Rail BIM 2030 Roadmap

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CONTENTS

What is BIM?

Building Information Modeling (BIM) is a method for planning, executing, and managing a construction project by making decisions based on high-quality information, including three-dimensional information, to minimize business risks.

Executive Summary

This Rail BIM 2030 Roadmap explains the phases of the BIM adoption and diffusion strategies from 2018 to 2030 under "level of information utilization in BIM" for the advancement of railway facilities in the 4th Industrial Age. The five classification levels discussed below are based on the gradual maturity of the BIM capabilities of the participants taking part in the project.

At the end of each level, the lessons from each project should be integrated into updated rail BIM guides, ensuring efficient and effective use of BIM in the following stage. The rail BIM guides must be continuously updated. This report details rail BIM adoption and diffusion strategies in terms of the people, processes, and technologies necessary for achieving the five levels below.

Rail BIM 2030 Roadmap

Level 1: Target 2018 (BIM 1.0) 2D-to-3D Conversion BIM

Very few project participants will carry out BIM during the 2D-to-3D conversion BIM (level 1) phase in 2018. 2D drawings will remain the primary communication media. Participants can benefit from deploying BIM in their projects, as this will allow them to review designs and detect design errors while converting 2D drawings to BIM models. Once BIM models of the project become available, the models can also be utilized for public hearings, communicating with clients, constructability reviews, and so forth.

Level 2: Target 2020 (BIM 2.0) Two-Track BIM (Parallel BIM)

During the two-track BIM (level 2) phase, targeted for 2020, BIM will be used for the parts of a project that can significantly benefit from deploying BIM, such as in areas where multiple trades interface with one another, areas with complex geometry, and areas that require heavy engineering. The other parts of the projects will be carried out using the traditional 2D-based method.

Level 3: Target 2022 (BIM 3.0) Integrated BIM or Full BIM

During the (fully) integrated BIM (level 3) phase, targeted for 2022, all the major project participants will generate and work with BIM models. This will enable the BIM-based, integrated project management of construction costs, scheduling, and processes, as well as issues concerning design and construction quality.

Level 4: Target 2024 (BIM 4.0) Lean BIM

During the lean BIM (level 4) phase, targeted for 2024, project management concepts influenced by the manufacturing industry, such as lean construction, offsite modular construction, construction automation, and integrated facility management, will be supported by BIM, generating synergy for improving the productivity and quality of projects.

Level 5: Target 2030 (BIM 5.0) Intelligent BIM (AI BIM)

During the intelligent BIM (level 5) phase, targeted for 2030, big data will be created by integrating BIM with sensors and multiple databases. This data will be used as a source for making informed decisions. The most optimal and effective solutions to many city-level problems, as well as individual facility-level problems, will be sought through the informed decision-making process.

Railway BIM2030 Roadmap

People / Process / Technology

		BIM 1.0 **2D-3D Conversion BIM** 2018	BIM 2.0 **Two-Track BIM** 2020	BIM 3.0 **Integrated BIM** 2022	BIM 4.0 **Lean BIM** 2024	BIM 5.0 **AI BIM** 2030
BIM Goals		**Procurement & Planning** • Communication between managers and project participants using BIM visualization tools • Application of AR/VR for design reviews or public hearings	**Design** **Expansion of BIM application** • Application for environmental assessment • Design review and coordination, budget review • Elimination of unnecessary social cost using visual information • Visualization/digitalization of construction plans and budgets	**Construction** **Expansion of BIM application** • Coordination between multiple trades • Quantity takeoff data linked with an ERP system • A BIM based total project management system for managing cost, progress, and field data	**Maintenance** **Expansion of BIM application** • Application of mobile devices, sensors, and VR/AR technologies • Real-time update of project construction and maintenance information • Lean-based off-site modular construction	**Expansion of application on whole life cycle of construction industry** • Big data, IoT, AI-technology-based decision-making • Continuous collection and analysis of projects, maintenance data • Visual management of a rail network linked with other traffic information
PEOPLE Culture Organization Education	**Company-wide level**	Company-wide BIM team	Monitoring, support, and management of multiple BIM projects	Continuous management of success and failure factors	BIM-based real-time project management during design, construction, and maintenance Lean-construction-based project management	A data science team that can run and use a decision support system to collect, maintain, and analyze big data
	Individual project manager level	Ability to manage the 2D to 3D conversion process Ability to handle BIM models	Ability to lead two-track BIM Design review using BIM	Ability to coordinate the multiple trade areas Quantity takeoff and progress management using a BIM model	BIM-based real-time project management during design, construction, and maintenance Lean-construction-based project management	Big data collection and analysis Big-data-based decision-making
PROCESS Policy Infrastructure Service & Reward Work Process	**Coordination process**	Design coordination between a limited number of team members	Increased importance of coordination between drawings and BIM models Limited use of BIM for specific issues by specific teams	Increased importance of interoperability of BIM tools, version control, and model synchronization; collocated and collaborative work process	Lean based management process, final scheduling system, and other pull-planning/scheduling system, manufacture-to-order (MTO) or engineer-to-order (ETO)	Data-driven decision-making processes, Data-driven design, construction, and FM/AM, Automated data processing and exchange, Automated production for on-site and off-site construction
	Tendering and management process	Application of existing tendering and project management methods	Little use of the lowest bid or the like Recommended use of services and CM at risk	Technology assessment system Personnel evaluation system	Use of tendering methods in which the owner can participate during the design and construction phases (e.g., IPD or the like) Tendering and management methods that can support off-site and modular construction	Contractor selection based on reliable quality, cost, time, and safety information, Risk prediction and management based on informed decision
TECHNOLOGY Software Hardware Information	**Fundamental technology**	BIM authoring tools BIM model checkers BIM viewers	BIM analysis tools Detailing tools Interoperability	Cloud based tools BIM servers, Field BIM tools 3D Scanning and photogrammetry for model-site synchronization Actual-progress-based 4D schedule management	Integrated lean-based BIM management tools, Construction automation 3D printing Off-site construction, Modular construction, IDM/MVD for automated data exchange, VR/AR	Semantic and intelligent information interfacing technologies, BIM data science (big data,) IoT-based manufacturing, project, and facility management AI-based design, engineering, and model quality checking, Construction automation, Modular construction, IDM/MVD for automated information requirements checking, Integration of "Smart Cities" and BIM
	Management technology	A system that enables project participants to share BIM models and error reports acquired through design conversion (e.g., CDE, Big Room System) A system that tracks and manages design errors	Coordination technology between 2D and BIM processes (e.g., 3D scanning, model version management)	Interoperability between various BIM software A change management system An integrated BIM and ERP system that can manage quantity takeoffs and progress	A company-wide system for monitoring and managing the progress and quality of projects A company-wide platform for lean-based railway construction progress management	A system that can collect and manage project information as big data A real-time decision support system based on big data

1. Purpose and Background

1.1. Purpose

This report presents a mid- to long-term strategy for diffusing building information modeling (BIM)* throughout the rail industry using a practical, step-by-step approach in line with the 4th Industrial Revolution. The goal of BIM adoption in the rail industry is to enable efficient task management, high-quality information generation, smooth collaboration, cost and schedule reduction, improvement in overall project quality, and effective asset management throughout the life cycle of rail infrastructure. To achieve this, this rail BIM roadmap divides BIM into five maturity levels, and suggests requirements from the people, process, and technology framework point of view for each step.
The Rail BIM 2030 Roadmap will help achieve fast and effective business performance, enhance collaboration, reduce costs, improve quality, shorten construction times, secure transparency, and ensure sufficient asset management. The primary goal of the Rail BIM 2030 Roadmap is advancing the railroad business during the 4th Industrial Revolution.

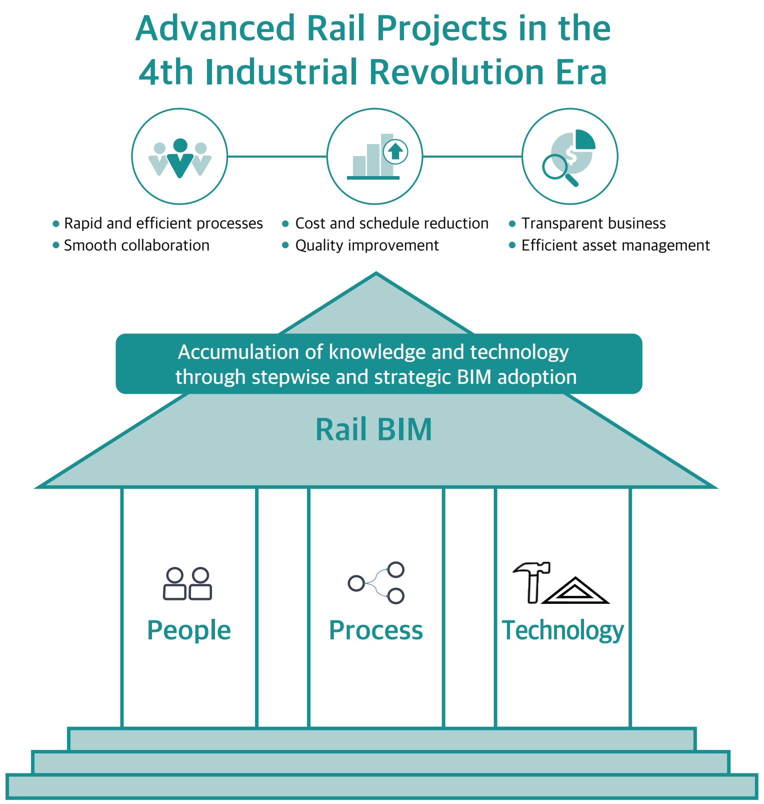


Fig. 1-1 The Rail BIM Framework.

*BIM involves planning, executing, and managing construction projects by making decisions based on high-quality information, including three-dimensional information, to minimize business risk.

1.2. Background

Since the early 2000s, the use of BIM to efficiently manage the information generated throughout the entire lifecycle of a project and to improve the productivity of the construction industry has exponentially increased. To expedite the adoption process and to provide guidelines for better implementation, various BIM guides and roadmaps were developed and distributed throughout the world, including the United States, Europe, Australia, Hong Kong, China, Singapore, and others. Korea was not an exception.
In Korea, the Ministry of Land, Transport, and Maritime Affairs prepared the first BIM Application Guide in 2009. The Ministry of Land, Transport, and Maritime Affairs and the Public Procurement Agency announced a BIM adoption and mandate strategy to be phased in from 2010 to 2016. Since then, the BIM guide has been updated at the end of each step of BIM adoption. These efforts began at a similar time in the building and infrastructure sectors, but BIM was first introduced in the building sector. The first public building projects that adopted BIM were carried out in 2008. The Korea Expressway Corporation, the Korea Water Resources Corporation, and the Korea Rail Network Authority have also deployed BIM in various projects since 2009.
More than ten rail projects have been carried out with BIM since 2009; however, as the projects were selected and conducted without employing consistent and systematic strategies, the lessons learned and knowledge obtained from each project have not been accumulated on an industry level.
To systematically implement and diffuse BIM knowledge in the rail industry by 2030, this report proposes employing a phased BIM adoption and diffusion strategy under the title, "Rail BIM 2030 Roadmap."

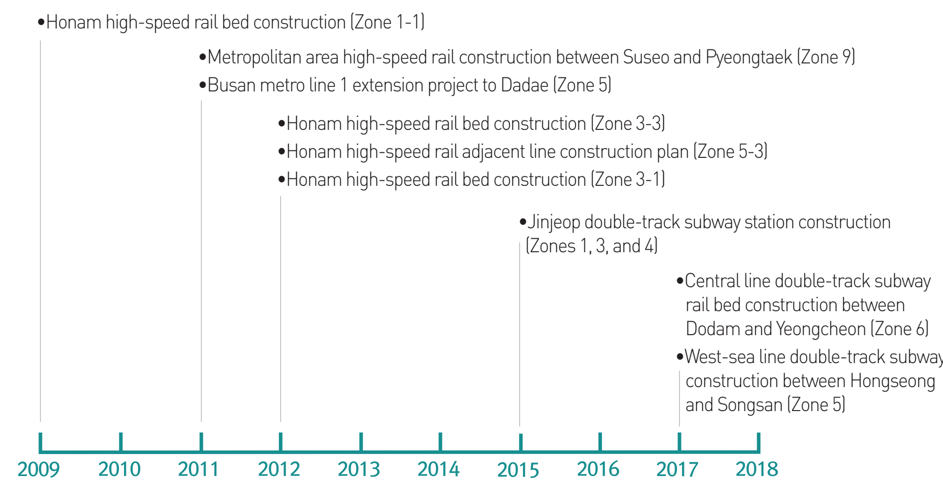


Fig. 1-2 Previous rail BIM projects in South Korea.

1.3. Scope

This report presents a phased, strategic, technical roadmap for implementing BIM in the rail industry from the perspective of public owners. Specific plans and action items, such as naming specific organizations, determining the number of personnel for BIM implementation, the hardware and software requirements, the implementation costs, and the target projects will be specified in an internal BIM execution plan for each organization or rail project. Additionally, specific methods for performing rail BIM during the design, construction, and facility management phases will be covered in the rail BIM owner's guide (1.0), the rail BIM design guide (1.0), the rail BIM construction guide (1.0), and the rail BIM facility management guide (planned), respectively.

2. Expected Effects and Benefits of BIM Adoption

This section describes the advantages of BIM adoption in four phases relevant to the rail industry: planning, design, construction, and operation and maintenance.

2.1. Benefits of BIM Adoption During the Planning Phase

- By using BIM from the early planning phase, a systematic and accurate feasibility study is possible.
  - BIM prevents unnecessary rework by reviewing information generated at the early stage of a project.
  - Effective and efficient decision-making can be achieved by utilizing information on risk prevention through 3D visualization, and managing the maintenance of facilities and assets.
- With BIM, early cost estimates are more accurate. It is possible to simulate and review projects in advance by using conceptual models.
- With BIM, design requirements and construction specifications may be defined more clearly.

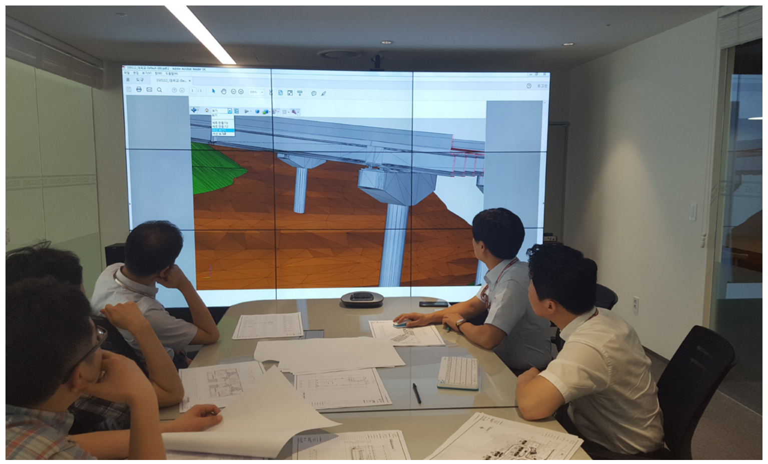


Fig. 2-1 Effective design review. (Courtesy of Seoyoung Engineering Co., Ltd.)

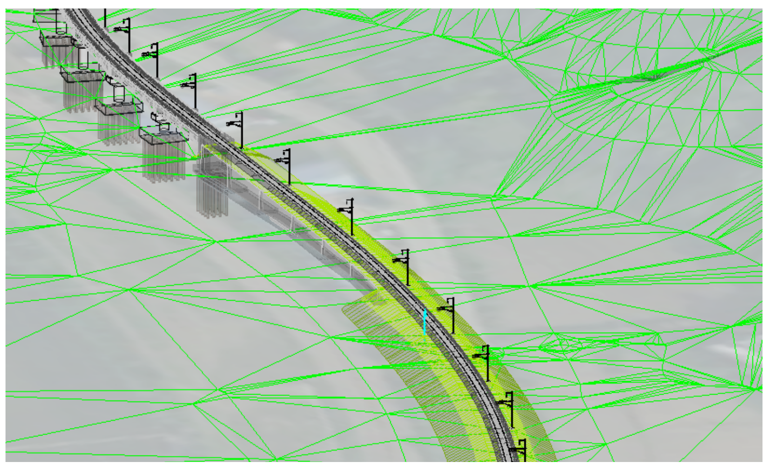
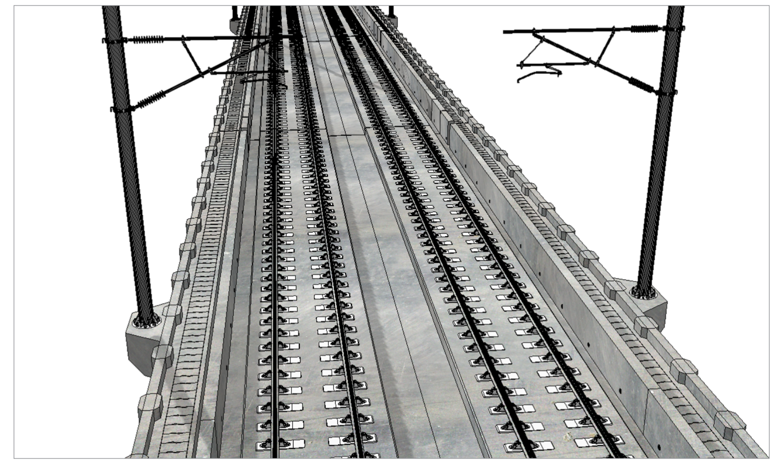


Fig. 2-2 Feasibility Study. (Courtesy of Seoyoung Engineering Co., Ltd.)

2.2. Benefits of BIM Adoption During the Design Phase

- BIM models can be superimposed with GIS and cadastral data to allow design review from the early stages of the design phase to consider visualization, surroundings, and cadastral situations.
- Greater accuracy is possible using the automatic reflection of design changes, as well as the benefits of visualization obtained from a three-dimensional model.
- It is possible to extract, discuss, and review drawings and documents using BIM models. It is possible to reduce errors and redesign time.
- Early collaboration prevents design errors and omissions relevant to each trade's design.
- Early design coordination is more cost-effective than value engineering (VE) after design completion, and, thus, the time and money required for post-correction work can be saved.



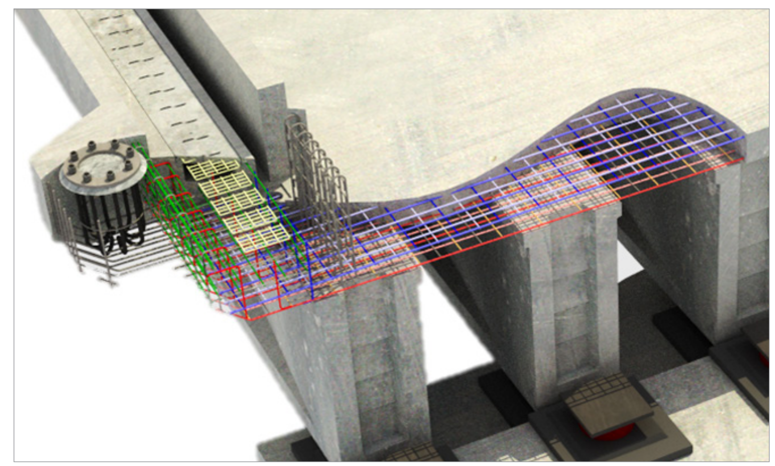


Fig. 2-3 Detailed design review. (Courtesy of Seoyoung Engineering Co., Ltd.)

2.3. Benefits of BIM Adoption During the Construction Phase

- Construction drawings are more accurate, as they can be extracted directly from BIM models without needing separate generation. When changes are made for constructability improvement, the time and cost for revising construction drawings can be saved by modifying the BIM models instead of creating new drawings.
- Precise process planning using equipment and construction simulation on the construction site leads to leaner construction and less unnecessary onsite waste.
- BIM facilitates collaboration between the different onsite trades, making it easier to review clashes and interferences with the different trades.
- Construction time and costs can be reduced due to the reduced number of design errors and the reduced rework rate.

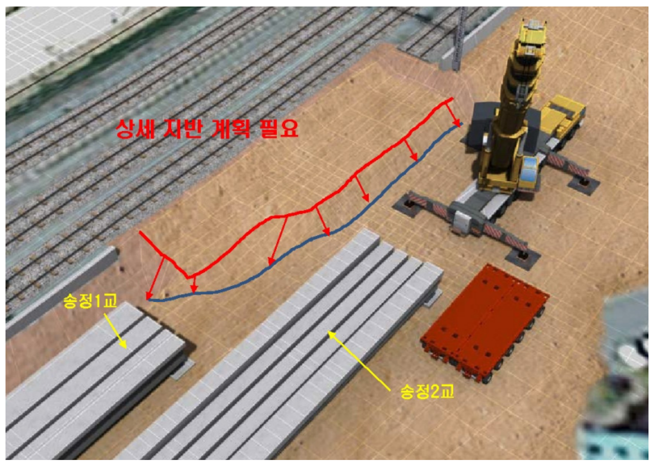


Fig. 2-4 Equipment simulation. (Courtesy of GS Engineering & Construction Corp.)

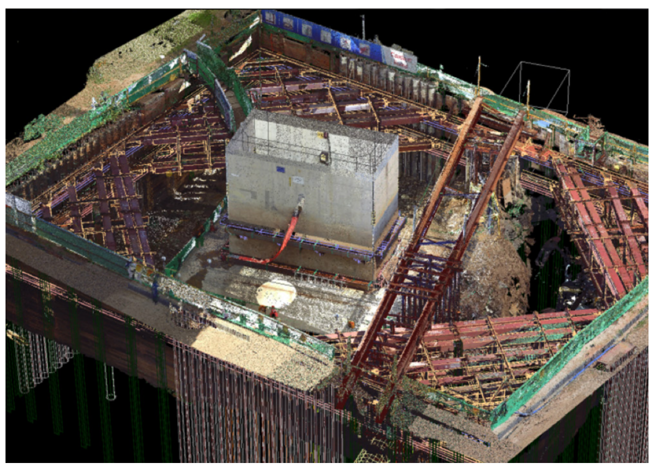


Fig. 2-5 Progress monitoring using laser scanning. (Courtesy of GS Engineering & Construction Corp.)

2.4. Benefits of BIM Adoption During the Operation and Maintenance Phase

- Accurate facility information is obtained through BIM models, which increases the accuracy of materials maintenance and asset drawings, such as facility, mechanical, electrical, and piping elements, thereby reducing the operation and maintenance efforts and costs.

Fig. 2-6 Facility management using augmented reality.

2.5. Key Factors for Maximizing the Effects of BIM

- The most critical success factors for maximizing the BIM benefits listed above are the "strong will and participation of decision-makers (Won et al., 2013)" such as owners and project managers because without decision makers' strong participation, it is difficult to make decision effectively. Moreover, iIf the BIM project is carried out without the involvement of the owners and project managers, knowledge will not be accumulated, even if dozens of BIM projects are carried out. Many case studies have demonstrated that significant differences regarding the number of defects and overall project quality exist depending on whether the decision-makers participated in BIM meetings. As important as the decision-maker's participation and willingness to push forward is the "project participants' willingness to share information (Won et al., 2013)." When information is not shared among project participants in a BIM project using excuses about confidentiality, it is difficult to expect an efficient and successful BIM project. Since information sharing is important, cyber security and confidentiality agreements are also very important. Refer to the UK's BS PAS 1192-5 Guide (BSI, 2015*) for more information on a guide to dealing with the cybersecurity issues in BIM projects.

* Won, J., et al. (2013). "Where to focus for successful adoption of building information modeling within organization." Journal of Construction Engineering and Management 139(11): 04013014.
* bsi (2015). PAS 1192-5:2015 Specification for security-minded building information modelling, digital built environments and smart asset management. London, UK, The British Standards Institution.

3. Status of BIM Adoption in the Public and Rail Sectors

3.1. Status of BIM Adoption in the Public Sector in Major Countries

The following section reviews BIM policies from the perspective of public owners in several major countries, such as the United States, Finland, the United Kingdom, Singapore, and others.

United States

- Both the public and private sectors have actively adopted BIM, and BIM is implemented throughout the entirety of the construction sector. Although the private sector plays a critical role in BIM adoption in the United States compared with other countries, BIM is also actively carried out by public owners, such as the Department of Transportation (DOT), General Services Administration (GSA), and the US Corps of Engineers (USACE).
- Since the late 2000s, BIM guides and case studies have been published through organizations such as National Institute of Building Sciences (NIBS), buildingSMART Alliance (bSA), GSA, American Institute of America (AIA), and others.
- Along with Finland's Common BIM Requirements (COBIM), the National BIM Standards (NBIMS) of the United States, published since 2007, has been the most influential on BIM guides around the world.

Finland

- Senaatti (Senate Properties), a public organization in Finland, recognized the need for BIM early and has been carrying out BIM projects since 2001.
- COBIM, published in Finland in 2007, was one of the first published BIM guides. Together with the NBIMS guides, COBIM has had an enormous impact on BIM guides globally.
- COBIM defines data and contents requirements for the model at each stage, including design, construction, and maintenance.

United Kingdom

- The government of the United Kingdom (UK) mandated BIM in the public construction sector, which accounts for about 7% of the GDP, and required the public construction sector to achieve UK BIM Level 2 by April 2016.
- Submissions and procedures for each BIM stage are defined as British Standards (BS 1192 series). UK BIM standards and education materials are distributed and promoted widely to the industry through websites (http://bim-level2.org) and online videos.
- Although the UK BIM mandate was requested relatively later than those of the United States, Northern Europe, South Korea, and Singapore, the UK BIM Guide is the most commonly referenced in the world because of its systematic and strategic approach.

Singapore

- To improve construction productivity by 25% by 2020, the Building and Construction Authority (BCA) of Singapore has made BIM obligatory.
- Like the UK, various policies and educational materials were promoted and distributed so the industry can easily follow the policies and provide industry-support schemes and BIM guides through a government BIM policy website.
- Recently, a new goal of Integrated Digital Delivery (IDD) based on BIM and Design for Manufacture and Assembly (Design for Assembly) has been presented.

3.2. Current Status of BIM Adoption in the Rail Industry in Major Countries

The rail industries in many countries adopted BIM to obtain the accurate facility information from the BIM information, thereby increasing the accuracy of operation and maintenance information, and reducing the cost of design, construction, and maintenance.

MTR Project, Hong Kong

- The Hong Kong Mass Transit Railway (MTR) plans to build high-speed railways and the West Kowloon railway station by 2015 using BIM. The West Kowloon railway station is the largest railway station in Hong Kong, with more than 15 platforms and four basement floors for transporting four million passengers per week.
- BIM was primarily introduced at the design and construction stage, and the main methods of use were checking for spatial interference, reviewing constructability, facilitating cooperation and coordination at project sites, and managing schedules. The main goal was to reduce risk.

Japan Central Japan Railway (JR) Project

- To rebuild railways destroyed during the Great East Japan Earthquake in 2011, USD 112 billion was spent and BIM was deployed. BIM design tools included Civil 3D, Revit Structure, and others.
- During the restoration of existing railways, BIM models have been utilized for construction-time reduction, quantity takeoff, cost estimation, and earthquake recovery planning. BIM was also used to improve the productivity of railroad work and the maintenance of existing tracks. A variety of models, such as terrain, architecture, and 3D point clouds were created and managed using commercial BIM tools.
- BIM models were linked to the Railway GIS, developed by the JR East Consultants Company, to manage railroad models, drawings, and satellite images, and to effectively plan new and existing tracks.

United States Measure R Project

- To solve the traffic problem in LA, 12 projects (including six subway projects) have been undertaken.
- Until 2010, the design was conducted using the existing 2D method, but after reviewing the possibility of adopting BIM in 2011, it was decided BIM would be adopted for all projects after 2012.
- BIM was adopted and utilized mainly in the design and construction phases and a system was designed to meet national standards.

United Kingdom – East London Line Project

- BIM was applied to the North-South lines that connected to the existing East London Line as an expansion for the 2012 Summer Olympics.
- The main contractor (URS Scott Wilson) provided BIM models (four stations, two Warren Truss bridges, an arch bridge, and three high-rise bridges) to the project participants. The entire team worked through a collaborative work solution, which enabled them to collaborate in real time.
- More than 300 specialists distributed in 15 offices swiftly shared engineering information and communication. Compared with past projects, the overall time savings was 25% or more.

UK – High Speed 2 (HS2) Project

- The HS2 project is a high-speed rail project that will connect London and Birmingham. It is targeted to open in 2026.
- Based on the knowledge gained from existing rail BIM projects, the company plans to prepare BIM guidelines and roadmaps and apply BIM throughout the design, construction, and maintenance phases of the project.
- Collaboration and contract methods have been systemized. To help participants easily understand the goals of, and participate in, the BIM projects, various promotional and educational materials have been prepared and distributed. Potential interoperability issues due to the use of various software applications are also being examined.

Germany – Deutsche Bahn

- With an overall goal of fully adopting BIM after 2020, a phased adoption plan was prepared. This plan intends to implement 13 pilot projects from 2017 to 2020 and use BIM through the preparation phase from 2015 to 2017.
- BIM-based design review and the promotion of BIM are carried out through these pilot projects.
- The reasons why BIM adoption in the building sector fell short of expectations were analyzed. BIM adoption in the public construction sector has been carried out under the leadership of the National Commission and the Transport and Digital Infrastructure.

Qatar – Doha Metro Red Line Project

- As Qatar will host the 2022 Doha World Cup, various infrastructure projects are planned. BIM execution plans have been mandated for railroad projects. The owners' expectations and explicit requirements for BIM projects in Qatar are provided as part of the bidding invitation.
- BIM are used in a wide range of areas, including quality management, project planning, space programming, progress management, record tracking and control, Project Management Information System (PIMS), Electronic Document Management System (EDMS), information and modeling management, change and geometry management, cost control, communication management between stakeholders, design management (including design inspection), value engineering (VE), requirements management, construction administration, safety management, requirements for sustainability, risk management, and interface management for coordination between stakeholders like designers and contractors.
- Additional requirements include design parameters (design specifications), linear design specifications, earthwork specifications, tunnel design specifications, cut and fill specifications, bridge design specifications, building design specifications, drainage design specifications, fire and electricity design specifications, and the other related specifications.

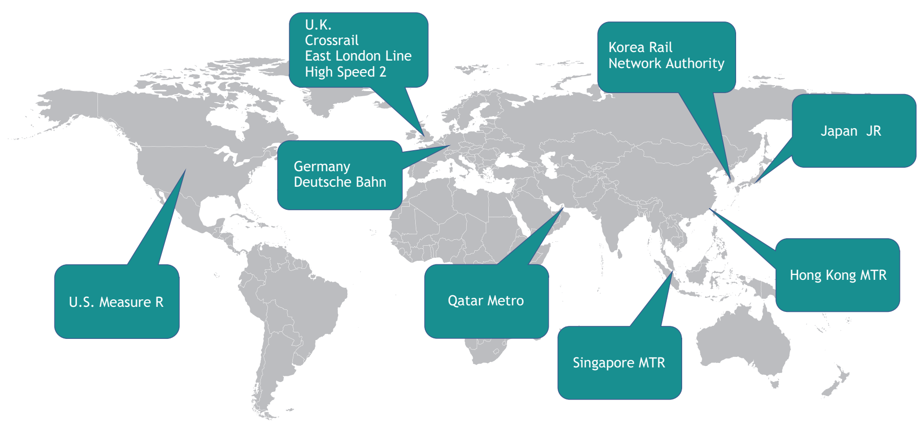


Fig. 3-1 Rail BIM projects in major countries.

3.3. Current Status of BIM Adoption in the Public Sector of South Korea

In South Korea, before the Ministry of Land, Infrastructure, and Transport mandated BIM adoption on public projects from 2010 onward, several public building projects, such as the Yong-in Citizen Sports Park and the Dongdaemun Design Plaza projects, had already deployed BIM.
Application of BIM in civil infrastructure projects began in 2009, starting with the Honam high-speed railway (HSR) in 2009, the Korea Expressway Corporation (EX) pilot project in 2011, and the Korea Water Resources Corporation (K-water) overseas dam design projects in 2013. In 2015, the civil BIM library was developed and distributed. The Ministry of Land, Infrastructure, and Transport announced that it would seek to apply BIM to 20% of civil infrastructure projects by 2020. The Korea Land and Housing Corporation (LH) has also begun adopting BIM in phases from 2016 onward. The status of BIM adoption by EX and LH are described below.

Status of BIM Adoption of the Korea Expressway Corporation (EX-BIM)

The rail industry can learn from the highway industry because they share many similarities:

- Both are key industries that greatly affect the development of a national infrastructure network and, thus, require consultation with local governments.
- The importance of the operation and maintenance of facilities and assets is paramount.
- Special considerations are required for the stopping, moving, and maintenance of vehicles.
- Buildings are also important parts of a project.
- An electronic (paperless) submission system is required to ensure the permanent storage of information assets. An information classification system for the data storage is necessary.

With the goal of strengthening the capability of designing and managing next-generation highways based on the multi-dimensional design environment, EX-BIM aims to improve information utilization (one-source multi-use), information acquisition and storage efficiency (one click for in and out), and information integration (one master model for digital expressways).
From 2011 to 2014, BIM was test-applied to the construction documentation phase of zone 5 of the Daegu circulation expressway and zone 12 of the Hamyang-Ulsan expressway. Through these pilot projects, the differences between the traditional drawing-based approach and BIM in costs, quantity takeoffs, errors, and changes in major construction work types were compared and analyzed. In 2016, the company implemented BIM design in zones 10 to 14 of the Sejong–Pocheon expressway. Based on the experiences of the pilot projects, EX established the EX-BIM roadmap in 2016. The objectives and the target year of each phase are as follows:

· Korea Expressway Corporation's Ex-BIM Diffusion Strategies

Phase	Goals	Action Items
Adoption (2017)	Development of a roadmap and guidelines; Design BIM	· Ex-BIM roadmap and guide development · BIM-based next-generation electronic drawing standard specification · Adoption of Ex-BIM during construction documentation · Information asset management through electronic submission of 3D design deliverables · Education of practitioners for Ex-BIM adoption
Expansion (2018–2019)	Construction and Facility Management BIM	· Establishment of an Ex-BIM execution plan for construction · Safety management and 3D construction simulation during construction · Inspection technology using virtual reality · Management of a 3D-based maintenance and repair history · Integrated information system for 3D-based design, construction, and O&M · Fostering of company-level Ex-BIM managers and Ex-BIM team
Settlement (2020 onward)	Company-wide BIM; New service creation based on BIM	· Phase-by-phase execution of the Ex-BIM adoption plan · Mobile-based 3D visualization and sharing technologies for an inspection and repair history · Database development for intangible assets, from the design and construction to the O&M phases · Full implementation of BIM in new international and domestic expressway projects · Advancement of Ex-BIM to cope with the next generation of transportation systems, such as autonomous driving

· Ex-BIM Goals by Project Phase

Phase	Adoption Goals
Planning	· Improvement of the design management system · Advancement of early design review technologies
Design	· Electronic 3D design models · Electronic submission system
Construction	· Advancement of construction management technologies · VR-based safety management and inspection system
Operation & Maintenance	· Digitalization of management technologies for pavement and highway facilities
Services	· Implementation of the expressway asset information management (Ex-AIM) · Implementation of an Ex-BIM review system

LH Civil BIM Implementation

LH began adopting civil BIM from 2016 with the aim of shifting to construction technology management focusing on 3D geometry and information reflecting the "4th master plan for the Construction CALS (continuous acquisition and lifecycle support of construction information)." Specific goals included "key technology advancement for smart cities," "the strengthened competitiveness of the national construction technologies," "provision of explicit construction information to workers," "demand for construction information for facility management," "the expanded adoption of advanced BIM technologies from," and "an environment for minimizing quality defects."

Prior to this effort in 2016, LH had already begun the BIM adoption, transforming its existing, two-dimension-based design process into a new, three-dimensional information and BIM design process. Through this, the company aimed to promote the 3D information and precision design, to improve the company's technologies, to reduce the total project cost, and to strengthen the company's competitiveness through 3D visualization, standardization, interconnection, collaboration, and sharing of information.

In May 2016, LH decided to adopt BIM (3D information-based precision design) in civil engineering work for collective housing projects. The goal was to apply BIM from individual units to the entire complex and to the city scale through the following five steps.

The LH's BIM effort has the following characteristics:

- The application of BIM in the building sector has been expanded to the civil engineering sector.
- LH focused on the practical use of BIM.
- The applicability was tested and improved through pilot projects.
- The importance of BIM use during construction, maintenance, and asset management was stressed.
- BIM experts were secured, and BIM systems were set up.
- BIM policies and guidelines were prepared in advance.

· LH Civil-BIM Diffusion Strategies

Phase	Goal	Detailed Plans
Phase 1 (Pilot BIM design 10%)	Establishment of an adoption system for BIM design	· Establishment of the plan and direction for each trade · Development of an object classification system · Definition of BIM-based quantity takeoff (QTO) items and the calculation method · Specification of BIM application systems · 3D contour and soil strata modeling · Other tasks specified in work orders
Phase 2 (Pilot BIM design 50%)	Establishment of the LH Civil-BIM design process	· BIM design for each trade · Preparation for detailed QTO · Development of standard BIM libraries · Preparation for the BIM roadmap development · Review of relevant regulations, standards, and guides · Review of BIM guidelines of the other sectors · Specification of standard forms · Other tasks specified in work orders
Phase 3 (Pilot BIM design 90%)	Establishment of the LH Civil-BIM design process	· BIM design for each trade · Design manual for each trade · Development of standard BIM libraries · Development of drawing standards · Development of the LH Civil BIM roadmap · Development of BIM guidelines · Specification of standard forms · Other tasks specified in work orders
Phase 4 (Pilot BIM design 100%)	Establishment of the LH Civil-BIM standard and system	· BIM evaluation for each trade · Clash detection from a consolidated model · Comparison report of 2D and 3D designs · Development of BIM modeling guidelines · Report of BIM analyses and results · Development of QTO tools · Specification of the direction of civil BIM · Development of education materials · Other tasks specified in work orders
Phase 5	Improvement of the LH Civil-BIM regulations and standards; Announcement of outcomes	· 4D and VR simulation · BIM design case studies · Revision of BIM manuals · Linking BIM and LH systems · Revision of BIM regulations, guidelines, and standards

· LH Civil-BIM System Tasks

Item	Tasks
LH Civil-BIM System	· Making BIM as simple and easy as possible · Application of BIM to visualization, detailed modeling, and detailed QTO · Simplification of guidelines, manuals, and example models
Expansion of BIM projects	· Application of BIM projects in LH apartment complexes starting from the second half of 2017
Security of BIM specialists	· Implementation of measurements to secure BIM specialists
Integration with existing systems	· Integration of BIM with existing 2D planning, design, construction, management, and other systems
Security of application systems	· Security of tools for BIM-based planning, design, construction, and management

UK Crossrail - Key Benefits

UK Crossrail identified six major benefits of BIM adoption:

· Better visualization of design and construction in three dimensions reduces the risks of a project.
· Safety during construction is improved by easily reviewing complex details and processes onsite.
· Information is managed through a single, trusted data source, making it effective for drawing and document management.
· It is possible to visually collaborate through the detailed design and construction views.
· Information generated from the beginning of a project can be reused for maintenance and asset management, thereby reducing costs and information loss.
· Advancements in data interoperability and mobility enable the advancement of project delivery practices.

3.4. Current Status of Rail BIM Projects in Korea

The Korean rail industry adopted BIM in 2009, starting with the Honam High Speed Railway project, but failed to accumulate BIM knowledge through pilot projects because BIM was deployed without a strategic approach. As of 2018, approximately ten rail BIM projects have been carried out in Korea. The following lists the projects.

· Rail BIM Projects in Korea

Rail BIM Projects	Period	Phase	BIM Uses
Honam high-speed rail bed construction (Zone 1-1)	2009.5.22–2013.5.21	Construction	4D simulation, Crane operation review, Safety review, BIM-based meetings and schedule management
Metropolitan area high-speed rail construction between Suseo and Pyeongtaek (Zone 9)	2011.5–2015.12	Construction	4D simulation, Laser scanning, Crane operation review, Safety review, BIM-based meetings and schedule management
Honam high-speed rail bed construction (Zone 3-3)	2012.8.1 onward	Construction	4D simulation of equipment operation plans by phase, Digital mockup of the project site, Train operation simulation, BIM-based meetings and schedule management
Honam high-speed rail adjacent line construction plan (Zone 5-3)	2012.12.1–2014.12.31	Construction	Clash detection, Design review
Busan metro line 1 extension project to Dadae (Zone 5)	2011.3.7–2013.3.31	Construction	BIM-based integrated project information management system
Honam high-speed rail bed construction (Zone 3-1)	2012.8.1–2013.1.30	Construction	Review of potential problems with adjacent lines in operation, Critical point management
Jinjeop double-track subway station construction (Zones 1, 3, and 4)	2015.2.6–2015.5.30	Design	Modeling of stations, tunnels, entrance, buildings, bridges, ventilation units, substations, and mechanical, electrical, and plumbing units
Central line double-track subway rail bed construction between Dodam and Yeongcheon (Zone 6)	2017.6	Construction	Use of BIM during construction of rail beds, tracks, and buildings
West-sea line double-track subway construction between Hongseong and Songsan (Zone 5)	2017.6	Construction	Bridge construction

4. An Analysis of BIM Roadmaps and Diffusion Strategies

4.1 The BIM Roadmaps and Diffusion Strategies in Major Countries

The BIM roadmaps and diffusion strategies of major countries, including the goals of each phase, were compared and analyzed. Nine countries were analyzed, including two North American countries (the United states and Canada), three European countries (the United Kingdom, France, and Germany), and four Asian countries (Singapore, Hong Kong, Australia, and South Korea).
Nordic countries (Finland, Norway, Denmark, etc.), which are commonly considered advanced in BIM adoption, were not included in this analysis because they did not officially publish a BIM roadmap. A brief overview of the roadmaps of the major countries except for Korea is provided below. The BIM roadmaps of Korean public organizations are reviewed in Section 4.2.

United States

The USACE produced a four-step BIM roadmap in 2006. The goals were to develop the initial BIM operational capacity by 2008; to obtain this overall interoperability in the facility lifecycle by 2010; to have full operational capabilities by 2012; and to achieve business automation by 2020. Compared with the roadmaps of other countries, these detailed strategies for both the in organizational and institutional aspects are sufficient.
A total of six specific objectives were established, including to establish process concept metrics; develop the initial operational capabilities by 2008; establish interoperability during the life cycle; use NBIMS-based e-commerce for full operational capabilities and asset management by 2012; and automate lifecycle tasks using NBIMS by 2020. In 2012, the USACE revised the BIM roadmap with a total goal of five stages. The five objectives include education, integration, collaboration, automation, and innovation.

Canada

The BIM roadmap announced by the Canadian Architecture, Engineering, Construction, Owners, and Operation (AECOO) Community in 2014 included five stages (isolated, networked, interoperable, integrated, and unified). The goal is to reach Level n by 2020. Each step was then divided into six categories, each with the achievable objectives. The six categories are engagement, development, education, deployment, evaluation, and sustainability. These six items indicate the objectives to be achieved at each stage of increased BIM maturity. One strength of the Canadian BIM roadmap is the easily identifiable objective of each stage.

Australia

The AIA's BIM roadmap divided the BIM development process into four phases: 2D phase, modeling phase, collaboration phase, and integration phase. Detailed work programs including specific activities and targets were specified. The six specified work programs (WPs) were procurement, BIM guidelines, training, product data and BIM libraries, process and data exchange, and regulatory frameworks. Each WP was systematically structured, and included target milestones. The roadmap described what had been already done, what was being done, and what needed to be done for each WP. These six WPs began in 2012–2013 and ended in the first half of 2016. The roadmap aimed to reach the very last stage in the second half of 2016. The Australian BIM roadmap's strength was that it provided specific work programs that included a sequence of activities and targets.

United Kingdom

Announced in 2011, the UK BIM roadmap was created with the goal of using BIM to improve cost, value, and carbon consumption through open and shareable asset information. The UK BIM roadmap presents a step-by-step strategy based on the B/555 "Design, Construction & Operational Data & Process Management for the Built Environment" of the British Standards Institute (BSI). In addition, opinions from various professional groups were incorporated into the BIM adoption strategy. BIM maturity was divided into four levels: Level 0 is the CAD and paper-based work method. Level 1 uses 2D and 3D. Level 2 is a BIM-centered working method for designing, constructing, and maintaining facilities. Level 3 utilizes BIM in a more consolidated form. The main data exchange medium for each level is defined as paper, file, model, and integrated Web-based BIM-hub, respectively, from levels 0 to 3. BIM Level 2 was mandated from April 2016. One of the strengths of the UK government's approach is the continuously published BS 1192 BIM Guide series that developed and distributed the training materials through websites, allowing practitioners to access, identify, and implement the BIM requirements mandated by the BIM roadmap.

Singapore

The Singapore BCA began e-submission of architectural, structural, and mechanical BIMs to submit permit drawings through CORENET in 2010. A Singapore BIM Guide announced that it would mandate the BIM e-submission on architecture for all new building projects over 20,000 m2 by 2013, on engineering or all new building projects over 20,000 m2 by 2014, and on all architecture and engineering for all projects over 5,000 m2 by 2015. The roadmap was established based on the expanded scope of BIM application rather than the specific levels of BIM maturity.

4.2. The BIM Roadmaps and Diffusion Strategies in South Korea

The Ministry of Land, Infrastructure, and Transport

When the Ministry of Land, Infrastructure, and Transport (MOLIT, then the Ministry of Land, Transport, and Maritime Affairs) announced its first Architectural Policy Master Plan in 2009, it promoted the adoption of BIM as a strategy to enhance construction and urban industries. MOLIT aimed to gradually expand the adoption scope of BIM through three stages. After a pilot project period from 2010 to 2011, it mandated the use of BIM on all public buildings over 50 billion KRW managed by the Public Procurement Service (PPS) from 2012 onward, and expanded the mandate scope to all public building projects managed by PPS from 2016 onward. The three stages were categorized as foundation composition, application and implementation, and advancement and settlement. The goals were to improve design quality and work processes, to reduce cost, and to promote business innovation through the policies implemented during the projects. In 2017, MOLIT announced that BIM would be mandated on more than 20% of civil engineering projects by 2020.

Korea Infrastructure Safety Corporation

The roadmap of the Korea Infrastructure Safety Corporation aimed to conduct the first three phases of the BIM roadmap over six years, from 2012 to 2018, followed by the fourth phase after 2018. The roadmap focused on facility management (FM). The roadmap aimed to derive FM requirements and to validate the effectiveness of BIM during the early phase, and later to standardize and extend this capability. Ultimately, the goal is to establish a BIM-based decision support system.

Korea Expressway Corporation

The Korea Expressway Corporation (EX) set 2014 as the starting year for BIM implementation, slightly later than other public organizations. It aims to implement BIM through two phases—adoption and implementation—over a five-year period ending in 2019. Like the roadmap of the MOLIT and PPS, the first step involves establishing a foundation for the use of BIM, and the final step is to secure key technologies derived from the application of BIM technologies.

4.3. Comparative Analysis of BIM Roadmaps

Comparison of BIM Roadmaps by Goal

Each country's BIM roadmap sets its step-by-step objectives in approximately three ways. The first group of BIM roadmaps specifies goals by the level of collaboration. In Australia and Canada, disconnected project entities become integrated and optimized with network connectivity and interoperability in the final stage. The second group determines goals by the level of data exchange and utilization. In the UK, a process based on file exchange during level 1 becomes model-based collaboration during level 2. Level 3 is based on integrated Web-service-based data exchange. The German and French roadmaps are also based on the maturity of the data exchange. The final group bases goals on expanding the scope of BIM application. The Singapore roadmap is based on increases in the gross floor area. The Korea roadmap is based on construction cost. The early USACE roadmap is based on the scope of application from initial operation capability to full operation capability and automation.

· Comparison of Strategic Goals of Existing BIM Roadmaps

Region	Organization	Strategic Goals
Australia	Australian Institute of Architects and CRC	Collaboration level (2D, modeling, collaboration, and integration)
Canada	buildingSMART Canada	Collaboration level (isolated, coordinated, collaborative, integrated, unified)
UK	The UK BIM Task Group	Collaboration level (2D, modeling, collaboration, and integration)
US	USACE	Level of application
Singapore	BCA	Increased scope of application (Gross floor area)
Korea	MoLIT/PPS	Increased scope of application (Total construction cost)

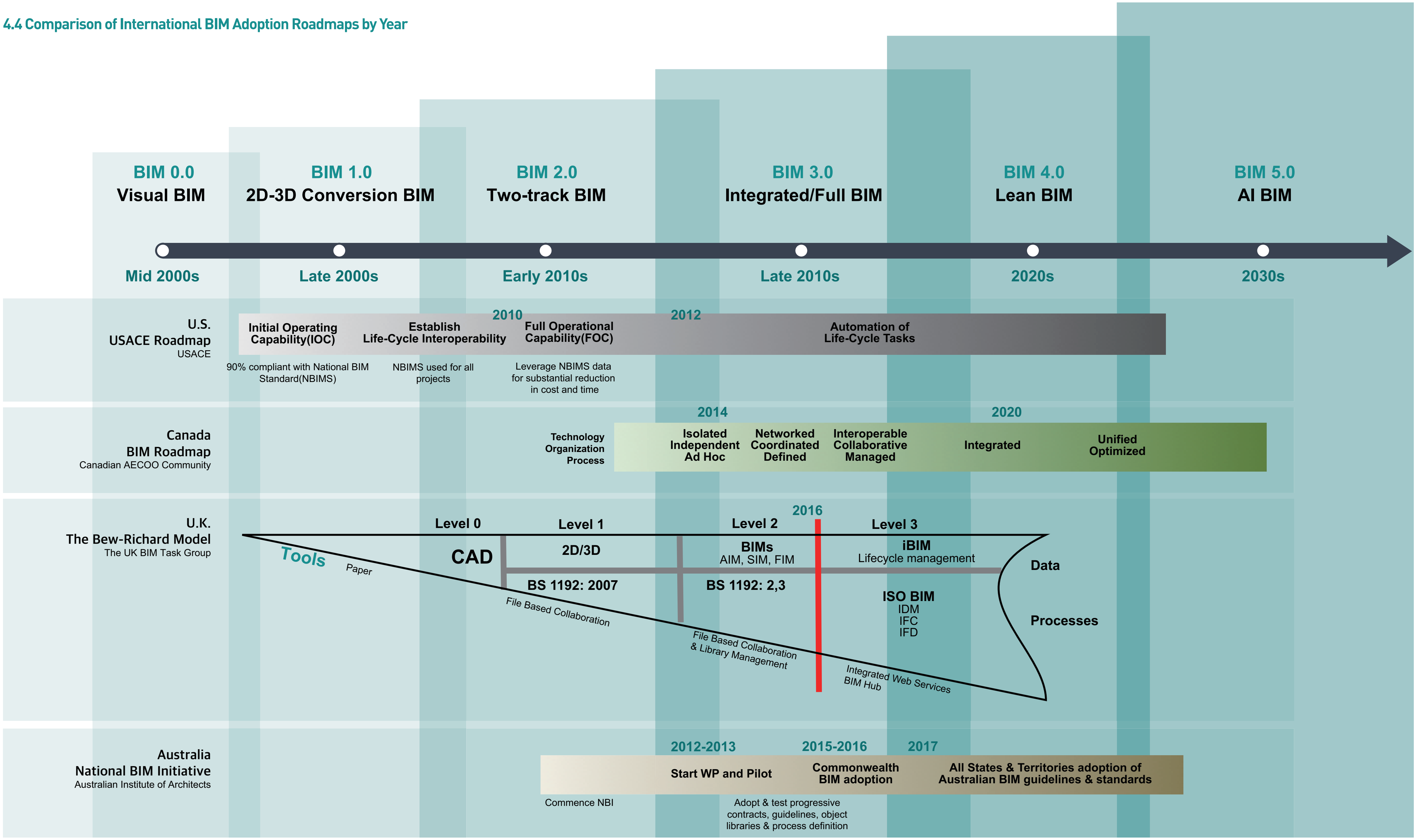
Comparison of BIM Roadmaps by Strategic Action Item

The BIM roadmap includes a step-by-step implementation strategy for each phase. Strategic action items can be broadly grouped into six categories. The first strategic action item is education and training, which is common across all roadmaps. This confirms that educating and training are perceived as essential for the adoption and diffusion of BIM. The second strategic item is the development of standards, guidelines, and policies. This action item was also adopted by all the roadmaps. The third strategic item is creating and leading the culture of using BIM by forming leadership organizations, such as BIM-related associations. Strategies, such as public relations activities and pilot project applications, are also included. The fourth strategic item is having a BIM mandate. The United States, Germany, Korea, and Singapore included BIM mandates in their roadmaps. The UK and Australia did not specify BIM mandates in their roadmaps, but announced them a separate, BIM-related policies. The fifth strategic item is developing the technologies for supporting BIM. This was included mostly in the roadmaps of Asian countries, such as Hong Kong, Korea, and Singapore. The final strategic item involves preparing for future BIM by reflecting on issues such as the preservation of public heritage and energy conversion. France included this in their recently established roadmap. The following table summarizes which roadmaps include which strategic items. However, most of the strategic items that were noted as not included in a roadmap were implemented, in one way or another, by each country during the BIM adoption process.

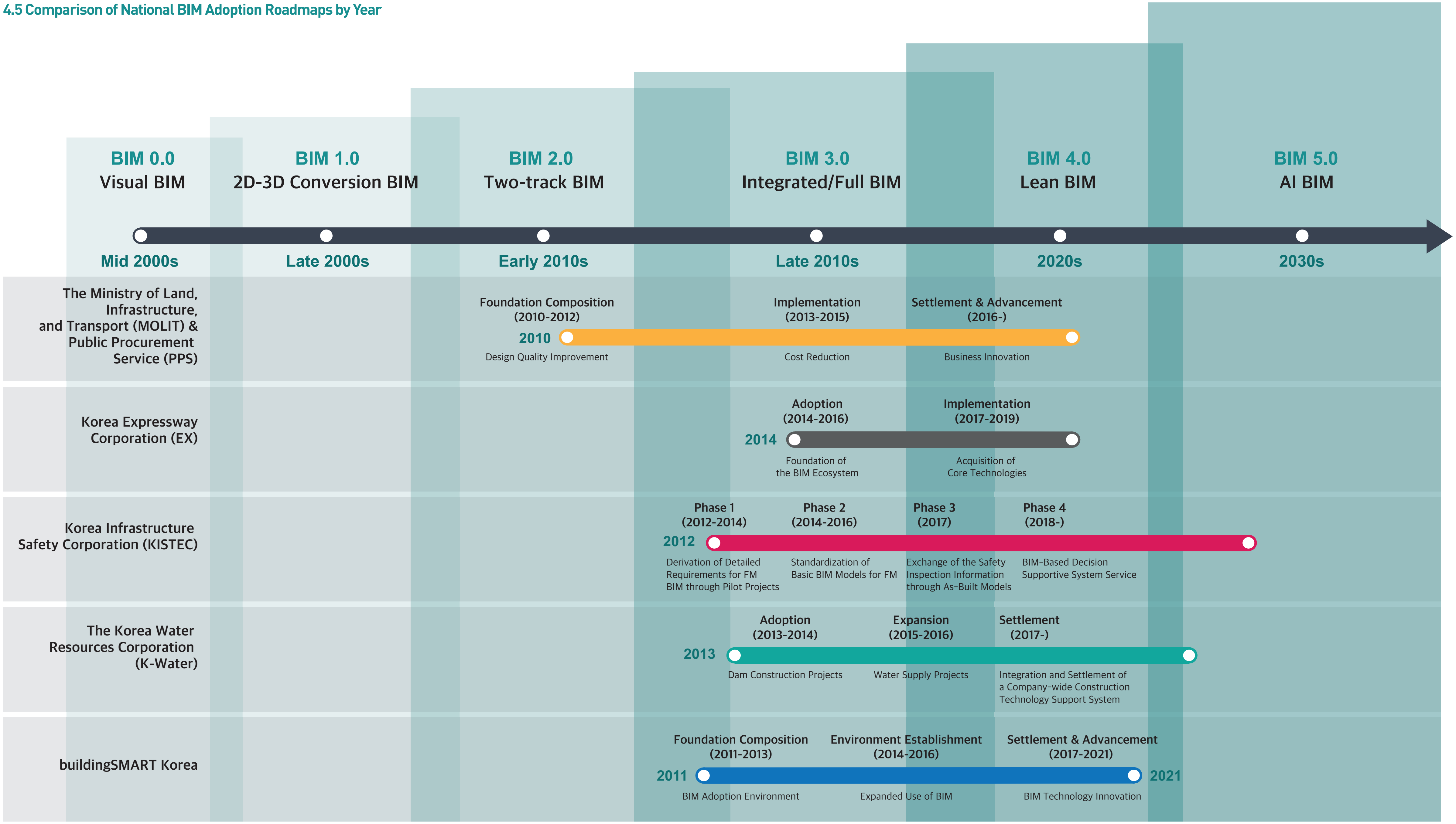
· Distribution of Strategic Items in BIM Roadmaps

Strategic Items \ Region	US	Canada	UK	France	Germany	Australia	Hong Kong	Korea	Singapore	Application Rate
Education and Training	•	•	•	•	•	•	•	•	•	100%
Standard, Guide, Policy	•	•	•	•	•	•	•	•		89%
Culture, Pilot Projects, Leadership Activities		•	•	•	•	•	•		•	78%
BIM Mandate	•		•		•	•		•	•	67%
Technology Development and Acquisition							•	•	•	33%
Preparation for Future BIM				•						11%

4.4 Comparison of International BIM Adoption Roadmaps by Year



4.5 Comparison of National BIM Adoption Roadmaps by Year



5. The Future of BIM and the BIM Maturity by Information Utilization Level

To establish a rail BIM diffusion strategy and to predict the future direction of BIM in the 2020s and 2030s, the past and present status of the BIM technological maturity was analyzed in terms of their information utilization level. First, changes in the BIM maturity level are observed during BIM adoption for the past 10+ years; then, the future direction of BIM technology development is discussed based on the analysis results.

5.1. The Past and Present Status of BIM

According to the BIM survey by Yonsei University, BIM projects were carried out in Korea as early as the early 2000s. However, Korea was not officially in the business of BIM until the late 2000s. Public organizations, such as the Ministry of National Defense, LH, and the Seoul Metropolitan Government, began ordering BIM projects in the late 2000s, although the foundation for BIM in Korea was still weak. As the result, except for a small number of relatively advanced BIM projects including the Yong-in Citizens' Sports Park, Dongdaemun Design Plaza, and the D-Cube Project, the use of BIM was often limited to visualization and marketing. This period, which used BIM mainly for visualization and marketing, is considered the visual BIM, communication BIM, or marketing BIM (BIM 0.0) phase.

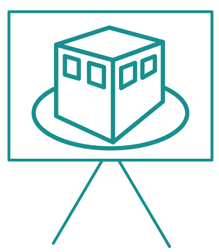


그림 5-1. BIM 0.0 시각 BIM

In approximately 2010, many projects learned that a significant percentage of design errors could be detected and the designs could be coordinated before construction using the 2D to BIM conversion process. Although the number of BIM consulting companies increased significantly during this period, BIM use was limited to pre-construction design review because most BIM activities were outsourced to BIM consultants, and most designers and contractors had not yet acquired the knowledge required to use BIM during construction. This manner of using BIM was referred to by the industry as 2D to 3D conversion BIM or, simply, conversion BIM (BIM 1.0) phase.

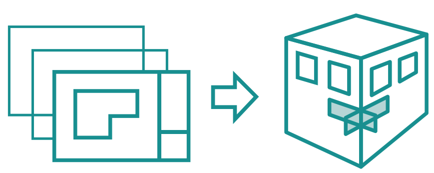


그림 5-2. BIM 1.0 전환 BIM

Around 2012, new attempts to make BIM more aggressive and practical for projects emerged. The 2D-based practice was still dominant, but the parts of a project that were difficult to design, engineer, and construct, such as irregularly shaped facades, engineering of long-span space, and heavily equipped ceilings, were carried out using BIM in parallel with 2D practices. In the construction industry, this referred to as the two-track BIM or parallel BIM (BIM 2.0) phase.

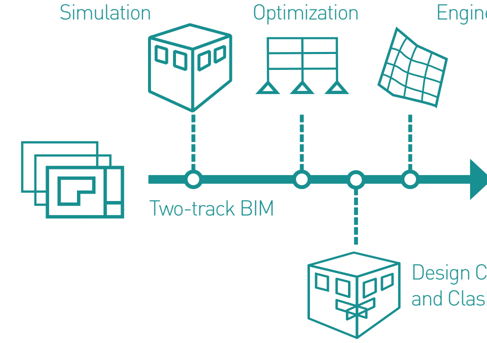


그림 5-3. BIM 2.0 투트랙BIM

Although using two-track BIM had many benefits, several limitations were revealed, including the mismatch between drawings and BIM models, and wasted time and effort due to the miscommunication and miscoordination inherent in having two sources of information. Starting in approximately 2016, BIM projects started mandating that all main project participants use BIM from the beginning to the end of a project to overcome these limitations. This was possible because of the increased number of designers, engineers, contractors, and subcontractors who could perform BIM. This phase was referred to as the (fully) integrated BIM or full BIM (BIM 3.0) phase. This period aligns with the period in which the MOLIT planned to mandate BIM on all public projects managed by the PPS.

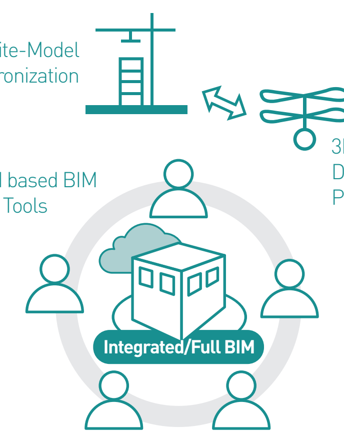
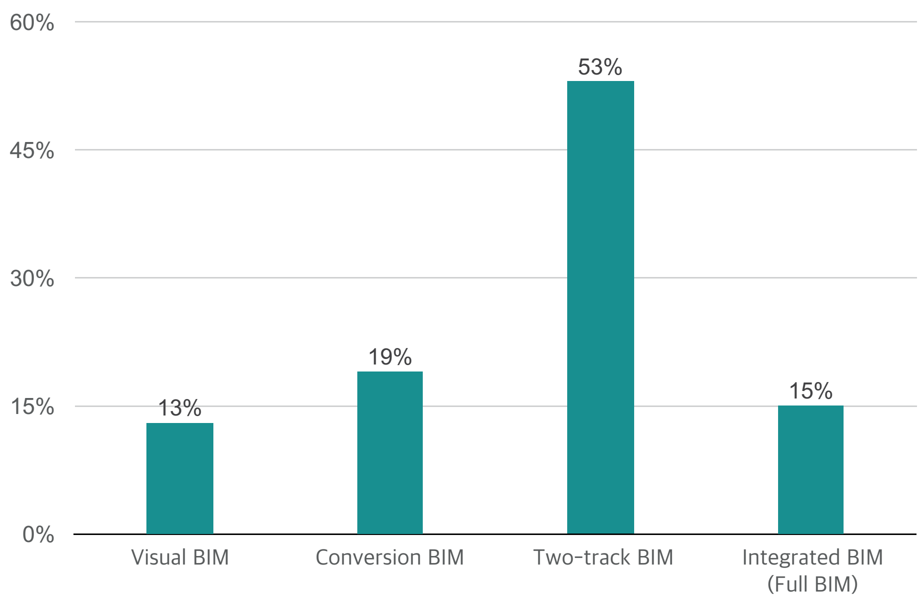


그림 5-4. BIM 3.0 통합BIM

The above timeline is based on the maturity level of the BIM-leading groups. Thus, the average BIM maturity level of an industry, specific domain, or organization may differ. According to the results of the BIM survey conducted by Yonsei University in 2016, 15% of the projects that were carried out by the respondents were integrated BIM projects. However, half the respondents (53%) were still conducting projects using the two-track BIM approach (Figure 5-5). Countries in Europe and Asia indicated similar tendencies.



Building Informatics Group (2016), The Korea BIM Survey 2016, Yonsei University, Seoul, Korea

Fig. 5-5 Distribution of BIM Projects in South Korea by Phase.

5.2. The Future of BIM

The construction industry's need to adopt the manufacturing and automation process is rapidly increasing due to the decrease in the working-age population, reduction of statutory working hours, and rising labor costs. Recently, a growing number of projects have deployed a construction method that produces certain construction components at a factory and assembles them onsite. This method is referred to as offsite construction, Design for Manufacture and Assembly (DfMA), or modular construction. Examples include a multi-trade, prefabricated mechanical, electrical, and plumbing (MEP) rack, and modular construction projects such as the ones conducted by Katerra, which was established in 2015 and selected as a unicorn company in two years. Many companies like ManufactOn also have a similar business model to Kattera. Although this manufacturing-based approach is not yet used by the entire industry, the number of projects that adopt similar approaches is increasing. 3D printing and construction automation are other technologies that are transforming the construction industry into more like the manufacturing industry.
As a technique for managing this new manufacturing-based construction production method, the industry is adopting a new lean construction management method combined with BIM. The lean-construction method was borrowed from the lean-manufacturing method, originally known as the Toyota Production System. Examples of lean construction supported by BIM include the KanBIM system, a lean-construction-based BIM project management system, and rebar production based on the just-in-time (JIT) construction method. The Integrated Digital Delivery (IDD), set by the BCA in Singapore is also based on BIM and DfMA. This report refers to this new phase of BIM as lean BIM (BIM 4.0). Since considerable applications are already in use, the lean BIM phase may become a generalized BIM practice in the 2020s among leading construction groups.

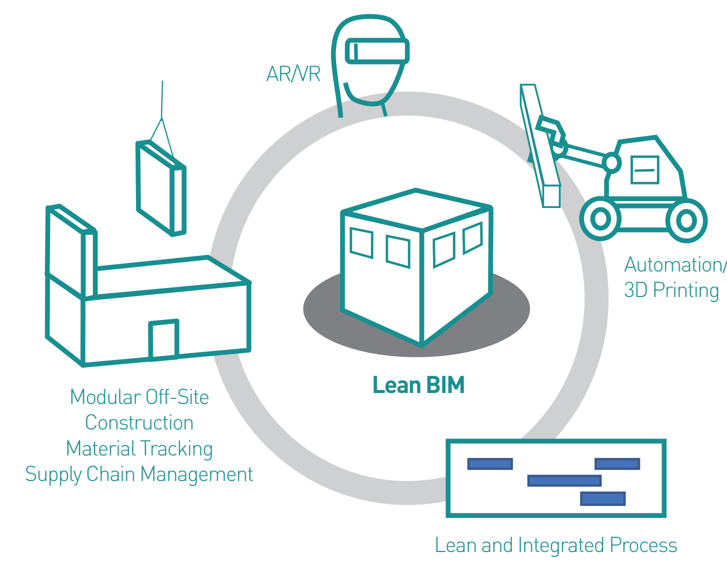


Fig. 5-6 BIM 4.0 Lean BIM.

Another trend in the construction industry, which is still in the exploratory phase, is the search for efficient and effective decision-making methods based on big data and artificial intelligence. Information is at the heart of BIM. Currently, little systematically collected information in the construction industry can be termed big data except for a few, such as energy and transportation data. However, as the BIM project grows, more high-quality data will be accumulated and further advances will be made in artificial intelligence, allowing for the possibility of informed decision-making. Additionally, this trend will grow from the current individual-facility level to a city level, expanding on a larger scale, such as smart cities, airports, seaports, and aerospace industries. Many of these technologies are still in the research phase, and some are already utilized. For example, the Seoul Metropolitan Government analyzed big traffic data to determine the operation of late-night buses, and analyzed population, land use, and cost data to find the right locations for welfare facilities. Other examples include analyzing CCTV videos onsite to detect workers who are not wearing a safety helmet using deep learning. Big data-based construction process and cost optimization are another example. This report refers to these technologies as intelligent BIM (BIM 5.0). They are also referred to as connected BIM or linked BIM because they are often based on a network of large databases and internet of things (IoT) technologies. Considering that research results require approximately ten years to become commercialized, intelligent BIM is expected to become a common technology among BIM leading companies in the 2030s.

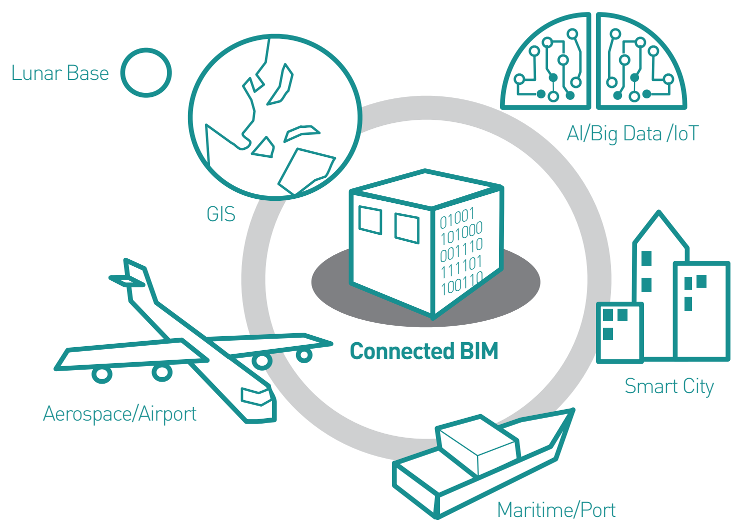


Fig. 5-7 BIM 5.0 Intelligent BIM.

5.3. The Maturity Level of BIM by the Information Utilization Level

The above can be summarized as shown in Figure 5–8. Currently, using two-track BIM is the most common, but the use of BIM 3.0, 4.0 and 5.0 is on the rise.

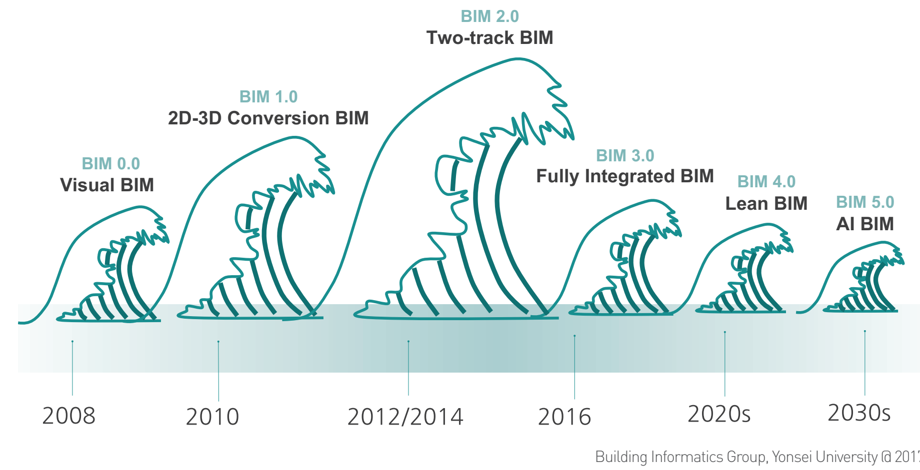


Fig. 5-8 The six waves of BIM.

The Maturity Level of BIM by the Information Utilization Level

BIM 0.0 – Visual BIM: BIM is utilized mainly for the creation of visual materials for public hearings, reports, marketing, and promotions (a.k.a. communication BIM or marketing BIM).

BIM 1.0 – (2D to 3D) Conversion BIM: The use of BIM focuses on the review of design errors through a 2D-to-3D design conversion process.

BIM 2.0 – Two-Track BIM: BIM is applied to parts of a project that are difficult to carry out using the existing 2D method. The remainder of the project is still carried out using the traditional 2D method (a.k.a. parallel BIM).

BIM 3.0 – (Fully) Integrated BIM: All main project participants use BIM throughout a project (a.k.a. full BIM).

BIM 4.0 – Lean BIM: Construction projects are carried out using the manufacturing approach, such as modular construction, lean construction, offsite construction, and construction automation (a.k.a. automation BIM).

BIM 5.0 – Intelligent BIM: Projects are carried out based on informed decision-making using big data and artificial intelligence (a.k.a. connected BIM or linked BIM).

5.4. The PPT Strategies to Achieve Each BIM Maturity Level

The most fundamental reason to strive for higher BIM maturity levels is that higher BIM maturity will return higher BIM benefits. Moving up the levels, however, is not easy.
In particular, visual BIM is sometimes criticized as BIM wash (superficial use of BIM) as the benefits are very low compared to the input costs. Yet, the visual BIM phase is an important step in the BIM adoption process. If one tries to skip this step to achieve high benefits without proper experience and knowledge about BIM, the project is likely to require more human resources, and higher financial and time costs than average, resulting in cost overrun, schedule delay, and, most of all, a strong resistance from project participants, making it very difficult to apply BIM to future projects.

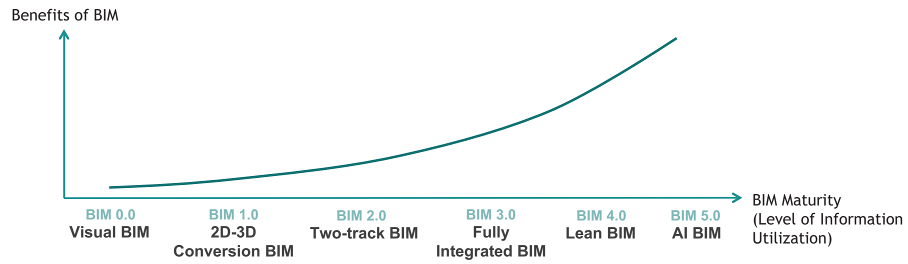


Fig. 5-9 The BIM Benefit-Maturity Graph.

The successful adoption of a new technology requires not only the technology, but also people and processes capable of using the technology. This concept is called the process, people, and technology (PPT) framework. The PPT framework has been widely used in technology adoption research and practice due to its simplicity. It has also been widely deployed in defining various BIM maturity models with minor variations. Some consider the diamond model (composed of technology, people, structure, and task) proposed by Professor Harold Leavitt in the 1960s as the origin of the PPT framework. Variations of the PPT framework include the TEO (technology, environment, organization) framework, and the PPTP (people, process, technology, policy) framework. The following describes the PPT strategies required to achieve each BIM maturity level.

BIM 0.0 Visual BIM

Visual BIM utilizes BIM for publicity, report generation, and public hearings. At least one person or a team of people who can develop a model is required. In terms of process, a modeler works in an isolated environment and does not require data exchange as far as they can receive drawings. The use of BIM in an isolated process is also referred to as shy BIM and isolated BIM. In terms of technology, knowledge of BIM authoring and rendering tools is the minimum requirement, as BIM is confined to modelling.

· PPT Elements for BIM 0.0 Visual BIM

PPT Element	Requirements
People	BIM modeler
Process	Isolated use of BIM by a single BIM modeler or modeling team for marketing purposes
Technology	BIM authoring tools

BIM 1.0 2D-to-3D Conversion BIM

In addition to a BIM modeler who can convert drawings to BIM models, the conversion BIM phase requires a BIM coordinator who can coordinate the interactions between various trades. The process consists of taking steps to convert drawings to BIM models to find errors, coordinate the errors, update drawings and designs reflecting the coordination results, and approve revisions. This process is continuously repeated until a design is finalized. Because both drawings and BIM models must be updated, the key to success is reducing the cycle time necessary for review, coordination, modification, and approval. Technically, in addition to BIM authoring tools, a model viewer and a model checker are required to assist with the BIM review process.

· PPT Elements for BIM 1.0 2D–3D Conversion BIM

PPT Element	Requirements
People	BIM modeler, BIM coordinator
Process	Design coordination among a limited number of team members
Technology	BIM authoring tools, BIM model checkers, BIM viewers

BIM 2.0 Two-Track BIM

The two-track BIM phase partially deploys BIM to address only challenging issues, such as getting geometry data for irregularly shaped facades, coordinating a heavily equipped ceiling, or engineering a complex design. All other areas are built using 2D drawings. To do this, in addition to BIM modelers and BIM coordinators, a BIM manager, who can carefully watch over this process, is required to coordinate the 2D drawing process and the BIM process. Procedurally, coordination between the actual work and designs in two forms, i.e., drawings and BIM models, further complicates the coordination and approval process. Also, the process of smoothly exchanging information between software applications becomes critical because the number of different software applications used during the process increases. Technically, knowledge about a variety of BIM analysis tools, detailing tools, and others is required, and interoperability skills are critical for exchanging information between the multiple software applications used in the project.

· PPT Elements for BIM 2.0 Two-Track BIM

PPT Element	Requirements
People	BIM modeler, BIM coordinator, BIM manager
Process	Increased importance of coordination between drawings and BIM models, Limited use of BIM for specific issues by specific teams
Technology	BIM analysis tools, Detailing tools, Interoperability

BIM 3.0 Integrated BIM

Since integrated BIM is carried out mainly using BIM, projects can be carried out very quickly and efficiently with no coordination with drawings. The premise is that all main project participants must be able to use BIM. Procedurally, collaboration between key players using BIM becomes critical. In addition to BIM modelers, BIM coordinators, and BIM managers, a BIM project manager who can oversee and coordinate the BIM utilization of all partners is required. Ideally, a project manager (e.g., a master architect or a site manager) can play the role of BIM project manager. However, if a project manager is not ready for this role, it is critical to find the right person and to grant the BIM project manager the proper authority and title necessary for conducting the role. Tasks of a BIM project manager include version control between different BIM models, synchronization between models and as-built site conditions, and coordination of information exchange and sharing. Using cloud-based BIM servers for managing and synchronizing different versions of the models is recommended. In the UK, these BIM servers are referred to as common data environments (CDE). Additionally, scan-to-BIM technologies, such as laser scanning and photogrammetry, are often used to synchronize as-built site conditions and BIM models. 4D simulation technology is also recommended; however, when 4D is used, it is critical to know how to update a 4D model in real time, reflecting the actual progress.

· PPT Elements for BIM 3.0 Integrated BIM

PPT Element	Requirements
People	BIM modeler, BIM coordinator, BIM manager, BIM project manager
Process	Increased importance of interoperability among BIM tools, version control, model synchronization, and collocated and collaborative work processes.
Technology	BIM servers, Field BIM tools, 3D Scanning and photogrammetry for model-site synchronization, 4D schedule management

BIM 4.0 Lean BIM

The lean BIM phase reduces reworking and delay, and increases construction efficiency and quality, by adopting the production management systems of the manufacturing industry. This transition from onsite construction to the manufacturing-oriented process involves professionals in lean construction, modular construction, and construction automation. In the case of Katerra, a representative example of the lean BIM approach, the board of directors consists of IT professionals as well as construction specialists. It is also important to establish processes that can help a project team immediately produce and assemble required parts as soon as an order is placed. Examples of such processes include lean construction, manufacture to order (MTO), and engineer to order (ETO). Examples of required technologies include integrated lean-based BIM management tools, construction automation control technologies, and an integrated ERP system that can manage resources integrally. Project managers who have sufficient knowledge to implement the concepts of lean construction and construction automation in their project are needed.

· PPT Elements for BIM 4.0 Lean BIM

PPT Element	Requirements
People	BIM modeler, BIM coordinator, BIM manager, BIM project manager, Lean specialist, Off-site/modular construction specialist, Construction automation specialist
Process	Based on lean management processes, such as the last planner system and other pull planning methods, Stresses manufacture-to-order (MTO) or engineer-to-order (ETO)
Technology	Integrated lean-based BIM management tools, Construction automation, 3D printing, Off-site construction, Modular construction, IDM/MVD for automated data exchange, VR/AR

BIM 5.0 Intelligent BIM

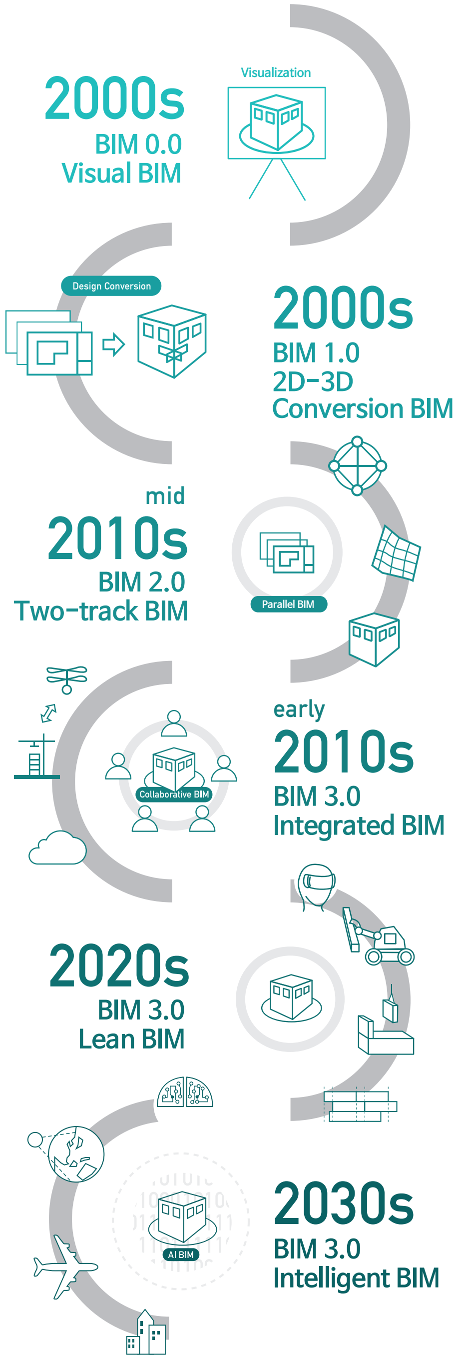
When big data is accumulated and AI technologies are sufficiently advanced, it will be possible to implement the ideal form of BIM—resolving problems based on informed decisions with the minimum of risks. For this, BIM data scientists in smart city, connected BIM, big data, Internet of Things (IoT), GIS, and AI are required throughout the project lifecycle. The required processes include an informed decision-making process; data-driven design, construction, and facility and asset management; automated data processing and exchange; and onsite and offsite construction automation. In this phase, required technologies include semantic knowledge and information exchange, BIM data science, big data, IoT-based manufacturing, IoT-based project and facility management, AI-based design and model quality inspection, construction automation, modular construction, and smart-city technologies. Additionally, various types of information specification technologies are required, such as IDM/MVD-based requirement specification and exchange including IDM/MVD-based LOD (level of development) specifications. (See http://idm.buildingsmart.org/ for more information on IDM.)

· PPT Elements for BIM 5.0 Intelligent BIM

PPT Element	Requirements
People	Minimize the role of the simple BIM modeler, BIM coordinator, BIM manager, BIM project manager, Lean specialist, Off-site/modular construction specialist, Construction automation specialist, BIM data scientist
Process	Data-driven decision-making processes, Data-driven design, construction, FM/AM, Automated data processing and exchange, Automated production for on-site and off-site construction
Technology	Semantic and intelligent information interfacing technologies, BIM data science (big data), IoT-based manufacturing, IoT-based project and facility management, AI-based design, engineering, and model quality checking, Construction automation, Modular construction, IDM/MVD for automated data exchange and information requirement checking, IDMs/MVDs at each LOD, Data science based on GIS and BIM, Integration of "Smart Cities" and BIM

The following figures summarize the BIM maturity level and the PPT elements required for each level of the information utilization discussed in this section.

5.5. The BIM 2030 Roadmap by Level of Information Utlization



2000s
BIM 0.0
Visual BIM

BIM mainly as a marketing and visualization tool.

2000s
BIM 1.0
2D-3D
Conversion BIM

BIM uses focusing on design review and coordination during design conversion from 2D to BIM.

mid
2010s
BIM 2.0
Two-track BIM

Parallel uses of drawings and BIM models in in drawing-led BIM projects. BIM is partially used for coordination and fabrication of geometrically challenging areas such as irregularly shaped façades or coordination of heavily equipped ceilings or complex engineering designs.

early
2010s
BIM 3.0
Integrated BIM

BIM-led projects, in which all main project participants create and use BIM models. Stresses the importance of collocation and collaboration.

2020s
BIM 3.0
Lean BIM

Use of BIM based on lean philosophy and integration between BIM and off-site construction. Stresses lean, modular off-site construction and automation.

2030s
BIM 3.0
Intelligent BIM

Extended use of BIM for urban, city, maritime, aerospace, and other large-scale projects. Extensive use of big data, Internet of Things (IoT), Geographic Information Systems (GIS), and artificial intelligence (AI) to enable "smart cities," "connected BIM," and informed decision making throughout the lifecycle of a project.

	Culture, Organization, Education PEOPLE	Policy, Infrastructure, Service, Outcome, Work Process PROCESS	Software, Hardware, Information TECHNOLOGY
2000s BIM 0.0 Visual BIM	BIM modeler	Isolated use of BIM by a single BIM modeler or modeling team for marketing purposes.	BIM authoring tools BM viewers
2000s BIM 1.0 2D-3D Conversion BIM	BIM modeler BIM coordinator	Design coordination between a limited number of team members.	BIM authoring tools BIM viewers BIM model checkers
mid 2010s BIM 2.0 Two-track BIM	BIM modeler BIM coordinator BIM manager	Increased importance of coordination between drawings and BIM models; limited use of BIM for specific issues by specific teams.	BIM analysis tools; Detailing tools; Interoperability
early 2010s BIM 3.0 Integrated BIM	BIM modeler BIM coordinator BIM manager BIM project manager	Increased importance of interoperability between BIM tools, version control, and model synchronization; Collocated and collaborative work processes.	Cloud-based tools BIM servers; Field BIM tools; 3D scanning and photogrammetry for model-site synchronization; Tight loop on 4D scheduling updates for scheduling
2020s BIM 3.0 Lean BIM	BIM modeler BIM coordinator BIM manager BIM project manager Lean specialist Off-site/modular construction specialist Construction automation specialist	Lean-based management processes, such as the last planner system and other pull planning methods; Manufacture-to-order (MTO) or engineer-to-order (ETO).	Integrated lean-based BIM management tools; Construction automation; 3D printing; Off-site construction; Material tracking and supply chain management; Modular construction; IDM/MVD for automated data exchange; VR/AR
2030s BIM 3.0 Intelligent BIM	BIM coordinator BIM manager BIM project manager Lean specialist Off-site/modular construction specialist Construction automation specialist BIM data scientist	Data-driven decision-making processes; Data-driven design, construction, and FM/AM; Automated data processing and exchange; Automated production for on-site and off-site construction.	Semantic and intelligent information; Interfacing technologies; BIM data science (big data); IoT-based FM; AI-based design, engineering, and model quality checking; IDM/MVD for information quality checking; Integration of "Smart Cities" and BIM

6. Rail BIM 2030 Roadmap: Adoption and Diffusion Strategies

6.1. Challenges of Railway Projects

BIM adoption fails or does not obtain the expected results because BIM adoption does not begin with awareness of the problems BIM is trying to solve. The purpose of BIM adoption should not be BIM adoption per se, but providing, through BIM, chances to identify and prevent problems while carrying out a project.
Table 6-1, below, provides examples of the challenges facing Korean railroad projects from the standpoints of owners, designers, engineers, and contractors, collected through a survey and advisory council meetings held in 2017. The Rail BIM 2030 Roadmap specifies how BIM can be applied and assists in solving such challenges with railway projects as the BIM maturity level increases.
As the BIM maturity level increases, technical knowledge for efficient decision-making and complex project management can be obtained through experience, but a prejudice against BIM, lack of manpower, and contractual and procedural issues will require additional resolution efforts. Also, new demands and challenges will continuously arise at each level. Thus, it is important to solve the problems at each level of the Rail BIM 2030 Roadmap with patience.

· Table 6-1. The Challenges of the Rail Industry

Challenges	Target Levels
A large number of stakeholders involved in coordination and decision making processes.	Rail BIM Levels 1, 2, 3
Perception about BIM being theoretical rather than practical.	Rail BIM Levels 1, 2, 3
Construction of multi-trade, highly difficult, and narrow areas with potential conflicts with temporary structures, obstacles, and existing facilities including bridges.	Rail BIM Levels 2, 3
Difficulty of monitoring and history-tracking of a large-scale project.	Rail BIM Levels 3
Transparency of construction costs.	Rail BIM Levels 3, 4
Efficient management of old rail facilities	Rail BIM Levels 4, 5
BIM-related contracting methods and work protocols	All Rail BIM Levels
BIM-capable personnel	All Rail BIM Levels

6.2. Differences Between the Existing BIM Roadmaps and the Rail BIM 2030 Roadmap

As described in Section 4.3, existing BIM roadmaps took several approaches. The most frequently used method is to broaden the scope of BIM application at each stage. For example, the scope of application can be expanded based on the total construction cost, the gross floor area, or the application areas of BIM. Another method is to increase the level of collaboration and information exchange. Another approach is to apply BIM throughout the lifecycle of a project, from design through construction to maintenance.
The variation of these approaches makes it difficult for users to clearly understand how to use BIM and what to do at each level. This Rail BIM 2030 Roadmap, developed based on the BIM 2030 Roadmap, provides users with a big picture of the goals they should achieve at each level of BIM adoption, and the BIM utilization method necessary for achieving these goals.
Although the rail industry is far beyond the other construction industries in full-scale BIM adoption with a strategic plan, the rail industry has already undertaken quite a few rail BIM projects. The knowledge and infrastructure gained through trial-and-error in previous rail BIM projects will help the rail industry to greatly reduce the BIM adoption time.

6.3 The Rail BIM 2030 Roadmap by Phase

The Rail BIM Roadmap provides practical strategies for solving the problems of railway construction projects using BIM. The strategy consists of two parts and a total of five phases. The first three phases are the introduction, growth, and maturity phases. Through these three phases, the Rail BIM Roadmap plans to achieve BIM levels 1.0 to 3.0. The subsequent 4 and 5 phases—the advancement phase and intelligent phase—will explore and prepare for future technologies. These two phases map to BIM levels 4.0 and 5.0. The roadmap begins in 2018 and aims to reach the 5th phase in 2030. The human resources, processes, and key technologies required for each step are specified based on the PPT framework.

The Rail BIM Level 1 (Introduction Phase: 2018–2020, Target: Conversion BIM)

BIM 1.0
2D-3D Conversion BIM

BIM Application Goals

2D-to-3D design conversion,
Public hearing using AR/VR,
Early design reviews
Design coordination,
GIS integration,
Feasibility analysis,

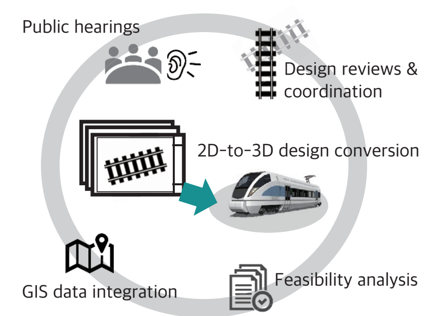


Fig. 6-1 Rail BIM Phase 1.

Since the Korean rail industry has undertaken several BIM projects, the rail BIM roadmap skips Level 0 Visual BIM and aims to achieve Level 1 2D-to-3D Conversion BIM from 2018 to 2020. The goal is to utilize BIM in planning, feasibility analysis, environmental impact analysis, project promotion, public hearings, early design reviews, and negotiations with a municipal government. BIM can be also used to facilitate communication both inside and outside the organization and among key project personnel.
Technically, BIM information can be fed into augmented reality (AR) and virtual reality (VR) for project promotion, public hearings, and design reviews and coordination. This phase will require BIM coordinators who can coordinate 2D to 3D conversions and design-review processes. Once the BIM models are developed from drawings, they can be overlapped with a cadastral model or a GIS model to review the design. Technically, BIM viewers and BIM model-checkers that can help project participants review and coordinate the plans can be deployed during the review and coordination process. Procedurally, at this level, the use of BIM and data exchange are limited to team members involved in the design coordination process. If done correctly, BIM may have a visible effect on increasing the design-decision effectiveness.

The Rail BIM Level 2 (Growth Phase: 2020–2022, Target: Two-Track BIM)

Phase 2
2020

BIM 2.0
Two-Track BIM

BIM Application Goals

Parallel use of BIM and drawings,
Environmental impact simulation,
Structural optimization,
Budget review,
Reduced social cost through public involvement,
Visualization of construction budget and process

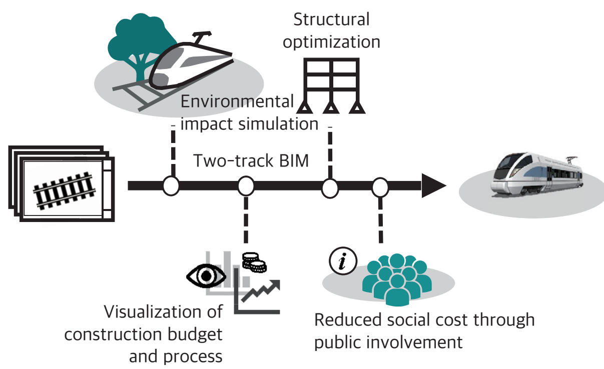


Fig. 6-2 Rail BIM Phase 2.

The goal is to begin the two-track BIM phase in 2020. The objectives of this phase are to use BIM for environmental impact analysis, design review, and to partially apply BIM to building areas with the challenging issues that cannot be easily resolved using the traditional 2D method. This phase also aims to reduce the social costs by proactively deploying BIM as a communication means. Another goal is to support cost and schedule planning and management by visualizing cost and schedule changes throughout the project.

In addition to a BIM coordination and a modeler, a BIM manager is required to conduct more complex coordination than in the previous phase. At this phase, the importance of coordination between drawings and BIM models increases because BIM is used selectively and both drawings and BIM models are used simultaneously in a project. Thus, a BIM manager must clearly understand the effectiveness of BIM application to determine where to apply BIM, and to manage any critical issues that arose during the BIM application.

Various BIM tools will be required to solve different types of engineering problems. Thus, interoperability will be a concern, as will the frequent data conversion and coordination between 2D drawings and BIM models. To resolve the information gap between 2D drawings and BIM models, tools that can help with automated data conversion or automated detailing may be used.

The Rail BIM Level 3 (Maturity Phase: 2022–2024, Target: Integrated BIM)

Phase 3
2022

BIM 3.0
Integrated BIM

BIM Application Goals

Collaboration and coordination between multiple trades,
ERP-linked QTO, Cloud based BIM tools,
3D scanning using drones, photogrammetry,
and laser scanning, Site-model synchronization,
BIM-based project management

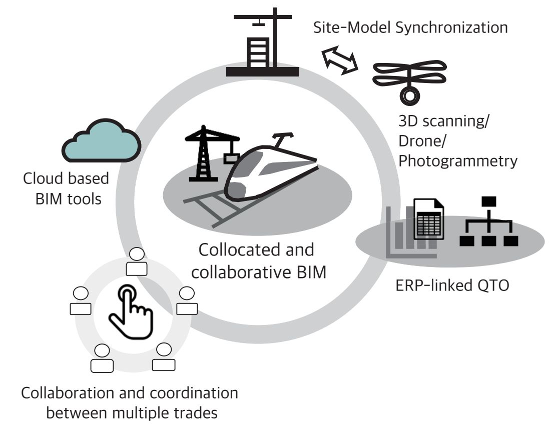


Fig. 6-3 Rail BIM Phase 3.

The third phase aims to begin in 2022. The objective is to enter the BIM level 3 Integrated BIM (or Full BIM) based on the experience accumulated from the previous two phases. This phase plans to use BIM to coordinate the construction areas where multiple trades interface, to conduct BIM-based quantity takeoff (5D BIM), and to link BIM data with the Korea Rail Network Authority's (KR) asset management system. BIM can facilitate coordination and collaboration among multi-trade tasks. In addition, an integrated BIM-based project management system links the quantity data such as cost data to the KR's existing enterprise resource planning (ERP) system, integrating and managing the project's cost, schedule, and site data.

At this stage, a BIM project manager is required. Integrated BIM is the first BIM-driven phase where all key participants of the project use BIM. Thus, a BIM project manager must be able to coordinate all the key participants of a project. The importance of coordination and interoperability between BIM tools, version control, and model-site synchronization also increases. Naturally, coordinated and collaborative work processes must be established. Key underlying technologies include cloud-based tools, BIM servers, BIM-based field management tools, photogrammetry for model-site synchronization, and 4D process management based on as-built conditions. These technologies have already been developed and commercialized, but there are still a room for improvement. However, by 2022, when the rail BIM enters its maturity phase, it is expected that these technologies will also have become mature.

The Rail BIM Level 4 (Advancement Phase: 2024–2030, Target: Lean BIM)

Phase 4
2024

BIM 4.0
Lean BIM

BIM Application Goals

Lean-based project management,
Real-time construction and facility management mobile, sensor, and VR/AR,
Modular construction, Off-site construction,
BIM-based supply chain management (SCM),
Construction automation

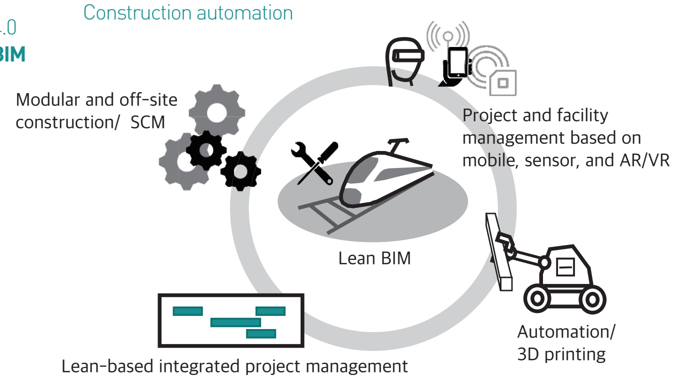


Fig. 6-4 Rail BIM Phase 4.

By 2024, BIM can be used in more advanced ways. The Level 4 Lean BIM phase aims to expand BIM to the operation and maintenance of rail facilities using various mobile sensors, and virtual reality and augmented reality (VR/AR) technologies. The lean method is a production management technique developed by the Toyota Motor Corporation, a leading Japanese automobile manufacturer, to eliminate overburden (muri), irregularity (mura), and waste (muda). The expected result is a reduction in production and delivery costs, wasted time, and project defects. Applying this method to the construction industry is called lean construction. Examples include lean-based project management, offsite construction, and modular construction. Various attempts to maximize the synergy between BIM and lean construction are already underway. Lean BIM is expected to become a general practice in the 2020s. Lean BIM will reduce uncertainty and make advanced information services available throughout the construction industry. Based on advanced information services, project and facility information will be managed and updated through the universal utilization of mobile devices, sensors, and VR and AR devices.
New personnel required for lean BIM include experts in lean construction, offsite construction, modular construction, and construction automation. During the lean BIM phase, the process will be significantly improved by applying pull planning methods such as the Last Planner System and the made-to-order (MTO) or the engineer-to-order (ETO) delivery methods. The pull planning method or the just-in-time (JIT) method aims to provide the exact amount of resources and products when and where necessary, avoiding the wait for resources during subsequent processes. Based on this method of production, custom production and custom design are possible without wasting resources.
The major technology required includes integrated lean BIM management tools. Also, systems must support construction automation, offsite construction, material tracking, and supply chain management. Construction automation technologies, such as 3D printing and construction robots, will be used not only in factories, but also onsite. Combined with such technologies, partial modular construction will become common. The diffusion of lean BIM will require innovation in data exchange, increasing the demand for information interoperability for automated data exchange.

The Rail BIM Level 5 (Intelligent Phase: 2030+, Target: Intelligent BIM)

Phase 5
2030+

BIM 5.0
Intelligent BIM

BIM Application Goals

Visual management of a rail network linked with other traffic information,
Informed decision based on BIM data science (big data),
Continuous collection and analysis of project maintenance data

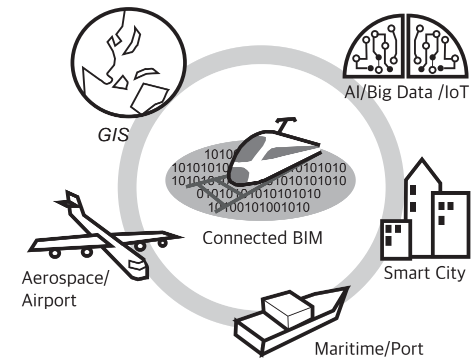
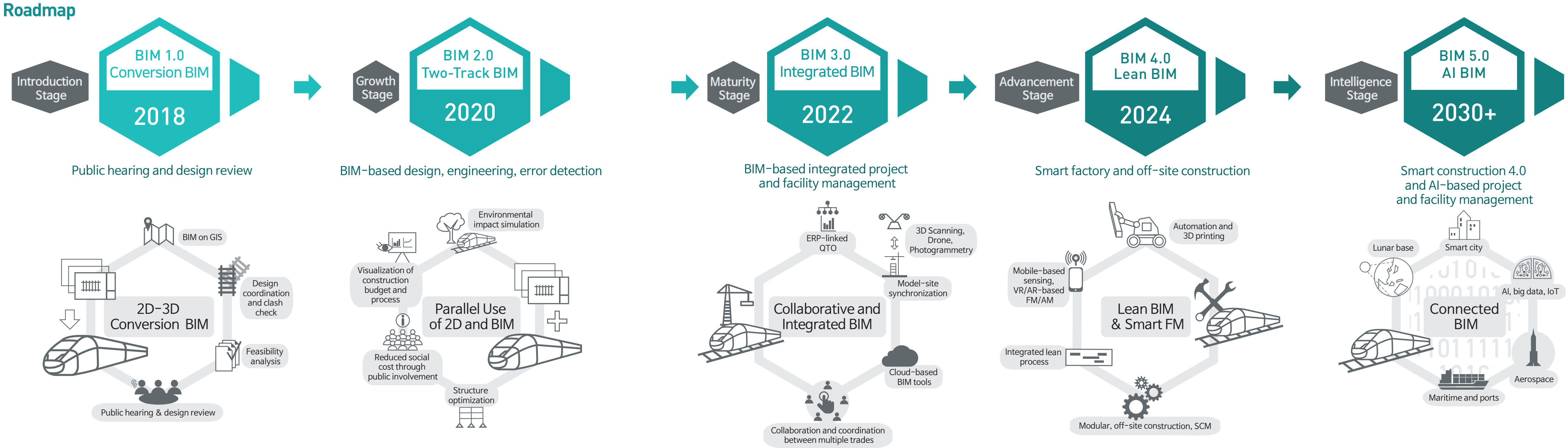


Fig. 6-5 Rail BIM Phase 5.

BIM Level 5 Intelligent BIM is intended to begin in 2030. As the 4th Industrial Revolution is realized, level 5 of rail BIM, led by AI, will integrate the rail BIM with other transportation systems, and strengthen the relationship between BIM and smart cities, and also between various types of BIM information, which will create the connected BIM environment. Rich information and advanced virtual simulation will create new project planning and management methods.
The goal of this phase is to make informed decisions based on BIM throughout the lifecycle of a project. Project and maintenance information will be continuously collected by technologies like IoT. The collected data will be processed to help project participants to make informed decisions using big data analysis and AI technologies. Big data is a data analysis technology that processes large sets of structured and unstructured data, such as images, speech, online documents, and videos, beyond the capabilities of traditional database management tools. Based on this analysis capability, railway networks can be managed visually in real time through the connections to other traffic information.
Key personnel necessary for intelligent BIM are BIM data scientists who can collect, process, and analyze information from design, construction, facility, and asset management activities. Informed decisions will be made based on the analysis results. Additionally, AI will be able to automate the data and exchange processes. Major technologies involved in this phase are big data processing and AI technologies that use data from BIM. AI will enable the automation of some design processes, as well as model quality checking. Onsite and offsite construction will be more tightly integrated and automated using IoT technologies. Modular construction will be generalized. IDM/MVD technologies for the interoperability of information and information requirement specifications will become advanced. Semantic knowledge will be exchanged more freely than ever. The interoperability of information and the sophistication of information sharing will break down the barriers to the full integration of various types of information, such as geographic information and smart city information.

Rail BIM 2030 Roadmap

6.4 Rail BIM 2030 Roadmap



		2018	2020	2022	2024	2030+
BIM Goals		**Procurement & Planning** • Communication between managers and project participants using BIM visualization tools • Application of AR/VR for design reviews or public hearings	**Design** • Application for environmental assessment • Design review and coordination, budget review **Expansion of BIM application** • Elimination of unnecessary social cost using visual information • Visualization/digitalization of construction plans and budgets	**Construction** • Coordination between multiple trades • Quantity takeoff data linked with an ERP system **Expansion of BIM application** • A BIM based total project management system for managing cost, progress, and field data	**Maintenance** • Application of mobile devices, sensors, and VR/AR technologies **Expansion of BIM application** • Real-time update of project construction and maintenance information • Lean-based off-site modular construction	**Expansion of application on whole life cycle of construction industry** • Big data, IoT, AI-technology-based decision-making • Continuous collection and analysis of projects, maintenance data • Visual management of a rail network linked with other traffic information
PEOPLE Culture Organization Education	**Company-wide level**	Company-wide BIM team	Monitoring, support, and management of multiple BIM projects	Continuous management of success and failure factors	BIM-based real-time project management during design, construction, and maintenance Lean-construction-based project management	A data science team that can run and use a decision support system to collect, maintain, and analyze big data
	Individual project manager level	Ability to manage the 2D to 3D conversion process Ability to handle BIM models	Ability to lead two-track BIM Design review using BIM	Ability to coordinate the multiple trade areas Quantity takeoff and progress management using a BIM model	BIM-based real-time project management during design, construction, and maintenance Lean-construction-based project management	Big data collection and analysis Big-data-based decision-making
PROCESS Policy Infrastructure Service & Reward Work Process	**Coordination process**	Design coordination between a limited number of team members	Increased importance of coordination between drawings and BIM models Limited use of BIM for specific issues by specific teams	Increased importance of interoperability of BIM tools, version control, and model synchronization; collocated and collaborative work process	Lean based management process, final scheduling system, and other pull-planning/scheduling system, manufacture-to-order (MTO) or engineer-to-order (ETO)	Data-driven decision-making processes, Data-driven design, construction, and FM/AM, Automated data processing and exchange, Automated production for on-site and off-site construction
	Tendering and management process	Application of existing tendering and project management methods	Little use of the lowest bid or the like Recommended use of services and CM at risk	Technology assessment system Personnel evaluation system	Use of tendering methods in which the owner can participate during the design and construction phases (e.g., IPD or the like) Tendering and management methods that can support off-site and modular construction	Contractor selection based on reliable quality, cost, time, and safety information, Risk prediction and management based on informed decision
TECHNOLOGY Software Hardware Information	**Fundamental technology**	BIM authoring tools BIM model checkers BIM viewers	BIM analysis tools Detailing tools Interoperability	Cloud based tools BIM servers, Field BIM tools 3D Scanning and photogrammetry for model-site synchronization Actual-progress-based 4D schedule management	Integrated lean-based BIM management tools, Construction automation 3D printing Off-site construction, Modular construction, IDM/MVD for automated data exchange, VR/AR	Semantic and intelligent information interfacing technologies, BIM data science (big data,) IoT-based manufacturing, project, and facility management AI-based design, engineering, and model quality checking, Construction automation, Modular construction, IDM/MVD for automated information requirements checking, Integration of "Smart Cities" and BIM
	Management technology	A system that enables project participants to share BIM models and error reports acquired through design conversion (e.g., CDE, Big Room System) A system that tracks and manages design errors	Coordination technology between 2D and BIM processes (e.g., 3D scanning, model version management)	Interoperability between various BIM software A change management system An integrated BIM and ERP system that can manage quantity takeoffs and progress	A company-wide system for monitoring and managing the progress and quality of projects A company-wide platform for lean-based railway construction progress management	A system that can collect and manage project information as big data A real-time decision support system based on big data

6.5 Requirements for Meeting BIM Level

BIM Maturity Level	BIM 1.0 2D–3D Conversion BIM	BIM 2.0 Two-Track BIM	BIM 3.0 Integrated BIM	BIM 4.0 Lean BIM	BIM 5.0 Intelligent BIM
PEOPLE	**[Company-wide level]** Does a permanent company-wide BIM team, which can procure, track, and manage BIM projects, exist? **[Individual project manager level]** Is the BIM project manager from the owner side capable of leading a decision-making process during design conversion? Can the owner-side BIM manager open, navigate, review, and screen-capture a BIM model from a model server?	**[Company-wide level]** Is the BIM team capable of monitoring, supporting, and managing the increased number of BIM projects? **[Individual project manager level]** Is the BIM project manager from the owner side capable of proactively reacting to any problems and leading two-track BIM from the owner's perspective? Can the project manager perform the initial design review using a BIM model?	**[Company-wide level]** Is the BIM team capable of continuously managing, sharing, and publicizing success and failure factors? **[Individual project manager level]** Is the BIM project manager from the owner's side capable of coordinating the multiple trade areas and conducting quantity takeoff and progress management using a BIM model?	**[Company-wide level]** Is the BIM team capable of real-time rail project management based on the lean-construction concepts? **[Individual project manager level]** Is the BIM project manager from the owner's side capable of BIM-based real-time rail project management based on lean construction concepts?	**[Company-wide level]** Is the BIM team capable of collecting and analyzing big data and making decisions based on the analysis results? **[Individual project manager level]** Is a BIM project manager from the owner's side capable of collecting and analyzing data from a construction site and utilizing the results to make informed decisions?
PROCESS	Do forms and a process exist to resolve issues raised during the design conversion process?	Does a process exist to determine when, how, and where to deploy BIM in a project? Does a process exist to coordinate 2D and BIM areas?	Does a process exist to exchange data between various BIM tools? Does a process exist to manage different versions of models and synchronize models with the site conditions? Does a process exist to coordinate multiple trades? Do a process and an information classification exist to integrate KR's ERP system and BIM models for efficient cost and schedule management?	Does a lean-based BIM rail-project management process exist? Does a process exist to manage projects and facilities based on lean construction in real time?	Does a process exist to automatically and continuously collect project data as big data and analyze them to help project participants make informed decisions before, during, and after a project?
TECHNOLOGY	Do the technologies and systems enable project participants to share the BIM model and error-check the report taken from converted design (e.g., CDE*, Big Room system**)? Does a system for detecting and managing design errors exist?	Does the company have technologies to coordinate tasks implemented by 2D and BIM, such as 3D scanning and model version management?	Can data be smoothly exchanged between various BIM tools? Can different versions of models be managed without confusion and synchronized with the latest status of the construction site? Does a total project management system that integrates a BIM model and ERP system for quantity takeoff and progress management exist?	Does a system for the real-time monitoring and management of quality and the construction progress exist? Does a company-wide platform to support lean-based railway construction progress exist?	Is there a system that can collect automatically and continuously project data as big data and analyze them to help project participants make informed decisions before, during, and after a project?

*CDE (Common Data Environment): CDE is a data server that allows project team members to share BIM data and models. It is more commonly known as a "BIM server."

** Big room system: The big room (also known as Obeya) is a working method proposed by Toyota rather than a technology. The big room approach forces all core project participants to work in one large space based on the premise that coordination and collaboration between team members and, thus, decision-making are facilitated when all core project team members work together in the same space (i.e., a collocated work environment).

6.6 The Rail BIM Cycle

Every project has its highs and lower. Best practices should be maintained, while the lessons from failures should be recorded and shared as future items for improvement, allowing subsequent projects to progress more effectively. The steps below describe the rail BIM cycle procedures for planning, performing, evaluating, and modifying BIM projects in seven stages:

Procedures for Carrying out BIM Projects

1. **Establish project objectives.** As BIM projects are also construction projects, focus on construction-specific objectives (e.g., reducing construction costs, reducing scheduling conflicts, improving safety) rather than BIM utilization.

2. **Set KPIs for each project objective.** Key performance indicators (KPI) must be set to evaluate if a project's goals have been achieved during and after a project. Examples of KPIs include planned vs. actual costs, the number of defects, and the number of safety-related accidents.

3. **Establish a BIM use plan by project objective.** Establish a specific and effective BIM use plan to achieve project goals. The parties involved in the bidding shall submit a BIM execution plan, which includes a plan to collect and evaluate KPIs during the project, as well as BIM use plans.

4. **Share BIM project goals and KPIs.** If the project goals are shared and the status of a project based on the KPIs is visible to all project participants through an open project dashboard, the project goals are more likely to be achieved.

5. **Assess achievement of the project goals.** When all the requirements for each BIM level are met, the team can proceed to the next level. If not, the same level should be retired based on the lessons learned from the previous projects.

6. **Report the results and share lessons.** The results and the lessons learned should be collected and shared through workshops involving the project participants.

7. **Update the BIM Guide.** Update the BIM guide based on best practices and lessons learned from the projects.

For more details and examples, see "How to tell if a BIM project is successful: a goal-driven approach."

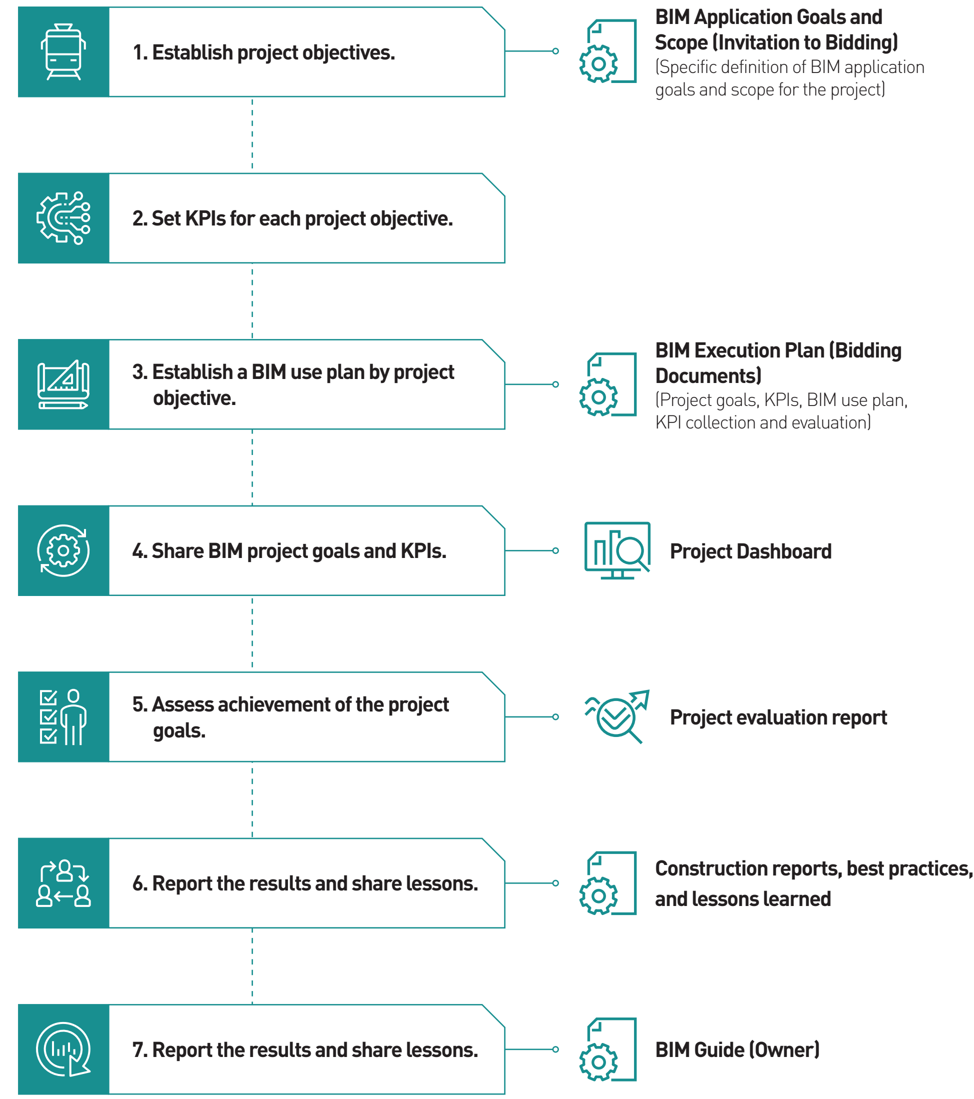


Fig. 6-8. The Rail BIM Cycle.

Won, J. and G. Lee (2016). "How to tell if a BIM project is successful: A goal-driven approach." Automation in Construction 69: 34-43.

7. Summary

This report presents the Rail BIM 2030 Roadmap as the first step in establishing a mid- to long-term strategy for the step-by-step adoption by the Korea Rail Network Authority of BIM in railway facilities. The status of BIM adoption in public construction projects, as well as in rail projects in Korea and major countries, was analyzed. The roadmap particularly focused on making it practical for owners. The Rail BIM 2030 Roadmap specifies the BIM information utilization plan for each phase from 2018 to 2030 according to five phases based on the PPT framework.

The BIM Level 1 Conversion BIM targeted for 2020 aims to deploy BIM in planning, feasibility analysis, environmental impact analysis, public hearings, and negotiation with municipal governments, mainly during the planning and design phases. The BIM Level 2 Two-Track BIM and Level 3 Integrated BIM aim to deploy BIM to coordinate multi-trade construction, BIM-based cost management, and asset management by 2024. After 2024, the roadmap aims to achieve more advanced levels—BIM Level 4 Lean BIM and Level 5 Intelligent BIM—by 2030. The roadmap also describes the rail BIM cycle and the qualification criteria for each phase.

A Rail BIM 2030 Roadmap was proposed based on the PPT Frame (PPT: People, Process, Technology). The Rail BIM 2030 Roadmap is intended for the adoption and diffusion of BIM from 2018 to 2030, with the aim of utilizing specific BIM information at each stage regarding people, processes, and technology. Based on the PPT framework, the technical maturity of the Rail BIM has been structured in five levels (BIM 1 to BIM 5).

The Rail BIM Roadmap, based on the PPT framework, was designed to start in 2018 and to reach the 5th phase of BIM maturity in 2030; the human resources, processes, and key technologies required for each stage are specified. In 2018, the Commission aims to achieve the first phase of BIM. The purpose of the project is to utilize BIM in an advance review, a preliminary feasibility study, an environmental impact assessment, and a state government consultation. From 2019 to 2020, the Commission aims to coordinate construction on a multi-interface section, conduct BIM-based estimates (a.k.a., 5D BIM), and link these estimates with the asset management system. As BIM applications reach a certain level by 2020, the goal is to gradually apply the more mature BIM levels 4 and 5.

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Rail **BIM 2030** Roadmap

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