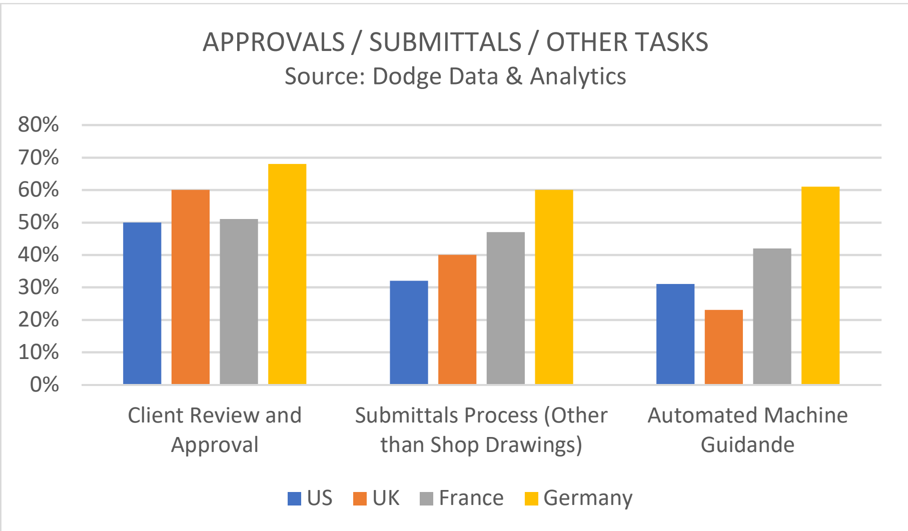


Fig.11.5 HIGH VALUE BIM ACTIVITIES (Source: Dodge- Data & Analytics)

It is notable that German respondents more frequently consider each of the activities to be of high value than the respondents from the US, UK, or France.

11.4 FUTURE PRIORITIES OF BIM INVESTMENTS FOR TRANSPORTATION INFRASTRUCTURE

All companies using BIM for transportation infrastructure expect investment in marketing their BIM capabilities to be a higher priority than now. There are also interesting differences by country in the current versus future investment prorities.

- **Future Priority Investments in France:** Developing collaborative BIM processes with external parties, strategic BIM program deployment.
- **Future Priority Investments in Germany:** BIM training, new hardware and strategic BIM program deployment.
- **Future Priority Investments in UK:** BIM training, BIM accreditation, upgrading software and strategic BIM program deployment.
- **Future Priority Investments in US:** BIM training, BIM accreditation, new hardware and developing collaborative BIM processes with external parties.

11.5 BIM RETURN ON INVESTMENT (ROI) FOR TRANSPORTATION INFRASTRUCTURE

While many companies are not formally measuring the ROI they get from using BIM, nearly 65% perceive that they get a positive ROI from their investment in BIM. Even more impressive, 26% believe that ROI is 25% or more.
The table below show how perceived ROI varies by country.

PERCEPTION LEVEL	US	UK	France	Germany
Positive	56%	65%	67%	75%
Break-Even	15%	0%	17%	9%
Negative	5%	2%	6%	2%
Not Sure	24%	33%	10%	14%

- There is a greater uncertainty in the US and UK about the ROI they are expecting from BIM than in Germany or France because of fewer measurements of ROI in US and UK.
- Germany has the highest percentage (75%) experiencing a positive ROI, and the US has the lowest.
- When those who are uncertain about ROI are factored out, the remaining users in the UK report an overwhelmingly positive response.

12.0 BIM APPLICATIONS FOR INFRASTRUCTURE – CASE STUDIES:

BIM for infrastructure is being applied broadly across the globe for a variety of projects, with distinct advantages over traditional practice. The level of advantage that this provides often has to do with the ability to streamline workflows by having all players adopting a model-centric workflow. Below is a brief synopsis of the various types of projects taking advantage of BIM as well as short detail of the benefits gained.

<u>TRANSPORT & BRIDGES</u>

CASE STUDIES:

- **The Wisconsin Department of Transportation (WisDOT)** is taking a lead role is testing the application of BIM on state roadway projects. Since, the state mandates Design-Bid-Build procurement, early integration of teams is not possible. WisDOT is testing a hybrid approach that uses its in-house design and construction departments to collaborate on design models to gain many of the benefits of working in an alternative delivery methods, such as Design-Build. WisDOT is testing its approach on two current projects – the $162.5 million Mitchell Interchange Project and the $1.7 billion Zoo Interchange.

Mitchell Interchange

Zoo Interchange

Fig.9.1 MITCHELL INTERCHANGE AND ZOO INTERCHANGE

On the Mitchell project, modelling was done after design was complete. Still, the team was able to use the model for visualization and clash detection that reaped savings. In addition, the team used that model for 4D scheduling of the construction phase. On the Zoo Interchange project, the team was able to start earlier, creating a robust model that could be provided for contractor bidding. Both 4D schedule and 5D cost estimation are possible with the model. The models include mobile, static, and aerial light detection and ranging. In total, the team expects to scale up to a 20,000-page set of design plans using models created by more than 200 designers.

- **Fore River Bridge Replacement:** STV has been using BIM on vertical buildings since 2006 but decided to test its application on the Fore River Bridge Replacement in Quincy, Massachusetts for Massachusetts DOT. The design calls for a vertical-lift bridge with towers that are nearly 300 feet high. After starting the design in CAD, STV decided that the bridge's complexity required modelling. The coordination of the different disciplines was a huge part of this project, e.g. lot of equipment required electrical conduits that had to be designed for extremely tight places. By designing in 3D STV could get immediate feedback over the placement of their components. In addition to MEP, STV created a structural model and architectural components of the bridge. There is a tight schedule for this project, and due to 3D modelling STV was able to speed up the process internally. The client, Massachusetts DOT, also gained direct benefits through better over-the-shoulder reviews of the models as the work progressed.

Fig.9.2 FORE RIVER BRIDGE, QUINCY

- **Chesapeake Roadway Projects:** While large, complex roadway projects are more common for BIM use, some firms are testing its applicability on small projects as well. Clark Nexsen used modelling on two intersection projects for the city of Chesapeake, Virginia. The team modelled the roadway and performed stormwater design analysis based on the model. Quantity takeoffs were performed for inclusion in the bid package. With the roadway model in place, Clark Nexsen added its traffic signal study. The city commissioned a laser scan to identify existing above-ground utilities and other features, such as trees and structures. The model, laser scan and additional digital drawings were integrated to create a virtual project "drive-through" for visualization and analysis.

AIRPORTS

High-cost airport expansion programs often include a mix of complex vertical and horizontal projects split among multiple bid packages. To better manage projects, many airport authorities encourage designers and contractors to collaborate in BIM.

CASE STUDIES:

- **Delta Air Lines Redevelopment at JFK:** Satterfield & Pontikes (S&P) is providing project-control services for the $ 1.2 billion Delta Air Lines Redevelopment Project at John F. Kennedy International Airport (JFK) in New York city. The program is split into multiple packages. Turner Construction and Lend Lease each oversee separate concourse packages. Turner's scope also includes significant civil work Peter Scalamandre & Sons was awarded a separate taxiway package. Several stakeholders are involved as well, including Delta, JFK International Air Terminal and the Port Authority of New York and New Jersey. Numerous businesses housed within the concourses are also affected by the program.

Fig.9.3 JOHN F. KENNEDY INTERNATIONAL AIRPORT

  To better monitor all contracts and keep stakeholders informed, S&P is modelling the project, providing estimating and scheduling analysis and cost controls. When S&P joined the project, the design was already complete, but S&P was able to work from the design team's models to build its own. S&P also incorporated models generated by contractors and some of their subcontractors. The teams conduct coordination and constructability reviews. Visualization is another major component. Team members work collaboratively in an on-site virtual studio on schedule planning, site logistics and other aspects of project execution.

  S&P broke out its model in accordance with how the project will be built, enabling 4D scheduling capabilities and 5D cost estimation. While mentioning BIM benefits on this project, S&P quotes – "If the schedule starts to slip, the team can react quickly to recover. When you are on a big project, you can lose control and not even know it….. It's too much to handle in the traditional way with 2D blueprints. Once you have modelled, and you can tie these other applications to the model, then you have incredible real-time knowledge about where your project is. That allows managers to focus on issues, and you can filter out the background noise."

- **The Green Build at San Diego International:** On the $1.2 billion Green Build project at San Diego International Airport, major contractors on separate contracts work in harmony through BIM. The program is split primarily between the team of Kiewit, Sundt Construction and URS, which handles the main roadway and parking aspect of the project, and the team of Turner Construction, Flatiron Construction, PCL Construction Services and HNTB, which is building a terminal expansion, new gates and a new taxiway. From the outset of the program, the airport authority envisioned a fully integrated program from design through construction with modelled content that was created as a deliverable for the facilities management. Both the teams of contractors were contractually obligated to collaborate in

BIM and create data-rich models. This approach allowed contractors to establish open dialogue about technology options and expectations of deliverables. On the civil side, the major initiative for the contractors was to model utilities and create highly accurate as-build drawings which has helped contractors to place new utilities at the right places. This has resulted in eliminating clashes and unnecessary costs. The overarching goal was to produce data-rich deliverable model for future facilities management. This process has significantly accelerated the program, trimming costs and keeping more of the airport open for business. It is estimated that between hard and soft costs, the $1.2 billion program might have cost nearly $ 2 billion using traditional means.

- **Terminal Renewal and Improvement at Dallas/Fort Worth:** Joint venture on the Dallas / Fort Worth International Airport's $2.3 billion Terminal Renewal and Improvement Program (TRIP) are also crossing competitive lines to work together. The airport authority wanted teams to work in common platforms to enable high-value BIM use and consistent communication. The airport also had a separate sustainability goal to go paperless on the project, necessitating greater use of BIM and related tools. The joint venture of Balfour Beatty Construction, Azteca Enterprises, H.J. Russell & Company and CARCON Industries was the first team in, so TRIP authorities worked with these firms to establish an implementation plan. Recognizing the potential savings, the airport agreed to pay for items such as software and plan rooms with large computer displays. The airport also purchased hundreds of iPads to allow managers, superintendents and subcontractors digital access to all plans. WiFi throughout the site enabled access to a cloud server for updated models and plans. When a second joint venture of Manhattan Construction Company, Thos. S. Byrne, James R. Thompson and 3i Construction came on board, the first team of Balfour Beatty was asked to get all parties on the same platforms. It is estimated that airport's paperless initiative alone could save the airport more than $8 million in printing costs and added efficiencies.

<u>TRANSIT PROJECTS</u>

The intersection of vertical and horizontal building is often referenced by BIM users as an ideal opportunity to use the technology in infrastructure. Many Transit Projects, which combine stations with roadways and rail lines, fits that description perfectly.

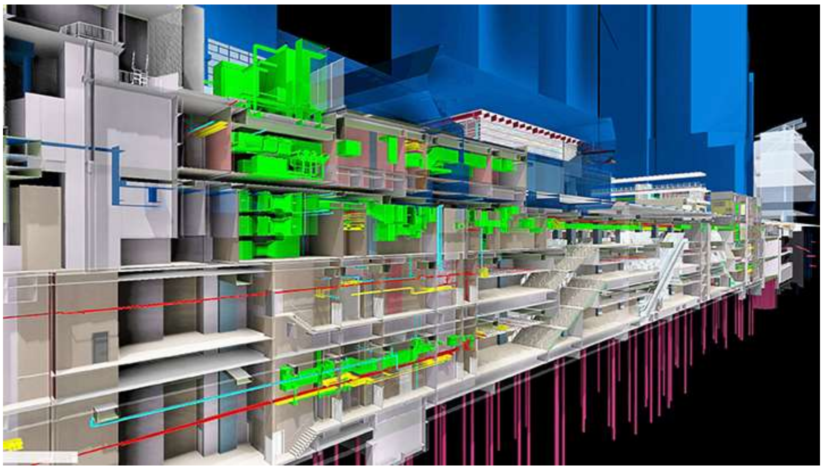


Fig.9.4 TYPICAL 3D BIM MODEL OF METRO STATION

CASE STUDIES:

- **Parsons Brinckerhoff (PB)**, an early adopter of BIM in vertical building sectors, has seen a interest in BIM slowly increasing within the transit world. Starting in 2006, the firm used BIM to deliver the 4th Street Bus Station in Reno, Nevada. The firm used modelling early in the project for conceptual design to identify the best site concepts. Architecture, MEP and structural elements were modelled by PB. The model was used for systems coordination and cost estimating. Since then, the firm has seen expanded use of BIM on transit projects, including the Fulton Street Transit project in Manhattan, on which PB served as a construction manager. The firm is also currently using BIM on mass transit stations in Mumbai and Los Angeles. It has been observed that more and more owners are preferring BIM due to value gained for long-term facility management, more so in case of underground facilities. In places like New York city, where PB has worked extensively on the subway system, use of BIM is proving its value.

- BIM is being used extensively for transit projects in Toronto, Canada. Multiple firms working on the $730 million Toronto-York Spadina Subway Extension project are modelling segments with the encouragement of the Toronto Transit Commission. Hatch Mott MacDonald (HMM) modelled its work on 6.7 km tunnel segment of the project. Given the tight spatial restriction, the model was used for coordination of various disciplines.

- **VivaNext Bus Rapid Transit System:** Extensive modelling is being used on this transit project in Toronto. A partnership of Kiewit and EllisDon is modelling much of a 7 km section of the project that will include road-widening for dedicated bus lanes, 22 stations, two pedestrian bridges and five new bridges built for environmental protection along the corridor. The team converted 2D drawings into 3D models to help analyse road structures, corridors, intersections and culverts for constructability. The team also generated quantity estimates and earthwork calculations from the model. For the stations and bridges, the team modelled structural elements; coordinated existing and proposed utilities; and performed quantity takeoffs. The model was also used for 4D scheduling with site superintendents to help them visualize the process. The most robust tool used in its modelling effort is laser scanning. The point clouds created by laser scanning are pulled into 3D model to compare site conditions with the design. When discrepancies are found, they can be addressed quickly. The point clouds are also used for quantity takeoffs and estimating as the scans are accurate to couple of millimetres. Potentially, one of the most valuable aspect of scanning will be realized after completion. The point clouds can be combined after completion to create highly accurate as-built models.

DAMS, CANALS AND LEVEES

BIM is beginning to pique the interest of public entities that own, operate and maintain dams, canals and levees. Such critical infrastructure is generally expected to remain in operation for many decades, and some owners recognize the long-term benefits of creating models for ongoing analysis and improvement of facilities.

CASE STUDIES:

- **U.S. Army Corps of Engineers:** The U. S. Army Corps of Engineers (USACE) released its BIM Roadmap in 2006, and since then it has made great strides by requiring use of the technology on its vertical building projects. Recently, the Corps started implementing 3D modelling and BIM on civil works projects as well. Corps started BIM application on the Howard Hanson Dam as a way to monitor a depression that appeared on an abutment. The team used terrestrial and aerial LIDAR data to build a 3D site model. The team has built models on top of that data, including a BIM model of a new fish passage facility at the dam. The facility had relatively complex geometries, such as a horn modelled as an elliptical curve, traction water conduit modelled as an ogee parabolic curve, and a flood control tunnel modelled as a helical horseshoe. Additionally, a pedestrian bridge comes in on an angle and has a slope. Multiple disciplines worked on the model, including structural, mechanical, civil and geotechnical. The team was able to use model for planning drilling locations for reinforcement of the fish ladder without conflicting with existing structure, pull quantities from model such as volume of concrete, rebar and structural steel; volume of rock and soil excavation; and vertical and horizontal surface areas. USACE is now planning to include BIM in their future workflows.

- **The Panama Canal:** In recent years, the Panama Canal Authority added BIM to their workflow at its ongoing $6 billion expansion project. The master plan includes several dredging projects, but the BIM initiative is focused on the Third Set of Locks project. MWH Global is part of a design joint venture with Tetra Tech and the Dutch firm Iv-Infra. The joint venture is subcontracted under the design-build consortium Grupo Unidos por el Canal. The team modelled the reinforced concrete structures that retain the water,as well as some earth dam components. Other modelled elements include filling and emptying components, large fixed-wheel gate valves, and 60 control buildings per block complex. All mechanical systems and electrical controls for the complex are also modelled, as well as supporting utilities. Additional civil works and earthwork models were created by outside consultants. The team designed the project to Level of Development 300 standards, which enables the team to create construction documents and provide rough quantity takeoffs for estimating.

Fig.9.5 PANAM CANAL EXPANSION PROJECT - MODEL

WATER AND WASTEWATER FACILITIES

Major design and construction firms are exploring ways to maximize models within the design-bid-build delivery system typical on water and wastewater projects.

CASE STUDIES:

- **Des Moines Combined Sewer Solid Separation Facility:** HDR was selected by the Des Moines Wastewater Reclamation Authority for design services on a combined sewer solid separation facility in 2008. It was the authority's first project designed in BIM. The team saved time by identifying conflicts early and being able to react quickly to changes, e.g. when the design reached 90%, the team identified a change in the floodplain that resulted in a need to raise the facility by one foot. The team was able to update construction documents and the model in less than 40 hours which would be taking 300 to 400 hours to do that.

- **Arbennie Pritchett Water Reclamation Facility:** The Okaloosa Country Water and Sewer Department in Florida selected CDM Smith to design, construct, outfit, start up, performance test and obtain permits for the new 10 mgd Arbennie Pritchett Water Reclamation facility. The team used BIM throughout the project lifecycle, including a delivery of a model for operation and maintenance (O&M). Through a design-build process, the team used BIM to help compress the design schedule to just over five months, and the construction team was able to start site work 2.5 months before construction documents were complete. The model was also used to create bid packages for subcontractors, who also used it in the field to aid in construction efforts. Upon completion, the model was connected to an electronic O&M system that helps manage data equipment, datasheets and manuals.

ENERGY PROJECTS

BIM is yielding powerful results on energy projects. Mortenson Construction, an early adopter of BIM in vertical building construction, has extended BIM commitment into its Renewable Energy Group. Enmax Power Corporation is another organization using BIM for construction planning and operation of electrical substations.

CASE STUDIES:

- **Wind Farms:** On its wind farm projects, Mortenson construct numerous turbines on vast sites that often have varying conditions. Speed of construction is critical, as most farms must be delivered within one season. Preplanning is where BIM offers the greatest benefit. The team investigates all site issues and maps how equipment and materials will be moved around. Scheduling is a major component of its modelling effort. Deliveries must be carefully planned so that materials are placed in the right location and in the proper sequence. With solid planning, construction follows almost an assembly line process, as crews move from pad to pad, ideally in near-repetitive pattern. Models are also used for quantity takeoffs and system coordination. For example, the electrical conduit for a tower, which can be 100 feet tall, typically conflicts with the structural rebar required in the foundations. Mortenson has also leveraged its preplanning modelling to create better proposals. They claim to have won projects based on the modelling as part of proposal because they showed that they knew the project better.

- Some owners in the energy sector are also adding BIM to their workflow. Engineers at Enmax Power Corporation, which owns and operates an electricity distribution and transmission network around Calgary, started modelling new substations in mid-2010. The modelling saved time and reduced errors. The software automatically creates wiring diagrams, which are prone to errors using traditional design methods. The team also generates bills of materials and estimates costs from its models.

WATER & SEWER NETWORKS, WATER & SEWAGE TREATMENT

The tools within the model for pipes and pipe placement can apply established design standards that include the characteristics of the pipes and appurtenances (e.g. size, thickness, material, etc.) to make sure the design will perform to the plan. This automation includes entire pipe network modelling to monitor and improve performance. Water Treatment Plants and Sewage Treatment Plants can be modelled to include hydraulic analysis as well.

STORMWATER

The ability to model stormwater networks and whole watersheds affords the opportunity to analyse existing conditions as well as try and test different retention and infiltration options for today's trend toward green infrastructure.

BIM ON RAIL PROJECTS:

In Jan 2014, the European Parliament issued a directive for European Union member states to encourage – or even mandate – use of BIM on public-funded projects, and some are extending that into rail infrastructure.

RAIL PROJECTS IN GERMANY AND FRANCE

In Germany, the Federal Ministry of Transport and Digital Infrastructure has launched a series of pilot projects to test BIM's potential with the goal of using BIM on all new projects by 2020.

- Deutsche Bahn's first major project to use BIM is the refurbishment of a 180-km rail line from Karlsruhe, Germany, to Basel, Switzerland. The project includes a 4.3 km long tunnel near Rastatt, Germany. In addition to addressing problems through 4D and 5D BIM, and financial benefits, another critical component of Deutsche Bahn's BIM strategy is the emergence of more collaborative contractual models.

In France, BIM is in use on portions of $24.7 billion Euro Grand Paris Express (GPE) project which will deliver 200 km of new tracks to the Paris Metro System including 68 new stations. BIM proved most beneficial in the collaboration between the architects and the engineers while designing the stations. BIM also helped resolving interfacing issues concerned with connecting its stations to the streetscapes and other city infrastructure. It has been observed that some benefits are more pronounced for rail than for vertical building projects, especially those related to interface management.

FEW MORE APPLICATIONS:

- BIM for Planning: The Chicago Urban River Edges Ideas Lab: Under this project BIM model is developed by WSP USA in partnership with Autodesk, which depicts 600 acres of the city of Chicago. The model is combined with technologies such as Chicago Data Portal, big data and internet, making it data-rich model to help transform development along the South Branch of the Chicago River.
- Smart Motorways Programme, UK: BIM is being extensively used on these £5 billion projects for collaborative lifecycle management.
- Orlando International Airport Terminal C: $1.8 billion South Terminal c, Phase 1 project at Orlando International Airport – BIM for design, construction, and facility management
- Denver International Airport: BIM for facility management
- Glen Canyon Dam, Page, Arizona: A 710 feet high, with a predicted useful life between 700 and 1000 years, Glen Canyon Dam, the second tallest concrete arch dam in United States is being modelled as a

pilot project at the Bureau of Reclamation that will demonstrate the advantages of BIM for existing infrastructure assets.

13.0 CONCLUSIONS

In recent years, Building Information Modelling (BIM) has become an important strategy in vertical building construction to improve productivity and profitability. However, in the horizontal world of infrastructure construction, use of BIM is just beginning. The capability of BIM to create data-rich models in three or more dimensions that facilitate optimized design, enhance construction efficiency and enable multidisciplinary collaboration, are the main features that hold equally strong benefits to horizontal infrastructure construction, and the industry has begun to take notice.

The benefits of BIM for infrastructure play out across projects and is an improved enterprise approach. BIM provides a more streamlined replacement for past practices, and improves project coordination and value delivery.

Firms are realizing that they gain control and add value by owning the modelling process and extending the ability to quickly visualize designs during client interactions. The enhanced feedback loop in the design-review stage enhances a client's feeling of engagement while improving the speed to consensus.

With large projects mandating a BIM approach to better coordinate project delivery, many firms are changing to BIM out of necessity. The sharing of models rather than drawings and documents provides a single point of truth, and cuts through confusion and conflicts in design and schedule that could cause costly delays. Greater awareness of the project sequence, and shared responsibility for model execution, means a more-streamlined construction process with fewer changes and cost overruns.

The model has become a starting point that is being extended to four dimensions with proper sequencing, five dimensions with financial details and on to six and seven dimensions with sustainable, holistic lifecycle asset management. The growing momentum for sustainable operations means that more owners will be looking to a BIM-based approach for daily operations, with an informed understanding of when infrastructure components need replacement as well as how best to plan and mitigate against manmade and natural disasters. This growing focus on resilience has implications for firms wanting to win traditional project work, but also holds potential to win extended work throughout the lifecycle of their projects.

With so many firms finding BIM to be a differentiator that can be extended to other areas to provide value, those not yet on BIM bandwagon will find it more difficult to catch up the longer they wait to engage. That, for all, is reason enough to make the move.

REFERENCES

[1] McGraw-Hill Construction (2012). "SmartMarket Report: The Business Value of BIM in North America – Multi-Year Trend Analysis and User Ratings (2007-2012)"

[2] McGraw-Hill Construction (2014). "SmartMarket Report: The Business Value of BIM for Infrastructure – Addressing America's Infrastructure Challenges with Collaboration and Technology"

[3] DODG Data & Analytics (2017). "SmartMarket Report: The Business Value of BIM for Infrastructure 2017"

[4] Autodesk. White Paper: "Better Business Results with BIM"

[5] Autodesk. White Paper: "Changing the Game with BIM"

[6] Autodesk. White Paper: "BIM Workflow for Civil Projects"

[7] Autodesk. "BIM Pilot: Getting Started Guide"

[8] Autodesk. “BIM Pilot: Deployment workbook”

[9] National BIM Standard – United States V. 3

[10] Autodesk, “Replacing Seattle’s viaduct – Parsons Brinckerhoff uses Autodesk BIM solutions to develop and visualize designs for Alaskan Way viaduct”

[11] The CIC Research Group, Pennsylvania State University (May 2011). “BIM Project Execution Planning Guide Ver. 2.1”

[12] The CIC Research Group, Pennsylvania State University (June 2013). “BIM Planning Guide for Facility Owners Ver 2.0”