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A FRAMEWORK OF BIM-BASED CONSTRUCTION PROJECT MONITORING SYSTEM FOR OWNER

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A Thesis Submitted in Partial Fulfillment of the Requirements

for the Degree of Master of Engineering Program in Civil Engineering

Department of Civil Engineering

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การติดตามความก้าวหน้าของโครงการก่อสร้างส่วนมากจะอาศัยการสื่อสารโดยใช้กระดาษซึ่งอาจนำไปสู่ความผิดพลาดหรือการขาดตกบกพร่อง อันเป็นสาเหตุของต้นทุนที่เพิ่มขึ้นและความล่าช้าของงาน การสร้างแบบจำลองสารสนเทศอาคาร (BIM) เป็นเทคโนโลยีสารสนเทศสมัยใหม่ซึ่งใช้โดยแพร่หลายในอุตสาหกรรมสถาปัตยกรรมศาสตร์ วิศวกรรมศาสตร์ และการก่อสร้าง (AEC) รวมถึงอุตสาหกรรมก่อสร้างในประเทศไทย BIM สามารถนำมาใช้งานในทุกขั้นตอนของโครงการก่อสร้างและเป็นประโยชน์แก่ทุกฝ่ายในโครงการ ผู้ที่ได้รับประโยชน์มากที่สุดจาก BIM คือ เจ้าของโครงการ ซึ่งสามารถนำสารสนเทศมาใช้ประโยชน์ตลอดวงจรชีวิตของโครงการ วิทยานิพนธ์นี้นำเสนอการพัฒนาและการนำระบบติดตามความก้าวหน้าโครงการก่อสร้างโดยอาศัย BIM มาใช้งาน กรอบแนวคิดของระบบที่นำเสนอถูกดัดแปลงมาจากระบบการติดตามโครงการทั่วไป แนวคิดต่าง ๆ เกี่ยวกับ BIM ถูกนำมาผนวกเพื่อสร้างระบบการติดตามที่มีประสิทธิภาพมากยิ่งขึ้น โครงการก่อสร้างอาคารสูงถูกนำมาใช้เพื่อแสดงการประยุกต์ใช้ระบบที่พัฒนาขึ้นจากมุมมองของเจ้าของโครงการ ซอฟต์แวร์ Autodesk Revit ถูกนำมาใช้เพื่อสร้างแบบจำลอง BIM ข้อมูลในแบบจำลองนี้ได้ถูกปรับให้สะท้อนความก้าวหน้าแท้จริงที่โครงการก่อสร้าง และถูกวิเคราะห์และรายงานโดยอาศัยซอฟต์แวร์ Microsoft Excel ระบบที่พัฒนาขึ้นนี้ให้ทางเลือกใหม่ที่มีประสิทธิภาพยิ่งขึ้นในการติดตามสถานะของโครงการก่อสร้าง

ภาควิชา	วิศวกรรมโยธา	ลายมือชื่อนิสิต	....
สาขาวิชา	วิศวกรรมโยธา	ลายมือชื่อ อ.ที่ปรึกษาวิทยานิพนธ์หลัก	....
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SOUKSAVATH LOSAVANH: A FRAMEWORK OF BIM-BASED CONSTRUCTION PROJECT MONITORING SYSTEM FOR OWNER. ADVISOR: ASSOC. PROF. VEERASAK LIKHITRUANGSILP, Ph.D., 107 pp.

Typical construction project monitoring relies on paper-based communications that are prone to errors and omissions, which often cause additional costs and delays. Building Information Modeling (BIM) is an advanced information technology that is widely adopted in the AEC industries, including the Thai construction industry. BIM can be implemented in every phase throughout a construction project and can benefit all participants in the project. The key beneficiary is the project owner who can exploit the information throughout the project life cycle. This thesis presents the development and implementation of a BIM-based system for monitoring construction projects. The framework of the proposed system is modified from typical project monitoring systems. BIM concepts were integrated to create a more efficient monitoring system. A high-rise building project was used to illustrate the application of the proposed system from the perspective of the project owner. Autodesk Revit was used for creating the BIM Model, the information in which was updated to reflect the actual work progress at the construction site, which was analyzed and reported by Microsoft Excel. This system provides an alternative approach that is more efficient to monitor the status of construction projects.

Department:	Civil Engineering	Student's Signature	....
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Finally, to all reader, due to my intention to present this research pervasively, please accept my sincere apologies for my English usage in this research and any misunderstanding, which may arise from English language.

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CHAPTER I

INTRODUCTION

1.1 Background

Information technology (IT) plays an important role in the modern Architecture, Engineering and Construction (AEC) industry in the last few decades. During year 2000 to 2010, there had been a large number of research papers related to IT in three main areas, namely, engineering, construction and building technology, and computer science (Xue, 2012). Most of the papers focused on the implementations of IT in civil engineering (70 papers, 84%) and construction and building technology (50 papers, 60%), as shown in Table 1.1.

Table 1.1 Distribution of the 83 IT papers in different research areas (Xue, 2012).

Subject area	Number of Papers	Percent (out of 83)
Engineering, civil	70	84
Construction and building technology	50	60
Engineering, industrial	15	18
Computer science, interdisciplinary applications	10	12
Computer science, artificial intelligence	9	11
Engineering, multidisciplinary	9	11

Among a variety of IT tools in the AEC industry, Building Information Modeling (BIM) has become the most vital tool that has a great impact on every construction project stakeholder, including project owner, designer, consultant, and contractor. The percentage of BIM usage increased from 28 percent in 2007 to 48 percent in 2009 (McGraw-Hill Construction, 2009).

An advantage of BIM is that all participants in construction projects can share and exchange electronic information throughout the construction project life cycle. This BIM concept is significantly different from the traditional method, which depends mainly on paper-based modes of communication. Errors and omissions in paper-based records often cause unanticipated field costs, delays, and potential lawsuits between different participants in the project. For the BIM approach, all necessary information is integrated into building models, which can then be shared among all relevant project members at the same time.

BIM encompasses development, use, and transfer of digital information models of a building project to improve the project design, construction and operation (Smith, 2009). BIM is defined as a digital representation of physical and functional characteristics of the facility (the National Building Information Modeling Standard Committee, 2007). BIM shares knowledge resources of information about a facility for forming a reliable basis for decision making during its lifecycle. It can be implemented in every phase throughout the project life cycle and can provide various benefits to all project members. In general, project owners have the most influence on the success of BIM implementation because they decide whether or not BIM will be adopted in the project. They can earn the benefits from BIM throughout the building life cycle, especially the operation phase. In addition, they and their representatives (e.g., construction management professionals) are the center of project information exchange for the other project participants. Efficient building information exchange can enhance building value, shorten project schedule, obtain reliable and accurate cost estimates, as well as minimize facility management and maintenance costs (Deutsch, 2011).

The Construction Industry Institute (CII) (2008) reported that for typical construction projects about one percent of the gross budget was spent on monitoring the status of construction activities. The traditional construction management approach, which mainly depends on paper-based modes of communication, contributes to errors and omissions in data recording, which subsequently causes unanticipated field expenses and delay. It was also reported that the field supervisory personnel on a construction site spent about 30 to 50% of their time for recording and analyzing field data (McCullouch 1997), and that 2% of the work on construction sites was devoted to manual tracking and recording work progress (Cheok et al. 2000). In addition, the accuracy of the collected data depends on judgment and writing skills of the data collectors (Liu 1995). Thus, it is necessary to introduce an alternative approach for monitoring the status of construction projects for the project owner by integrating BIM technology.

1.2 Research Objective

The main objective of this research is to develop a BIM-based construction monitoring system that can be used by project owners or their representatives (e.g. construction management professionals).

1.3 Research Scope

The proposed system was designed as a BIM-based computer program for monitoring the status of construction projects by project owners or their representatives. The application of the system was illustrated through a high-rise building project, Chamchuri 10 building, Chulalongkorn University, Bangkok, Thailand. The system was developed by using Autodesk Revit 2013 and Microsoft Excel 2010.

1.4 Research Methodology

Figure 1.1 shows the steps of conducting this research. As can be seen, literature review mainly focused on BIM implementation in different construction project management areas. Important components of the proposed system were then identified and structured, especially necessary information in each phase of construction. Based on the defined components and information, the system framework was developed in accordance with the construction phases. This preliminary system was then applied to an actual high-rise building project, Chamchuri 10 building, Chulalongkorn University. The feedback from implementing the system was reviewed and used to adjust and derive the final system. Detailed discussion of each step will be presented later in Chapters 3 to 5.

1.5 Research Outcome

The main outcome of this research is the framework (steps) for developing a BIM-based construction project monitoring system. The owner can adapt the proposed guideline for developing a BIM-based project monitoring system that is appropriate for its own construction project.

1.6 Research Contribution

This research presents a transformation from general BIM concepts to a computer-based system for construction project monitoring. Even though the proposed system is designed specifically for the owner's use, it can be modified for other parties to use for similar purposes such as for the contractor's cost control.

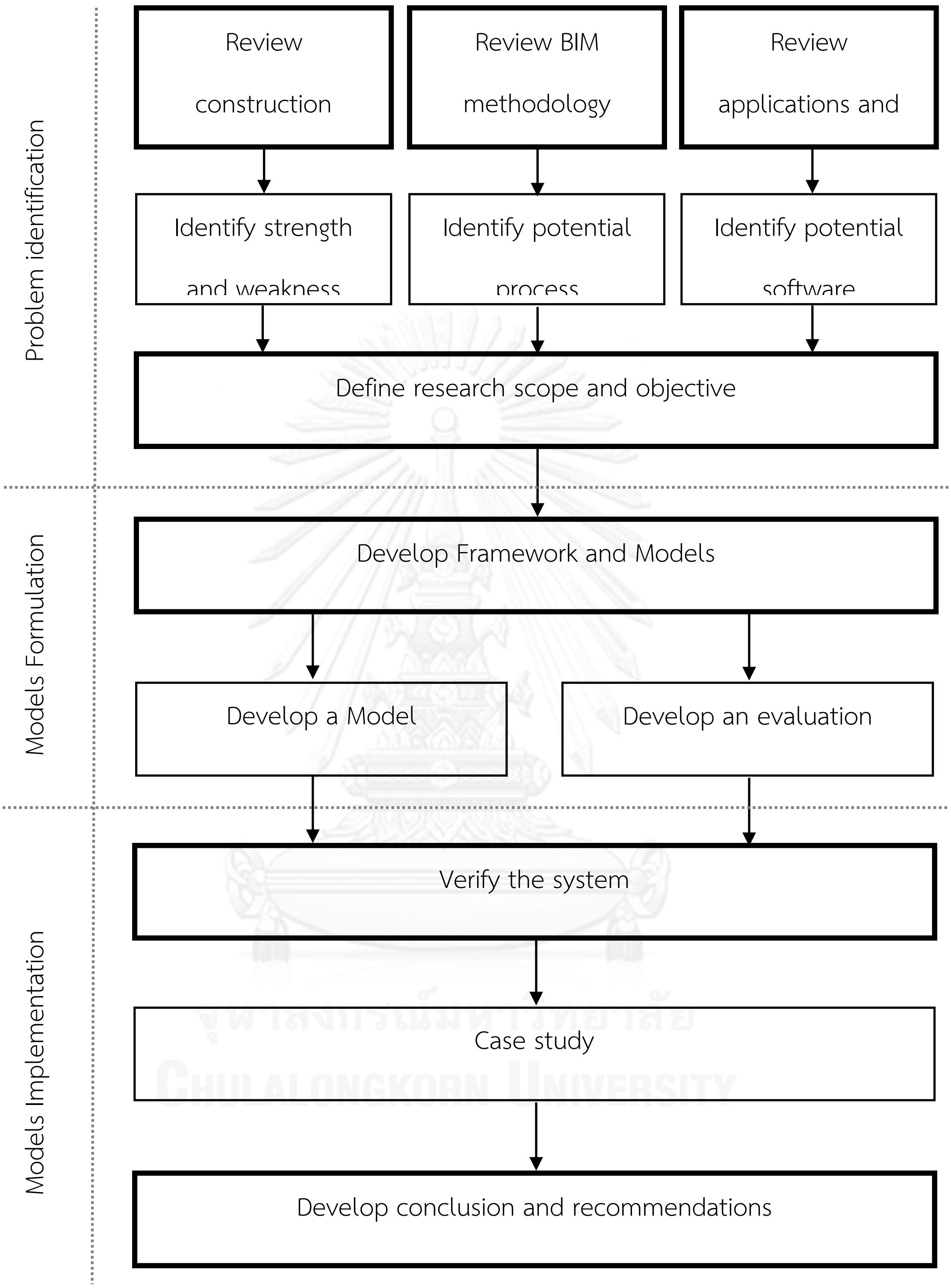


Figure 1.1 Steps of Research

CHAPTER II

LITERATURE REVIEW

This chapter presents a literature review on building information modeling (BIM). First, it discusses general concepts of BIM, including its definitions, applications of BIM in construction, and BIM participants in construction projects. It then reviews the BIM implementation by the owner and current applications of BIM in construction projects. Finally, it focuses on the construction project monitoring process.

2.1 Building Information Modeling (BIM)

2.1.1 Definitions

BIM is a process that focuses on the development, use, and transfer of digital information model of a building project, which can improve the design, construction and operation of a project or of facilities (Dana K, 2009). Figure 2.1 shows Building Information Modeling (BIM) Composition

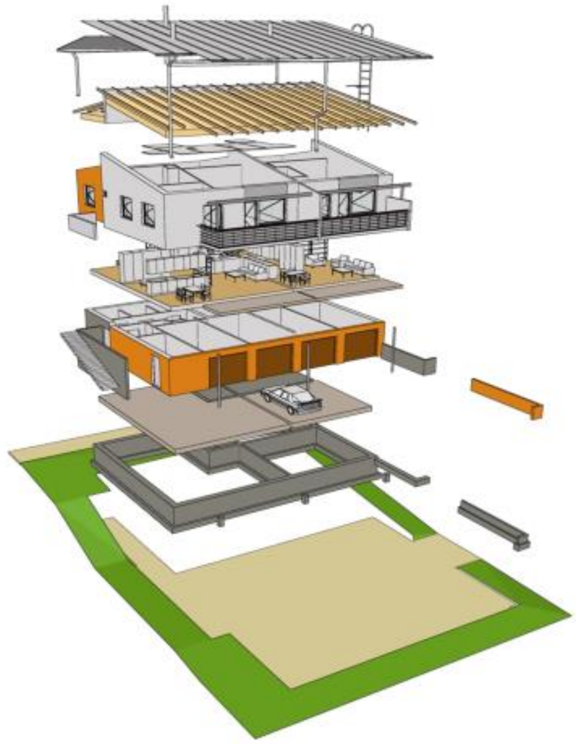


Figure 2.1 Building Information Modeling (BIM) Composition (Dana K, 2009)

The National Building information Modeling standard (2007) defined BIM as a digital representation of physical and functional characteristics of the facility. Which ranges from conception to demolition. A basic premise of BIM is a collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update, and modify information to support and reflect the roles of that stakeholder. BIM can be used for construction management in various purposes such as visualization, 3D coordination, prefabrication, construction planning and monitoring, cost estimating, and data recording. Figure 2.2 illustrates of BIM-Building life cycle.

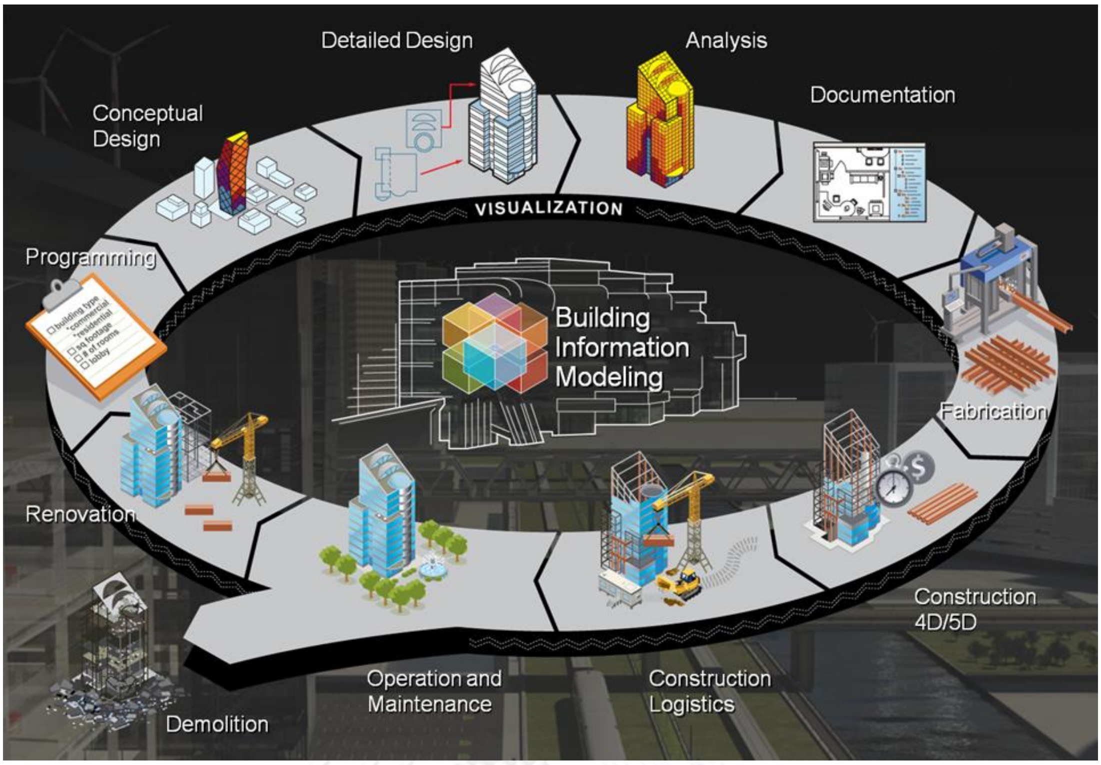


Figure 2.2 BIM-Building life cycle (Source: http://www.arquibim.es)

BIM was defined as a relatively recent switch in design and documentation methodology in the design and construction industries. BIM is information about the entire building and a complete set of design documents stored in an integrated database. All the information is parametric and thereby interconnected. Any changes to an object within the model are instantly reflected throughout the rest of the project in all views (Krygiel, 2008).

BIM is defined as the creation and use of coordinated, consistent, computable information about a building project in design parametric information used for design decision making, production of high-quality construction documents, prediction of building performance, cost estimating, and construction planning. AEC (UK) BIM

Standard for Autodesk Revit (2010) defined Building Information Modeling is data beyond graphics. The creation and use of coordinated, internally consistent, computable information about a building project in design and construction.

2.1.2 Building Information Modeling (BIM) values

BIM technology can support and improve many business practices which increasing pressures of greater complexity, faster development, improved sustainability while reducing the cost of the building and its subsequent use (BIM Handbook, 2011).

Building Information Modeling (BIM) is extensively recognized as a mature design methodology in the building industry, with high adoption rates by architects, engineers, and contractors. The application of BIM for Infrastructure is quickly accelerating as owners and engineering service providers progressively recognize the benefits of 3D modeling using smart objects. Implementing BIM on capital projects can provide benefits across planning, design, delivery, and operational areas. Access to coordinated and consistent model views by all stakeholders supports: Increased project control such as Improved coordination, clash detection and visual analysis, Mitigated cost and schedule risk with real-time assessment of project data and interdependences, Accelerated delivery using visual representations for approvals and stakeholder coordination, Greater accuracy of construction documentation and handover information, Better predictability with integrated schedule (4D) and cost (5D) information to support logistics and supply chain management. More efficient asset management such as Improved quality using analytical tools to help ensure compliance to engineering codes and safety standards, Potential to reduce post-construction rework and costs of operation supported by earlier project visibility and data continuity, link precise geometry associated with asset data to enterprise asset management and facilities management systems, simplify location and identification of built assets during inspection and maintenance activities, support facility assessments for renovation, rehabilitation, and replacement requirements. (Autodesk, 2012)

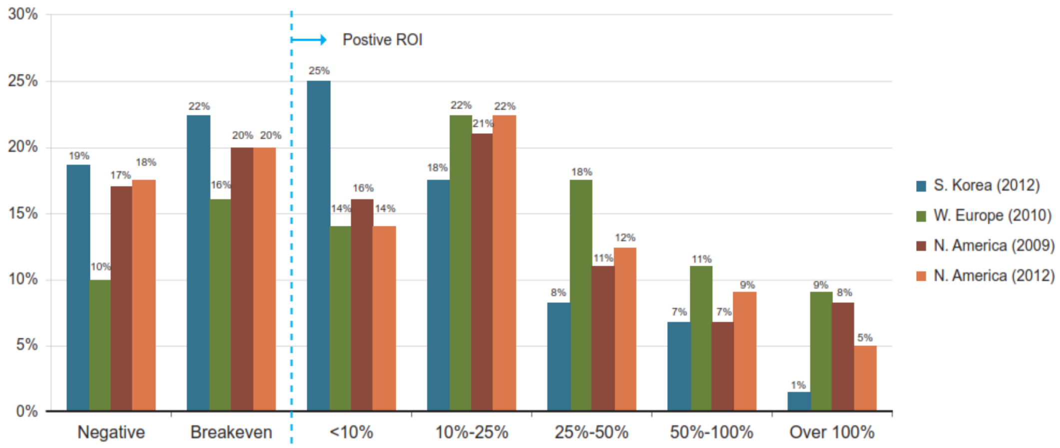


Figure 2.3 ROI on BIM (Source: McGraw-Hill Construction, 2013)

BIM is firmly entrenched in the building industry and expanded in the infrastructure industry, as recent studies conducted within the United States and Western Europe confirms. For example: Building industry overall. The 2009 McGraw-Hill Construction SmartMarket Report, The Business Value of BIM: Getting Building Information Modeling to the Bottom Line (2009 SmartMarket Report), states that nearly half of the U.S. building industry is using BIM, a 75 percent increase since 2007. According to the 2010 McGraw-Hill Construction SmartMarket Report, The Business

Value of BIM in Europe: Getting Building Information Modeling to the Bottom Line in the United Kingdom, France, and Germany (2010 SmartMarket Report on BIM in Europe), 36 percent of the industry in Western Europe has adopted BIM. Architects: The 2009 SmartMarket Report reports that six out of ten architects in the United States create BIM models, with half of those users also performing analysis on the models. According to the 2010 SmartMarket Report on BIM in Europe, in Western Europe 70 percent of architects that use BIM believe that it leads to better-designed projects. Engineers: The 2009 SmartMarket Report states that over the next two years, the use of BIM is expected to double by structural engineers, triple by mechanical, electrical, and plumbing (MEP) engineers, and quadruple by civil engineers. The 2010 SmartMarket Report on BIM in Europe states that in Western Europe nearly 70 percent of engineers report positive ROI and 62 percent found BIM to be of high or very high value during the construction phase. Contractors: According to the 2009 SmartMarket Report, the use of BIM among U.S. contractors has almost quadrupled in the past two years, with half of all contractors currently using BIM. The 2010 SmartMarket Report on BIM in Europe reports that 52 percent of contractors in Western Europe found BIM to be of high or very high value during the construction phase. Owners: Fully 70 percent of the U.S. owners surveyed by the 2009 SmartMarket Report reported a positive ROI from using BIM. In Western Europe, 65 percent of the owners surveyed report asking for BIM, according to the 2010 SmartMarket Report on BIM in Europe. (Autodesk, 2012)

2.1.3 BIM standard

There is no doubt that BIM adoption in the AEC industry has come a long way since the term was introduced in 2002—most of the larger firms are using BIM on many of their projects, and it has come part of the standard lexicon of the AEC industry.

Figure 2.4 BIM around the world (source: http://www.wspgroup.com)

Lachmi Khemlani (2012) report that In the Singapore, The main organization governing the construction industry in Singapore is the BCA (Building and Construction Authority). Singapore was one of the earliest countries to realize the potential of model-based design, and this was before the term BIM was even introduced. As early in the 1990s, Singapore had a CORENET project, which was a system for automatic code-checking a design. This, of course, could only be done for a building that was represented using a model rather than drawings.

In the meanwhile, BIM instead has taken off in Singapore, and the BCA has a roadmap for BIM that pushes its construction industry to be using BIM widely by 2015. While the BCA is not going so far as to mandate the blanket use of BIM on all building projects, it does have various strategies for promoting it as outlined in a roadmap. These include developing BIM submission templates to ease the transition for the industry from CAD to BIM—architectural and structural templates were introduced in

2010, while the M&E template was introduced on April last year. In collaboration with buildingSMART Singapore, BCA is developing a library of building and design objects, as well as project collaboration guidelines. To incentivize early BIM adopters, it introduced an S$6-million BIM Fund in June 2010 to covers costs on training, consultancy, software, and hardware. An important part of the roadmap is also to encourage Singapore universities to offer courses of BIM, and organize BIM workshops and seminars regularly. While there was surprisingly no mention of CORENET in BCA's roadmap, it does call for mandatory regulatory submissions using BIM starting in 2013. The BCA is also working with Singapore's public sector agencies to specify BIM requirements for all new public sector building projects.

Lachmi Khemlani (2012) report that In the China operates upon a series of five-year plans, each of which lists the social and economic development initiatives that are considered most critical for the development of the country during that time period. The first plan period was from 1953 to 1957; the eleventh ran from 2006 to 2010. Thus, we are currently in the middle of the twelfth five-year plan period, which runs from 2011 to 2015. While the plan lists several initiatives to rebalance China's economy, shift development from urban and coastal areas toward rural and inland areas, enhance environmental protection, and accelerate openness and reform, one of the key construction-related initiatives in China's twelfth five-year plan is energy-efficient buildings, which ties in with the overall goal of sustainability. This, in turn, is absolutely critical to China, given that it has the world's largest population and its economy is developing rapidly, putting a severe strain on its existing finite resources.

Lachmi Khemlani (2012) report that In the UK, In contrast to most countries, the UK Government has actually mandated the use of BIM. In May 2011, the UK Cabinet Office published a "Government Construction Strategy" document that has an entire section on "Building Information Modelling," within which it specifies that Government will require fully collaborative 3D BIM as a minimum by 2016. The document also acknowledges that the lack of compatible systems, standards and protocols, and the differing requirements of clients and lead designers, have inhibited widespread adoption of BIM, a technology which has the capacity to ensure that all team members are working from the same data. Therefore, the government will also focus on developing the standards that will enable all members of the supply chain to work collaboratively through BIM.

This government mandate for the use of BIM is supported by an AEC (UK) BIM Standard Committee that has released the AEC (UK) BIM Standard (in Nov 2009), the AEC (UK) BIM Standard for Revit (in June 2010), and the AEC (UK) BIM Standard for Bentley Products (in Sep 2011). It is working on similar standards for other BIM applications such as ArchiCAD and Vectorworks, as well as updated versions of the standards that have already been published. All these standards aim to provide practical protocols and procedures to AEC firms in the UK for transitioning from CAD to BIM; for example, what to name models, what to name objects, modeling of individual components, data exchange with other applications or disciplines, and so on. The product-specific standards are intended to interpret and expand the concepts in the generic standards with specific reference to that particular BIM application, for example, using worksets, linked models, families, parameters, and so on in Revit. The committee members writing these standards include AEC professionals that are using

BIM in their day-to-day work, so the standards are not simply theoretical but can actually be applied when implementing BIM.

AEC firms in the UK are already quite advanced in their BIM implementation, with London being home to many of the leading firms in the world such as Foster and Partners, Zaha Hadid Architects, BDP, and ArupSport, as well as the European headquarters of firms such as HOK, SOM, and Gensler, all of which are well known for their cutting-edge use of AEC technology. In such a milieu, a government-issued mandate for BIM can only thrive and bring the rest of the AEC firms in the UK more rapidly up to speed compared to the average AEC firm located elsewhere in the world.

Lachmi Khemlani (2012) report that In the US, the official use of BIM is synonymous with the GSA's BIM initiatives. The GSA (General Services Administration) is responsible for the construction and operation of all federal facilities in the US, and in 2003, it established a National 3D-4D-BIM program through the Office of the Chief Architect of its Public Buildings Service. Thus, the GSA is not only endorsing BIM, but also the application of 3D and 4D technologies as a transition from 2D technologies. It recognizes that a 3D geometric representation is only part of the BIM concept, and not all 3D models (for example, those created in 3D modeling applications like form.Z, 3dsMax, and even SketchUp) qualify as BIM models. Yet, even 3D models are much better at communicating design concepts than 2D drawings, so if BIM cannot be implemented on a project, at least 3D modeling technologies should be used on it. 4D is where the added dimension of time is added to a 3D model, which is most useful for construction sequencing and scheduling. A 4D model can be created from any 3D model—it does not have to be a BIM model. Thus, the GSA is taking a more pragmatic approach to its building projects, recognizing that it may not be able to commission firms that are BIM experts for all of them, so it is encouraging the use of 3D and 4D technologies that are at least more advanced than drawing-based 2D technologies.

The GSA, however, has mandated the use of BIM for spatial program validation to be submitted prior to final concept presentation on all its projects starting from 2007. This allows the GSA design teams to validate spatial program requirements such as required spaces, areas, efficiency ratios, and so on more accurately and quickly than traditional 2D approaches. As it owns over 300 million square feet of space, this concept design stage validation helps the GSA to better manage it over the long term. The GSA has provided more details about how to create this Spatial Program Validation BIM for its projects in a special Guide that is available on its website. This is one of a series of guides that the GSA has made available for different aspects of its 3D-4D-BIM program such as laser scanning, energy performance, circulation, facility management, and so on.

In the US, the GSA is a very active presence in AEC technology conferences such as the AIA-TAP, and its projects are frequently nominated in the annual AIA-BIM Awards. Therefore, its strong advocacy of BIM is bound to influence the entire AEC industry in the US and enhance its overall technology adoption.

Recently, several AEC technology vendors including Graphisoft, Tekla, Nemetschek, and Vectorworks came together to launch an “OpenBIM” initiative under the aegis of BuildingSmart, which would allow their applications to exchange data even more seamlessly with each other. At the moment, the initiative seems to be more about marketing than any real technological development, but it is worthwhile keeping an eye on it and seeing if it yields any additional benefits over and above what the IFC currently provides. (Lachmi Khemlani, 2013).

2.2 Building information modeling in construction

BIM is one of the most promising AEC industries. Building information modeling comes to be concerned issue of the construction project stakeholders as owner, designer, consultant, contractor and facilitator. (McGraw Hill, 2009) reported that in year 2007 percent of usage BIM equal 28%, year 2009 48% the number is showing of the tendency of AEC industry.

Overall Adoption of BIM has increased from 17% in 2007 to 71% in 2012– 45% growth over the last 3 years; Over 400% growth over last 5 years.

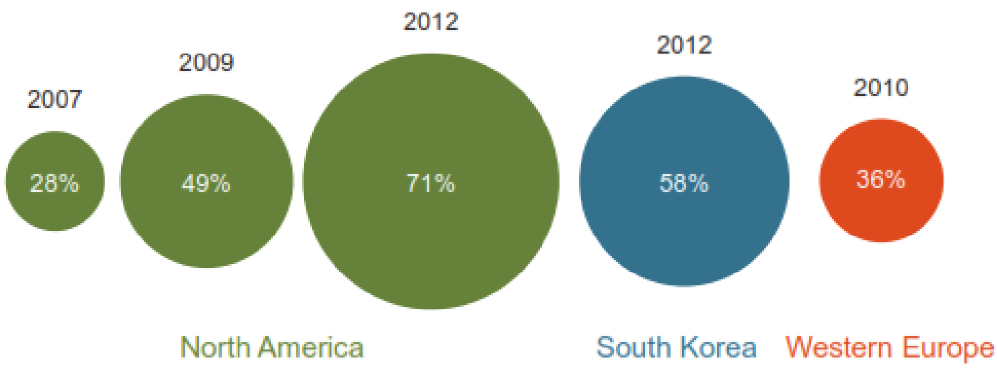


Figure 2.5 Overall Adoption of BIM (Source: McGraw-Hill Construction, 2013)

Building Information Modeling (BIM) is rapidly reforming the way of construction project team work together. Building Information Modeling is processed to successful in construction project so that implement BIM to construction project is depended on Organization as policy, budget, and leader. BIM is increased productivity and improve the final project outcomes (cost, time, quality, safety, functionality, maintainability, etc.) For all the parties involved.

Project controlling, the construction planning involves the scheduling and sequencing of the model to coordinate virtual construction in time and space. The schedule of the anticipated construction progress can be integrated to a virtual construction. The utilization of scheduling introduces time as the 4thdimension (4D).

There are two common scheduling methods that can be used to create 4D Building Information Model. These are critical path method (CPM) and line of balance. In the Critical Path Method, each activity is listed, linked to another activity, and assigned durations. Interdependency of an activity is added as either predecessors or successors to another activity. Moreover, the duration of the activities are entered. Based on the dependency and duration of the activities, the longest path is defined as the most critical path. The activities defined in the longest path are defined as the critical activities. These activities do not have any float. In other words, if these activities are not completed within anticipated duration, the total duration of the project will be further pushed out. Overall CPM is a commonly used technique that helps projects stay within schedule.

Line of Balance technique uses location as the basis for scheduling. This method is an alternate to the CPM. It is advantageous for repetitive tasks to increase labor productivity. In this method, activity durations are based on the available crew size and the sequence of the location. Productivity of the labor force can be altered as needed to accurately depict the construction schedule. The approach focuses on the locations being completed by a trade before the other trade moves in. This reduces the number of mobilizations and resources. Overall, line of balance is a good scheduling method to plan and monitor repetitive tasks during construction progress. (Kenley, 2010)

The planning through using BIM enhances site utilization, space coordination, and product information. A 4D model can either include a site logistics plan or tools such as SMARTBOARD on top of a virtual construction can be utilized to visually depict the space utilization of the job site. The model must include temporary components such as cranes, trucks, fencing etc. Traffic access routes for trucks, cranes, lifts, excavators, etc. need to be incorporated into the BIM as part of the logistics plan. Moreover, the site utilization consists of lay down areas, site work progress, and location of trailers and equipment and hoist assembly. Similarly, when the building is being closed in, the space coordination must be managed for the roughing and eventually finishing activities.

Visualizations, Building Information Modeling (BIM) is a great visualization tool. It provides a three dimensional virtual representation of the building. During the bidding phase of the project, the construction manager can provide renderings, walkthroughs, and sequencing of the model to better communicate the BIM concept in 3D.

Visualization provides a better understanding of what the final product may look like. It takes away thought process of bringing the different traditional 2D views together to come up with the 3D view of a detail. Furthermore, virtual mock-ups such as laboratories or building envelope can be provided to the designer and the owner. This would help to visualize, better understand, and make decisions on the aesthetics and the functionality of the space. As depicted in figure 5 and presented in the BIM Forum Conference in San Diego, virtual mock ups can be used to review 3D shop drawing of the building envelope (Khemlani, 2011). The virtual mock ups help to communicate and collaborate among the project participants. It promotes planning, and sequencing the curtain wall construction. Even though a virtual mock up is cost efficient in comparison to a physical mock-up, a physical mock-up may still be required if a member such as casework drawer or an assembly of the building such as a curtain wall need to go through a series of physical tests. Hence, virtual mock-ups could become a good standard to initiate the mock up process and an actual mock-up may be necessary after the virtual mock up is approved.

2.3 Building Information Modeling (BIM) Applications

Due to the complexity of gathering all the relevant information when working with BIM on a building project some companies have published architectural and planning software designed specifically to work in a BIM framework. These packages differ from the standard architectural tools such as AutoCAD and VectorWorks by allowing for the addition of intelligent information to the building model. Some examples of BIM Software include Autodesk Revit and Schematic Ltd's AutoScheme. The creation of BIM software was facilitated by the creation of Industry Foundation Classes which enabled programmers to represent BIM elements in a software language.

Table 2.1 Current Commercial Application Software

Current Commercial Application Software		
Organizations	Product	Websites
Autodesk, Inc	AutoCAD MEP	www.autodesk.com
	AutoCAD MEP Revit MEP	www.autodesk.com/autocadmep
	Autodesk NavisWorks Manage	www.autodesk.com/revitmep
	Autodesk Green Building Studio	www.autodesk.com/greenbuildingstudio
	Autodesk Ecotect	www.autodesk.com/ecotect
	Autodesk Buzzsaw	www.autodesk.com/buzzsaw
	Autodesk Constructware	www.autodesk.com/constructwar
Bentley Solutions	MicroStation	www.bentley.com
	Bentley Architecture	
	Bentley Building Mechanical Systems	
	AutoPipe	
	AutoPlant	
	Bentley Buidling Electrical Systems	
	Hevacomp M&E Designer V8i	
	Hevacomp Simulator V8i	
	Bentley Tas Simulator V8i	
	Bentley Tas Ambiens CFD	

Table 2.2 Current Commercial Application Software (Continue)

Bentley Systems	Architecture	www.bentley.com
	Structural	
	Civil	
	Mechanical	
	Electrical	
	Piping	
	Instrumentation and Wiring	
	HVAC	
	Geospatial (GIS) and Facilities	
Granlund	RIUSKA Integrated Building Solutions	www.granlund.fi
Graphisoft	ArchiCAD	www.graphisoft.com
Wrightsoft	Right-Suite Universal	www.wrightsoft.com

Table 2.3 Current Viewing Management Software

Current Viewing Management Software		
Organizations	Product	Web Site
Bentley Systems Collaboration	ProjectWise Navigator	http://www.bentley.com/en-US/Products/Bentley+Navigator/
Progman Oy	MagiCAD	www.progman.fi
Navisworks	Jetstream 3-D (Open Protocol Management)	www.navisworks.com
Nemetschek	Integrated IT Solutions	www.nemetschek.com
Newforma	Project Viewing and Mangement	www.newforma.com
Solibri	IFC Optimizer – Data Storage and Transmission All Plan IFC	www.solibri.com

Table 2.4 Current Related Construction Management Software

Current Related Construction Management Software		
Organizations	Product	Web Site
Autodesk	Buzzsaw	www.autodesk.com
Bentley Systems	Project Wise	www.bentley.com
E-Builder	Web Based Project Management	www.e-builder.net
Newforma	Newforma	www.newforma.com
Primavera	Project Management	www.primavera.com

Table 2.5 Other Technology/Schema

Other Technology/Schema		
Organizations	Product	Web Site
Ansys	CFX5 Computational Fluid Dynamic Software for Airflow Simulation	www.ansys.com
Cyra Technologies	Laser Scanning	www.cyra.com
Disco Systems	Laser Scanning USD-M2	www.usdm2.co.uk
Leica Geosystems HDS	Laser Scanning of Site Systems	www.leica-geosystems.com

Table 2.6 BIM-aware Downstream Applications

BIM-aware Downstream Applications		
Organizations	Product	Web Site
Carrier	HAP	www.commercial.carrier.com
Elite	Chvac	www.elitesoft.com
Energy Design Resources	eQuest	www.energydesignresources.com
Trane	TRACE 700	www.trane.com
Wrightsoft	Right-Suite Universal	www.wrightsoft.com

2.4 Conclusion

This chapter is describe about building information modeling (BIM) that is advantageous in the AEC industry. BIM can be implemented in any phases throughout a project, and it can deliver many benefits to all participants in the project. The key participant is the owner because the owner needs to use BIM throughout the building life cycle and it is the central of project information exchange.

CHAPTER III

RESEARCH METHODOLOGY

This chapter presents the methodology used in this research. It discusses the development of a BIM-based construction monitoring system for the construction projects, which was designed primarily for project owners. This chapter consists of three main parts. The first part illustrates the steps of research works. The second part concerns construction information identification and categorization. The final part outlines the framework of the proposed BIM-based construction project monitoring system.

3.1 Steps of research

The steps of this research can be divided into six major steps, as shown in Figure 3.1. The relevant literature was first reviewed by primarily focusing on the application and implementation of BIM in building projects. Important requirements and necessary building information for the owner's project monitoring were identified and used to structure a preliminary framework of the proposed system. To verify the practicality of the system, the preliminary system was applied to an actual high-rise building project, Chamchuri 10 Building of Chulalongkorn University. The framework was then revised in accordance with the feedbacks and suggestions by the experts and users to derive the final framework of the system. Detailed discussions on each step are as follows.

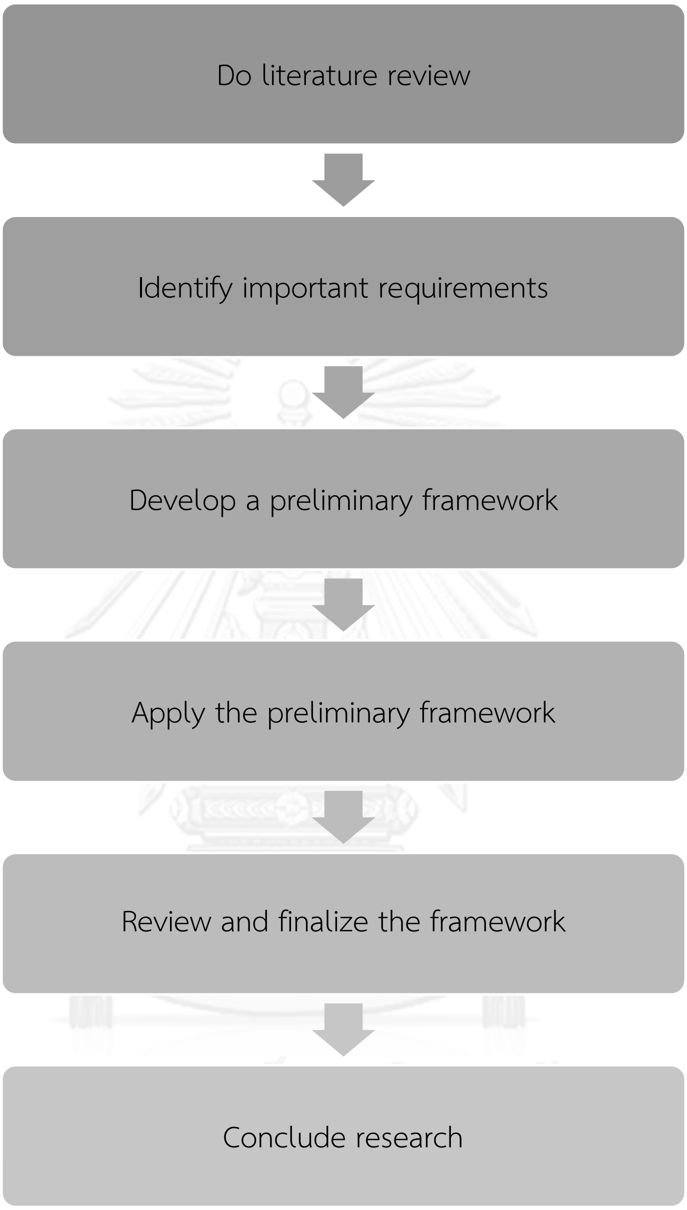


Figure 3.1 Steps of research

3.1.1 Do literature review

Several types of literature were examined, including academic papers, textbooks, reports, and magazines. The review focused on BIM and construction monitoring to appreciate BIM definitions, BIM values, and challenges in construction project monitoring. Finally, gaps in this research area were identified.

3.1.2 Identify important requirements

The second step is to identify important requirements of applying BIM for monitoring construction projects. The requirements include information and tools that are necessary for developing a preliminary framework of the proposed system. These requirements were derived from relevant literature and interviews with the owner's representatives (i.e., construction management professions).

3.1.3 Develop a preliminary framework

In this step, a preliminary framework of the system was created based on the requirements identified in the previous step. Briefly, the framework consists of two stages and four parts.

3.1.4 Apply the preliminary framework

The preliminary framework developed in the previous step was applied to monitor the progress of an actual high-rise building project, Chamchuri 10. The system was implemented in structural works of floors, beams, and columns between floor 12 and floor 17.

3.1.5 Review and finalize the framework

The feedbacks and observations from implementing the preliminary framework in the previous step were integrated for modifying and finalizing the system. The revised system was reapplied to the project to check its practicality.

3.1.6 Conclude research

In this step, the final framework of the proposed system was concluded and the thesis was prepared.

CHAPTER IV

FRAMEWORK OF BIM-BASED PROJECT MONITORING SYSTEM

4.1 Construction Information

The entire construction project's life cycle can be divided into three stages: pre-construction, construction, and post-construction. The pre-construction stage consists of the programming phase, the conceptual design phase, and the documentary phase. In this stage, the project owner has to clarify information that should be included into BIM models. This information can be represented by multiple layers, as shown in Figures 4.1 and 4.2.

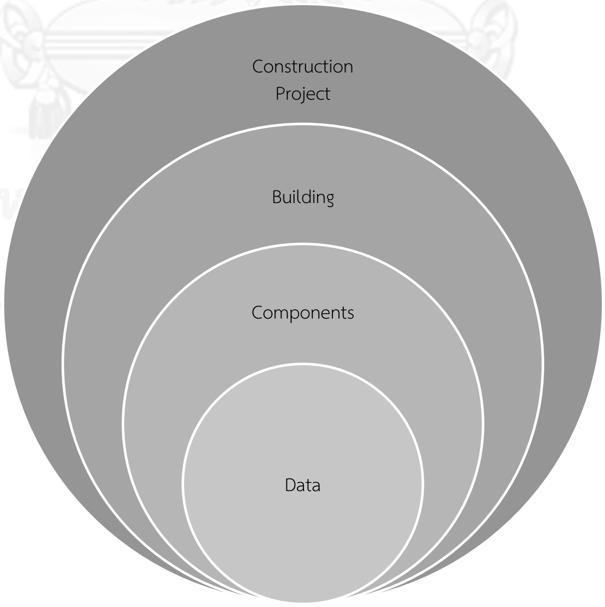


Figure 4.1 Information layer of BIM-Model

Construction project information encompasses building and environment information such as landscape, location, road, weather, and other buildings around construction project.

Building information includes components and functional information of buildings such as architectural information, structural information, MEP information, room type, room function, room area, building temperature, and light in buildings.

Component information encompasses type and component geography such as detailed information of beam, column, stair, wall, window, MEP component, component location, comment name, and component category.

General data contain text, number, day and time such as planning information, QR code, ID, live load, and dead load.

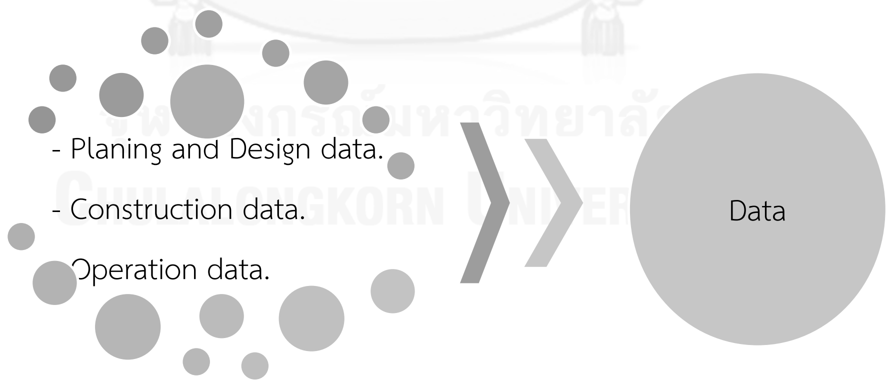
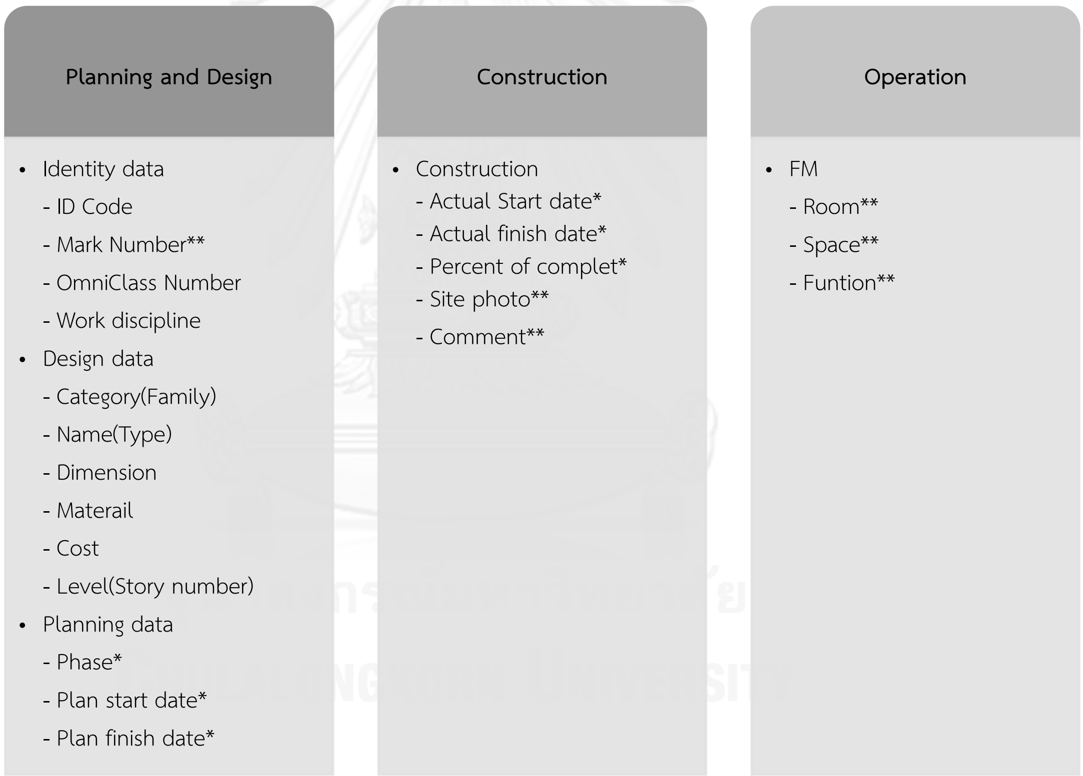


Figure 4.2 Information composition

During construction, the owner or its representative monitors construction project progress. Figure 4.3 shows important information that is used as BIM model inputs. These inputs need to be dynamically updated during construction.

Figure 4.3 also shows important information for the post-construction (operation) phase, especially information for facility management (FM). Such information includes room number, room space, and room function.



Note: ( ) Application requirement (*) Traditional requirement (**) System requirement

Figure 4.3 Importance information in BIM-Master model

4.2 System Structure

4.2.1 Overview

The two parties that are closely associated with the proposed system are the owner and the designer. As the key party, the owner initiates the project and chooses the construction management (CM) team to be its representative during construction. After that, the owner (or CM) has to set up the ***BIM-Construction Monitoring Database (BCMD)*** in the owner office and the construction site office.

The designer is selected by the owner to fulfill the owner requirements of the facility. The designer has to set up the ***BIM-Design Database (BDD)*** in its office. The BDD is connected to BCMD at the owner's office, as shown in Figure 4.4. Figure 4.5 highlights the information transfer from the construction site to the BCMD at the owner's office via cloud technology.

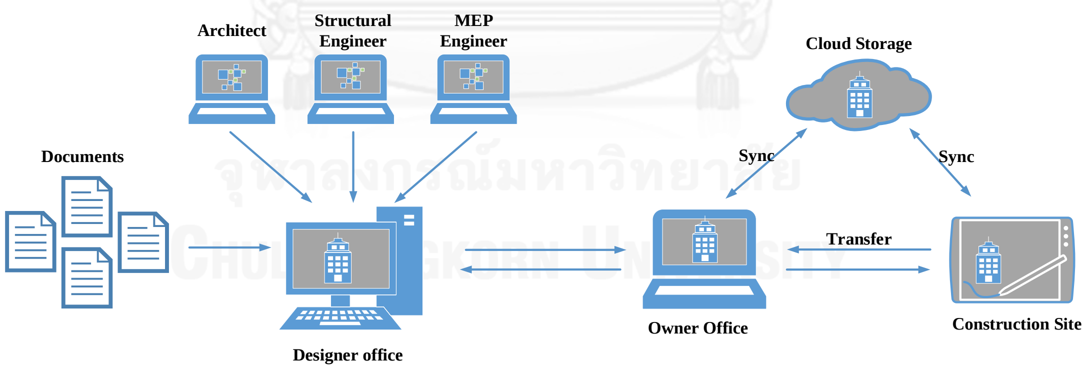


Figure 4.4 System architecture of BIM-based construction project monitoring system

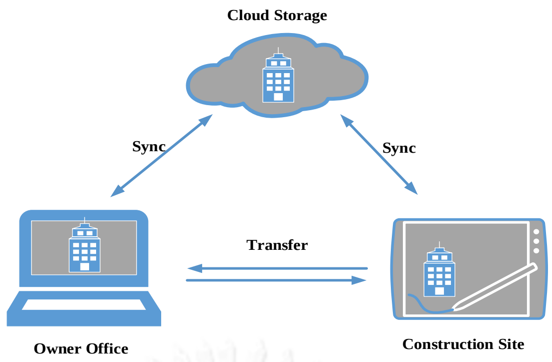


Figure 4.5 Information transfer between the BCMD and the construction site

The BDD at the designer's office and the BCMD at the owner's office were designed to use a common file naming system, which entails three disciplines: architecture, structure, and MEP. These three disciplines of information are part of the BIM-master file, as shown in Figure 4.6.

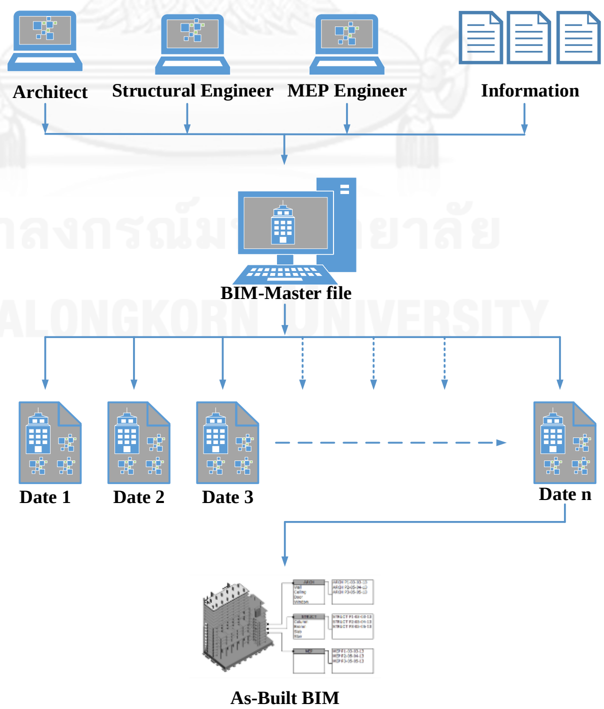


Figure 4.6 Data structure of the BIM-construction monitoring database (BCMD)

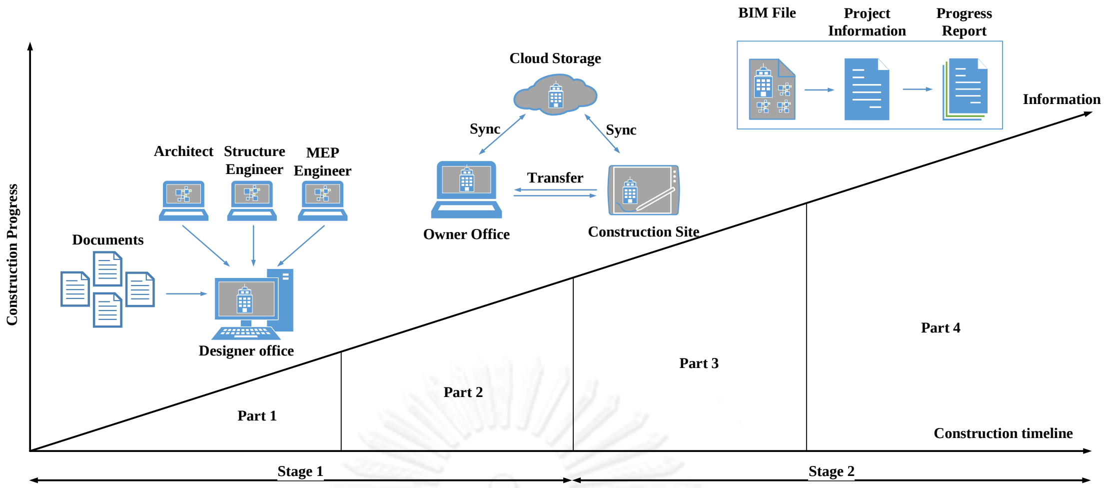


Figure 4.7 Stages and parts of the proposed system

As the central party of the proposed system, the owner provides necessary information and requirements for the designer. The central database of the system, which is located at the owner office, stores the ***BIM-master model*** and updates the ***BIM-record model*** during construction.

At the construction site office, the construction management (CM) collects construction information and updates construction progress. The construction site office database is connected to the owner office database via cloud storage.

The designer team consists of the architect team, the structural engineer team, and the MEP team. They create the ***BIM-design model***, which consists of each design components of the facility such as the architectural model, the structural model, and the MEP model, as shown in Figure 4.7.

The ***BIM-master model*** is the final version of the ***BIM-design model***. This model is analogous to blueprints or master plans in the traditional approach. It consists of the completed BIM models of architectural, structural, and MEP model works.

The ***BIM-record model*** integrates the relevant data collected from the site to update and report construction work progress. The construction management is the party that uses this model to monitor construction progress and report the percentage of completion and payment validation to the owner.

The ***BIM-as-built model*** is comparable with the as-built plans in the conventional approach. This model is the final BIM model of the project that represents the actual dimension, location, and associated information of all components of the facility.

In this system, the timeline of construction project development is divided into two stages: the pre-construction stage and the construction stage. Each stage contains a number of relevant activities. Herein, we focused on the construction stage where the construction manager and the contractor are directly involved in tracking and reporting construction work progress.

As shown in Figure 4.7, each stage is subdivided into parts. The pre-construction stage is divided further into the design part and the project monitoring preparation part. Meanwhile, the construction stage entails the data collection and project updating part and the project progress report part.

4.2.2 Pre-Construction Stage

The first stage of the system is the pre-construction stage, which consists of two parts: the design part and the project monitoring preparation part. In the design part the design team, consisting of the architect team, the structural engineer team, and the MEP team, works together to create the facility design, which is the main input of the ***BIM-design database*** (BDD), as shown in Figure 4.8.

Figure 4.9 illustrates the workflow of the BIM-design part, which consists of five steps.

1) The owner identifies necessary information that is required for project monitoring.
2) The owner establishes an information package for project monitoring and forwards it to the designer.
3) The designer integrates the information package into the ***BIM-design database*** (BDD) and shares it among the team members.
4) The owner verifies whether or not the BDD contains all necessary information for project monitoring.
5) The design team develops the BIM models of the facility and transfer the completed BIM-Model from the ***BIM-design database*** to ***the BIM-construction monitoring database*** (BCMD) in the owner office.

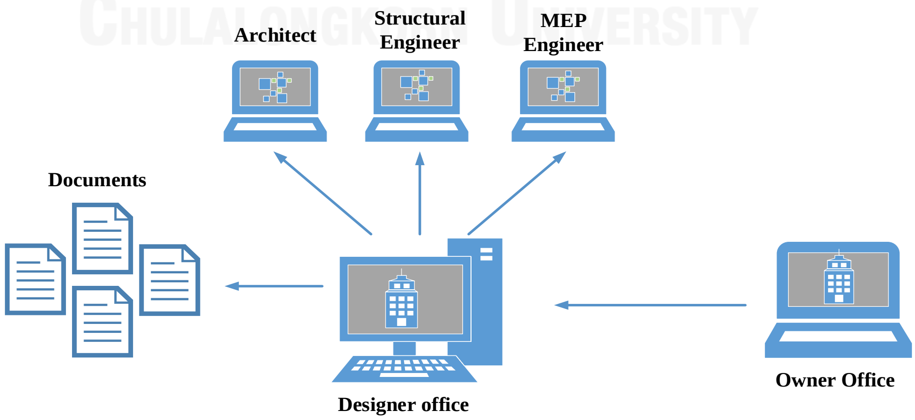


Figure 4.8 Components of the BIM-design database (BDD)

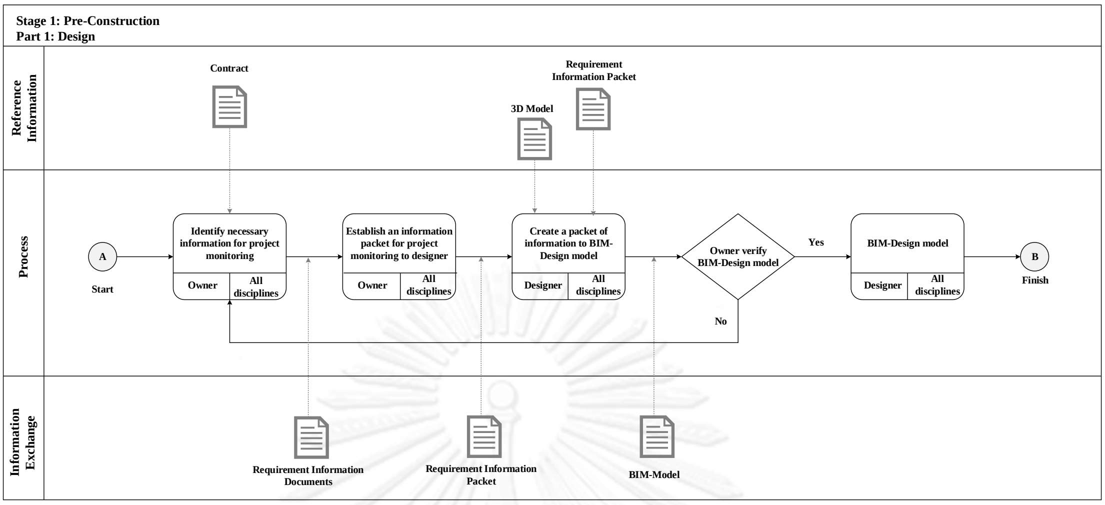


Figure 4.9 Workflow of the BIM-design part

The project monitoring preparation part is the responsibility of the construction management (CM), which is the owner's representative. The CM has to integrate the BIM models that are transferred from the designer into the ***BIM-construction monitoring database*** (BCMD) in the owner office, as shown in Figure 4.10.

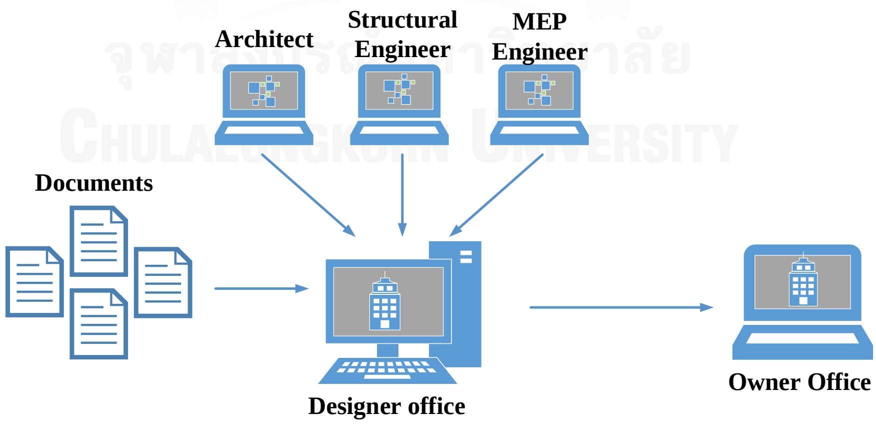


Figure 4.10 Project monitoring preparation part by CM

Figure 4.11 illustrates the workflow of project monitoring preparation part, which consists of five steps.

1) The CM received the BIM models from the designer.
2) The CM creates the BIM-project in the BIM construction monitoring database (BCMD) in the owner office.
3) The BIM-master model is created in the BIM-project.
4) The BIM models are linked to the BIM-master model and the construction stages are established.
5) The BIM-master model is shared with the owner site office to be used during construction.

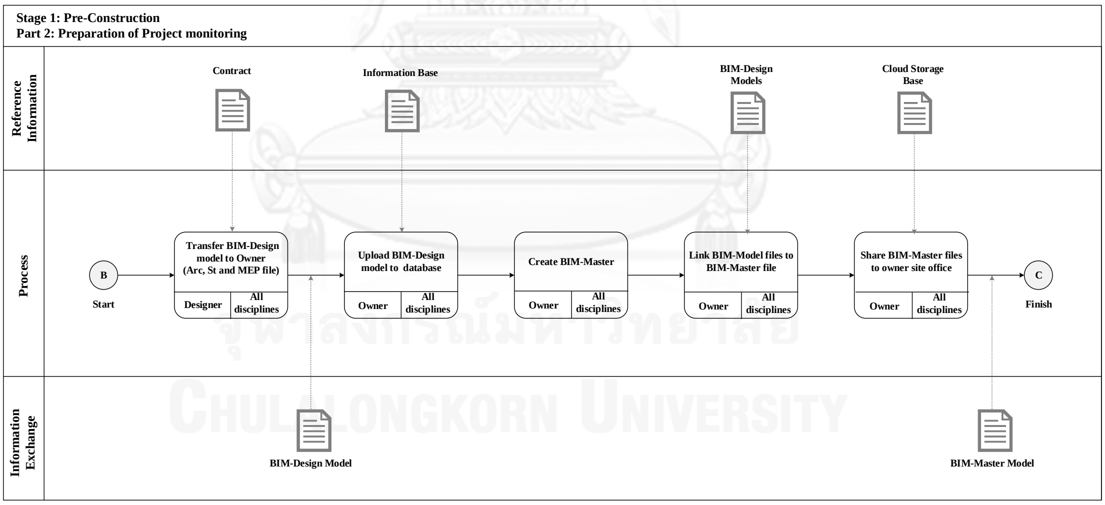


Figure 4.11 Workflow of the project monitoring preparation part

The BIM-project is a directory in the BIM-construction monitoring database, contains three BIM-master models (i.e., architectural, structural, and MEP models), as shown Figure 4.12.

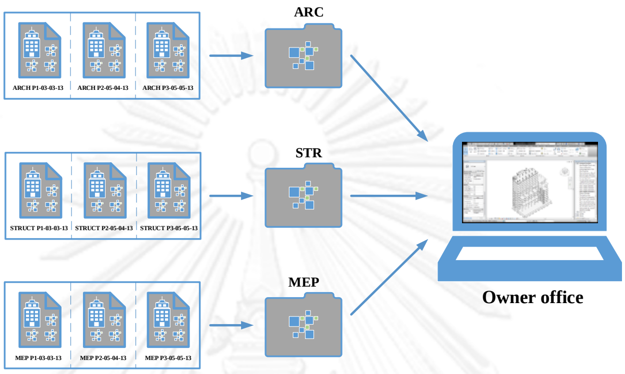


Figure 4.12 Three BIM-master models

4.2.3 Construction Stage

The construction stage is the main part of the system. This stage consists of two parts: (1) the data collection and project updating part and (2) the project progress report part. Figures 4.13 shows the system architecture of this stage.

The data collection and project updating part directly involves construction progress monitoring. In this part, the CM has to collect site data and update project progress information on a timely basis (e.g., every week). Figure 4.14 shows the workflow of the data collection and project updating part, which consists of the following ten steps:

1) The CM imports the corresponding BIM-master model files from the BIM-construction monitoring database (BCMD) at the construction site office to a tablet PC.
2) The CM selects the corresponding project stage on the BIM-record model in the tablet PC.
3) The CM selects an object (i.e., building component), the progress of which will be updated.
4) The information of current work progress of the object is input into the model.
5) The photos of the existing conditions of the object are taken and added into the model.
6) The updated project information is uploaded to the cloud storage.
7) The image URL is generated.
8) The construction progress of the selected object is completely updated.
9) The system checks if there is information of other objects to be updated.
10) The BIM files are exported to the BCMD at the site office.

As shown in Figure 4.15, the BIM-record model plays a major role in storing updated information and images of current conditions, including construction stage, object ID, actual start and finish dates, and actual activity duration, cost.

Different BIM-record models contain different BIM-model files and external information from the cloud storage depending on object types and locations. Thus, the file name system was introduced to avoid any confusion. Figure 4.16 shows an example file name of a BIM-record model for a column, which contains type file, floor level, object name, and current date.

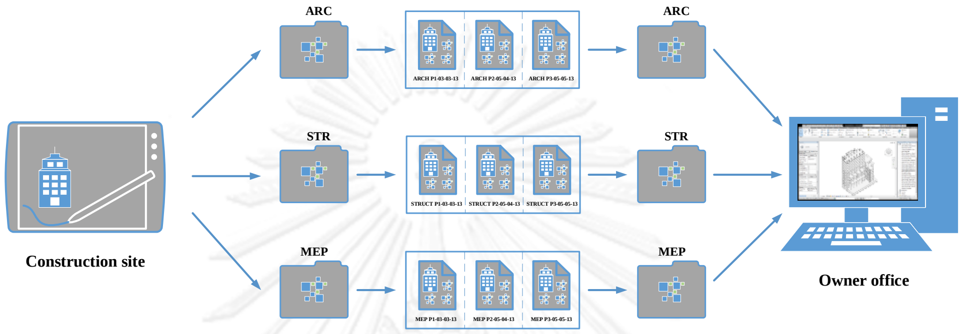
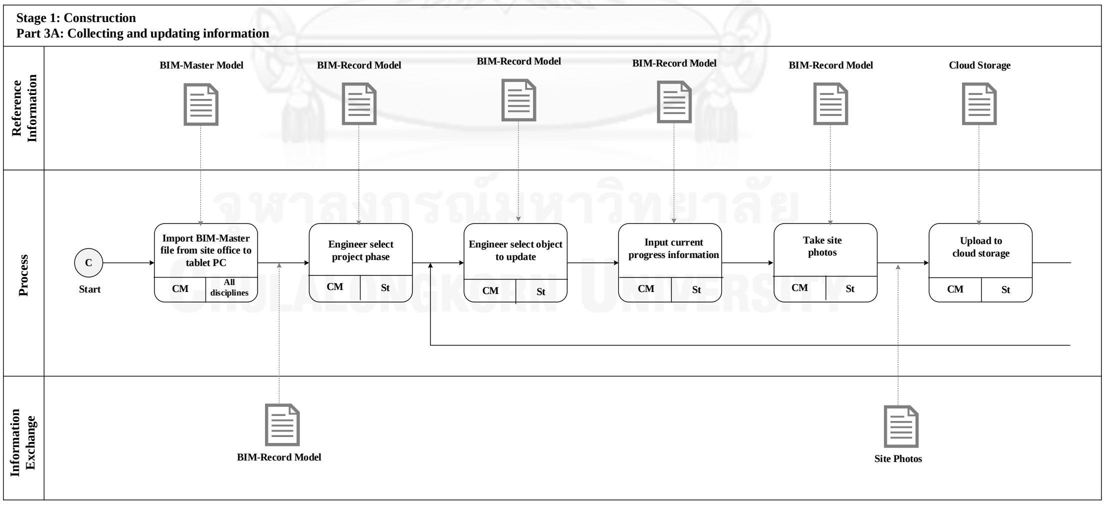


Figure 4.13 System architecture of the construction stage



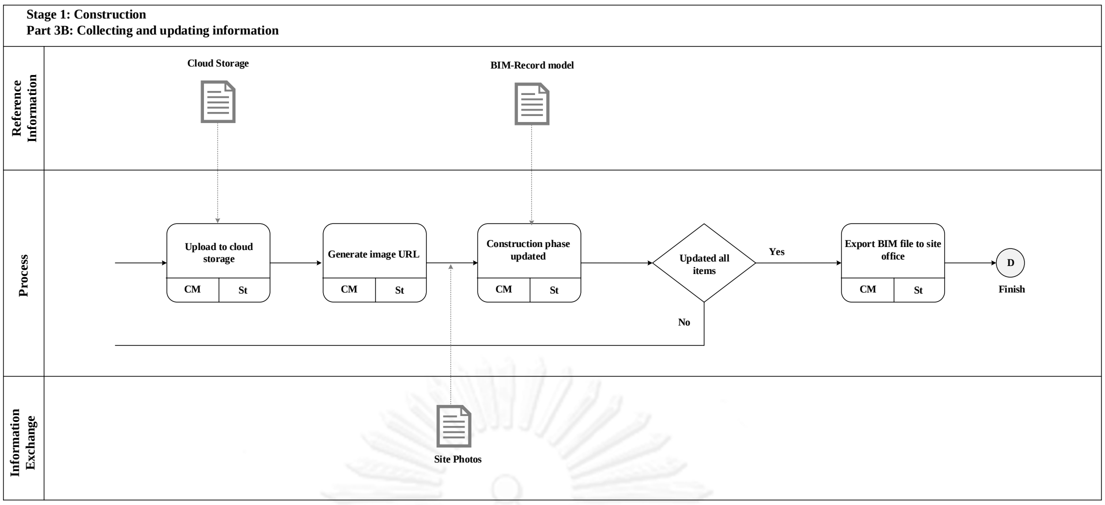


Figure 4.14 Workflow of the data collection and project updating part

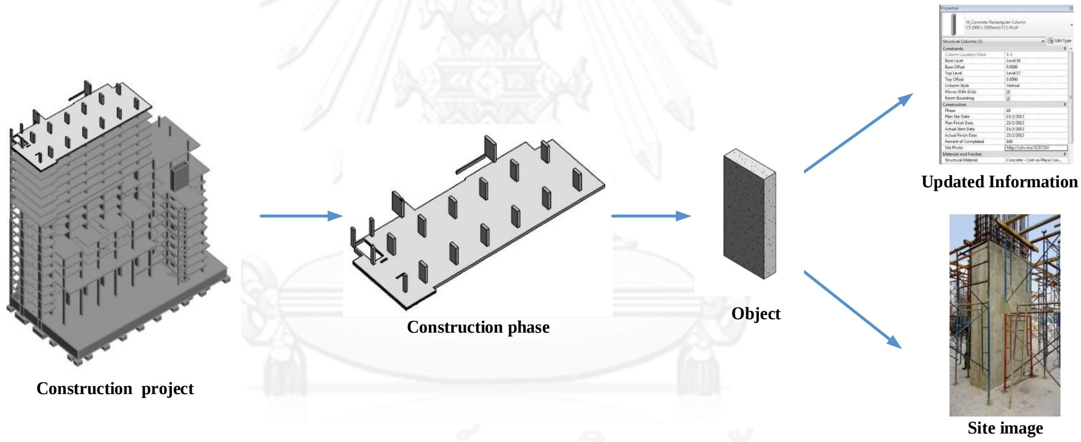


Figure 4.15 BIM-record model and updated information

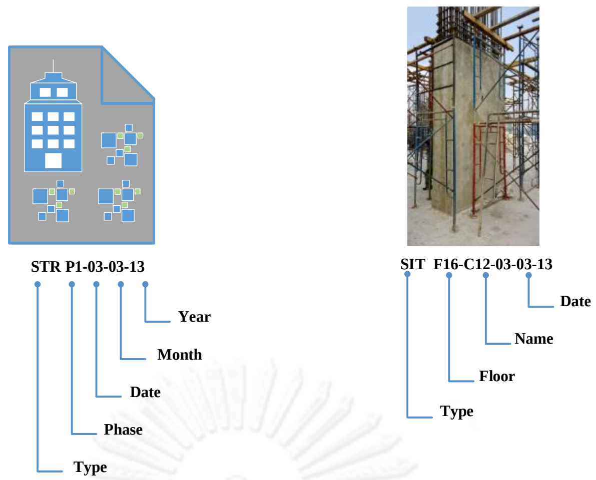


Figure 4.16 File name of BIM-record model for a column

The project progress report part shows the status of each construction work, the progress of which is collected and analyzed in the former part. The BIM-master model file combines the updated BIM-record model files of all objects in three disciplines (i.e., architectural, structural, and MEP works). Microsoft Excel is programmed to analyze the collected data and present the current status of the project, including percentage of completed and uncompleted work, in-progress items, total cost, and actual site images, as shown in Figure 4.18.

Figure 4.19 displays the work flow of the project progress report part, which is broken down into the following six steps.

1) The BIM-record files are imported (or sync) from the BCMD at the site office.
2) The BIM-record files are combined to BIM-master model file.
3) The CM selects current construction phase and filtered Information for monitoring.
4) The CM exports information to text file.

5) The CM Imports text file Excel temple file for analysis construction progress.

6) The Report of construction project progress is present in Excel file.

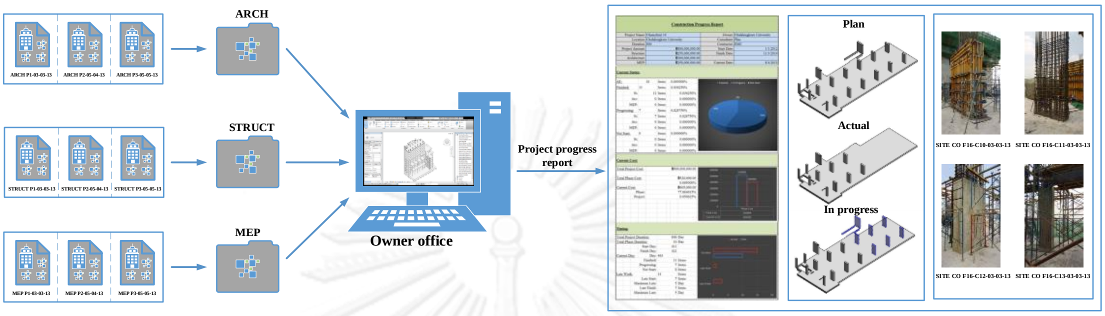


Figure 4.18 Project progress report part

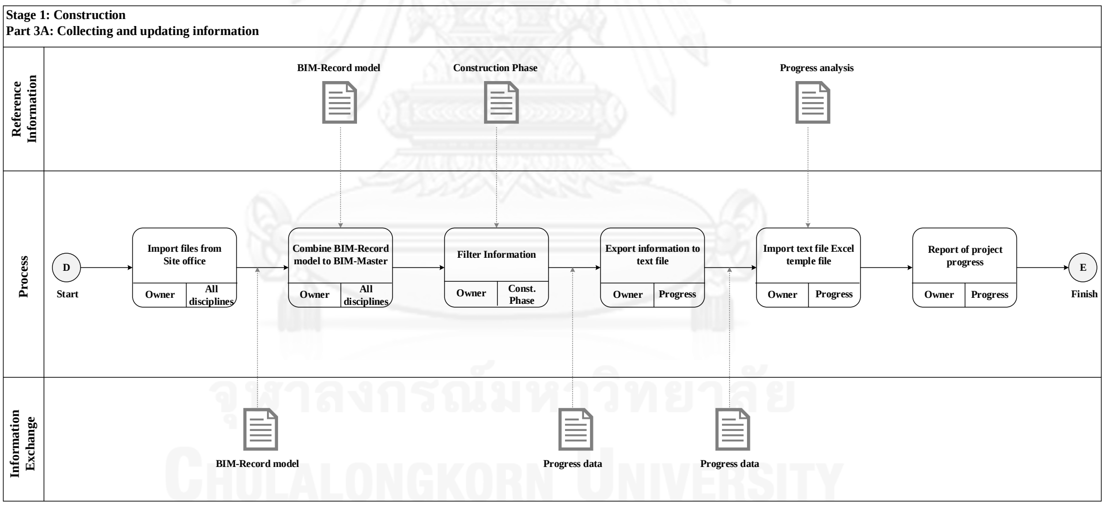


Figure 4.19 Workflow of the project progress report part

The project progress report must be stored in the database systems at both the construction site office and the owner office. The most updated BIM-record model file is transferred from the database at the site office to a directory in the BCMD at the owner office. Thus, the BIM-central model, which contains analytical tools, can access and analyze current project information and report the status of the construction project.

4.3 Conclusion

This chapter presents the framework of BIM-based Project Monitoring System (BPMS). This system divided into three stages: pre-construction, construction, and post-construction. The pre-construction stage consists of two parts: the design part and the project monitoring preparation part. The construction stage is the main part of the system. This stage consists of two parts: the data collection and project updating part and the project progress report part.

CHAPTER V

SYSTEM APPLICATION

This chapter illustrates an application of the proposed BIM-based construction project monitoring system in an actual high-rise building project. It presents detailed discussions on each step of system development and its results.

5.1 Project Case Study

The practicality of the proposed system was tested by applying it to Chamchuri 10 building project, a new high-rise academic building of Chulalongkorn University, Bangkok, Thailand. Figure 5.1 shows the location of the project. Chamchuri 10 building is a 21-floor reinforced concrete structure that houses graduate classrooms and the offices of international units of Chulalongkorn University. Since this facility is a modern high-rise building that is very complicated (as shown in Figures 5.2 and 5.3), the proposed system is appropriate to monitor and report its progress.

In this construction project, Chulalongkorn University has hired Plan consultants Co., Ltd as its construction management (CM) professional, which acts as the university's representative. The construction contract was awarded through the open-bidding process to EMC Public Company Limited (EMC), which has been in the construction industry for more than 20 years.

5.2 Application Tools

Several software was integrated to develop the proposed system. Autodesk Revit was used for creating the BIM models, and Drop Box was used for creating databases. Smart PC was a tool for updating information on the construction site. The construction work progress of the project was analyzed and reported by using Microsoft Excel.

5.2.1 BIM models

Autodesk Revit is a BIM software that is widely used by architects, structural engineers, MEP engineers, and contractors. It allows users to design a building, structure its components in 3D, annotate the model with 2D drafting elements, and access building information from the building model database. Figure 5.4 shows a user interface example of Autodesk Revit 2014 developed for this case study.

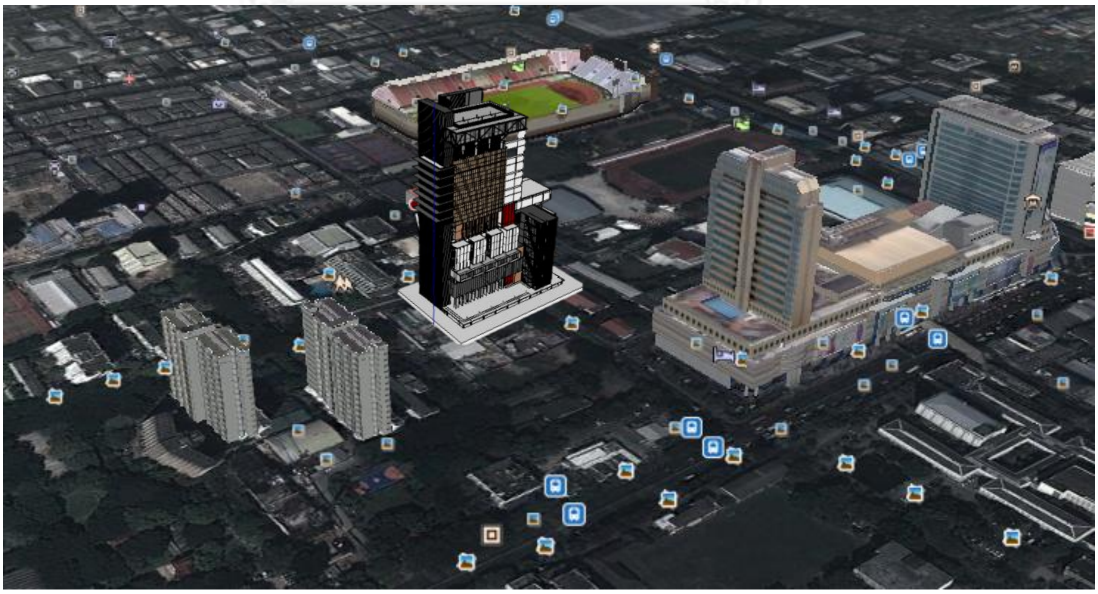


Figure 5.1 Location of Chamchuri 10 building project

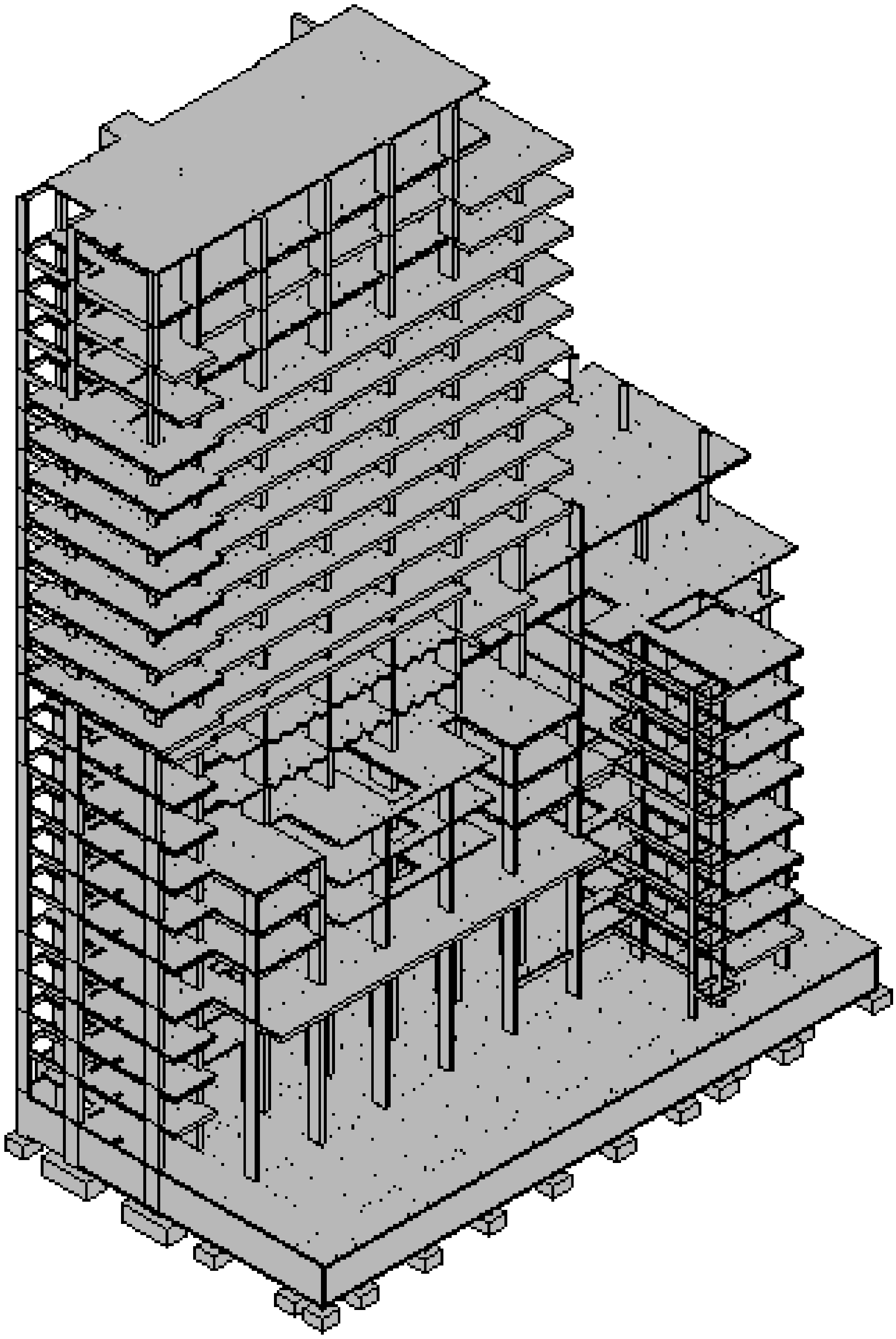


Figure 5.2 3D model of Chamchuri 10 building

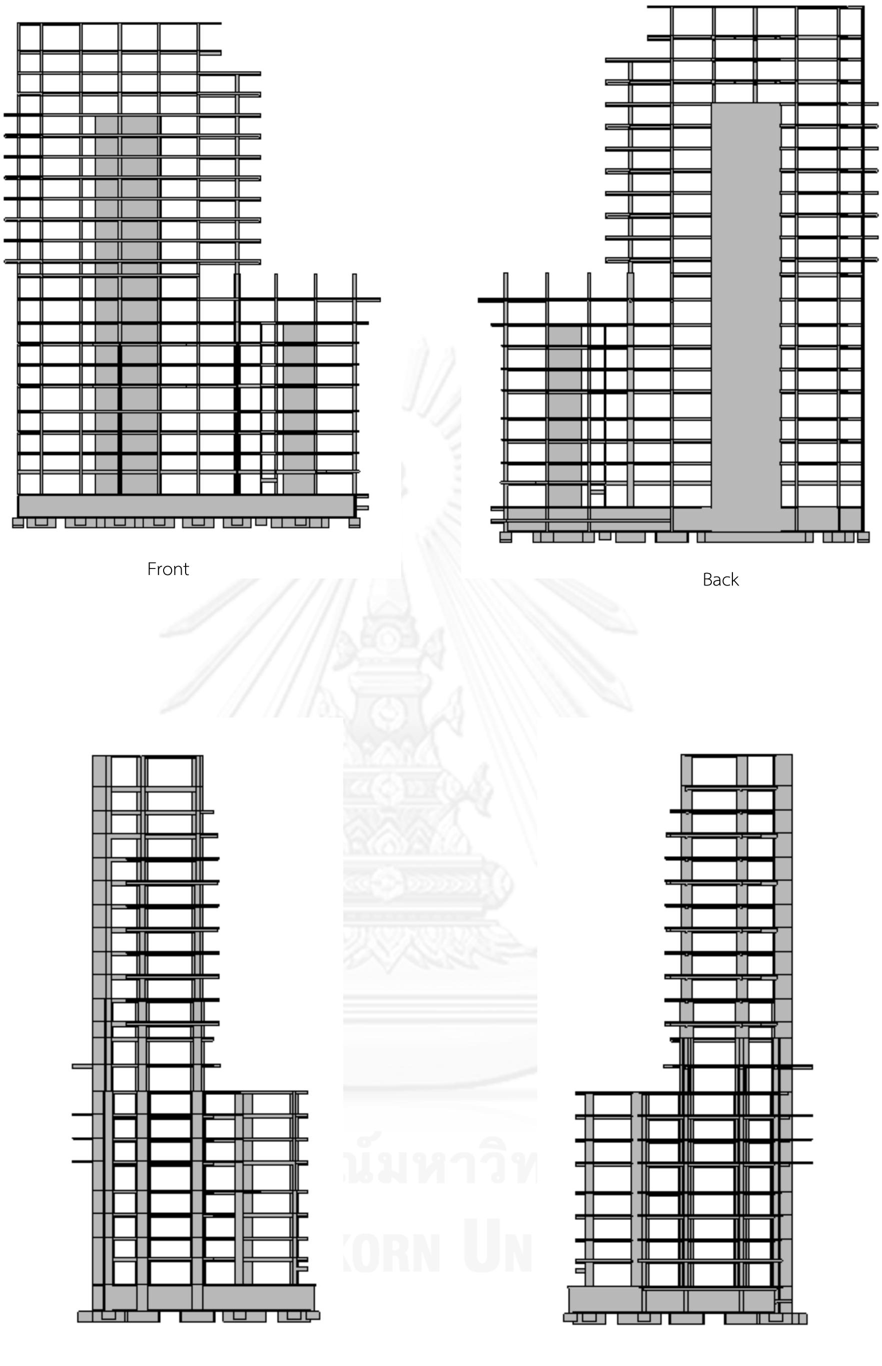


Figure 5.3 Perspective model of Chamchuri 10 building

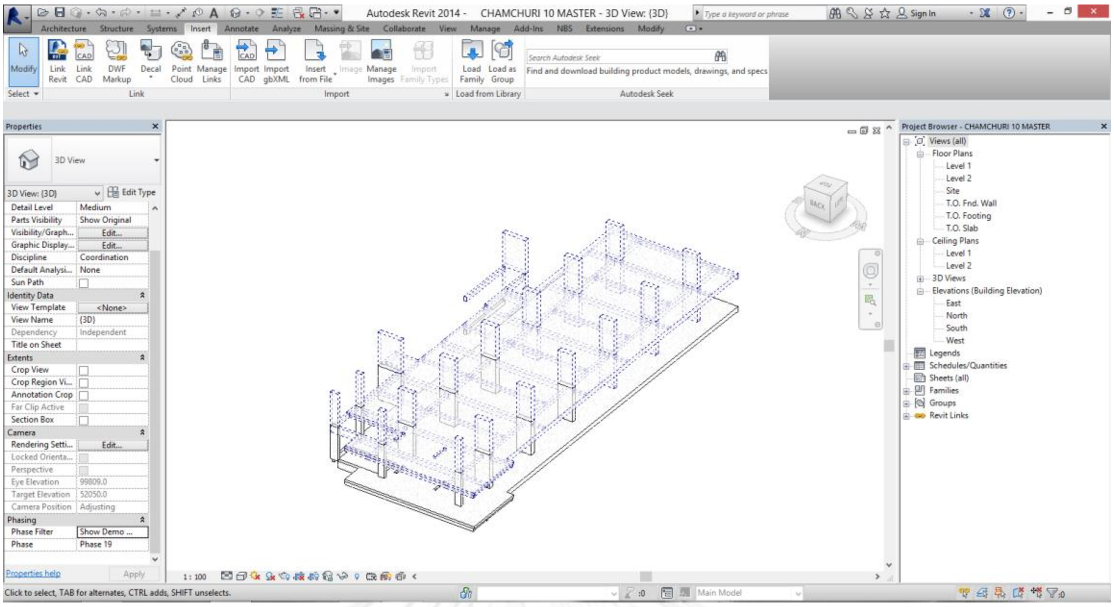


Figure 5.4 User interface of Autodesk Revit 2014

5.2.2 Database

Dropbox is a file hosting service operated by Dropbox, Inc., headquartered in San Francisco, California. It offers cloud storage, file synchronization, and client software. Dropbox allows users to create a special folder on each of their computers, and Dropbox can synchronizes them so that they share the common contents. The files placed in these folders are accessible through a website or mobile phone applications. Figure 5.5 shows a user interface example of Dropbox for the case study.

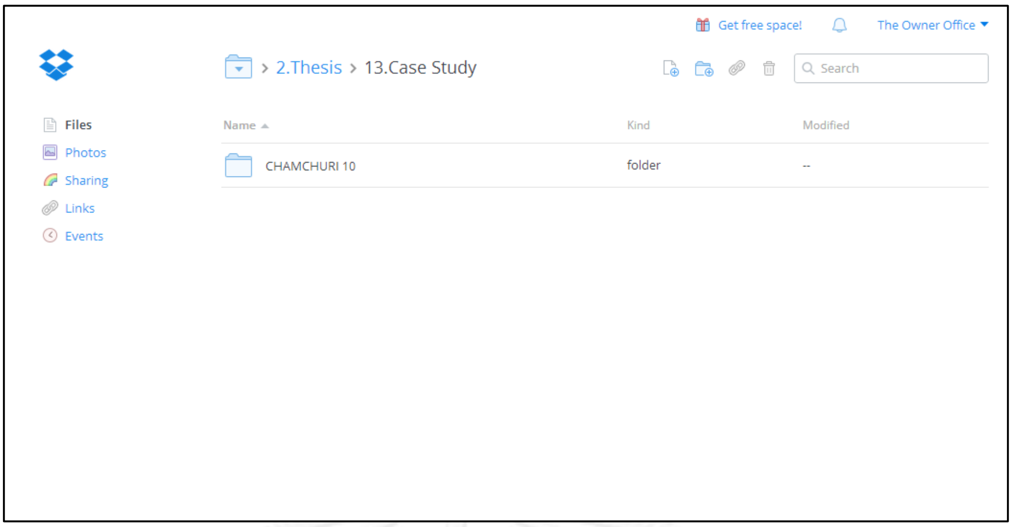


Figure 5.5 User interface of Dropbox

5.2.3 Analytical software

Microsoft Excel is a spreadsheet application developed by Microsoft Corporation. It features calculation, graphing tools, pivot tables, and a macro programming called Visual Basic for Applications. It has been a widely used spreadsheet for these platforms, especially since version 5 in 1993, and has replaced Lotus 1-2-3 as the industry standard for spreadsheets. Figure 5.6 displays a user interface example of Microsoft Excel that was developed for this case study.

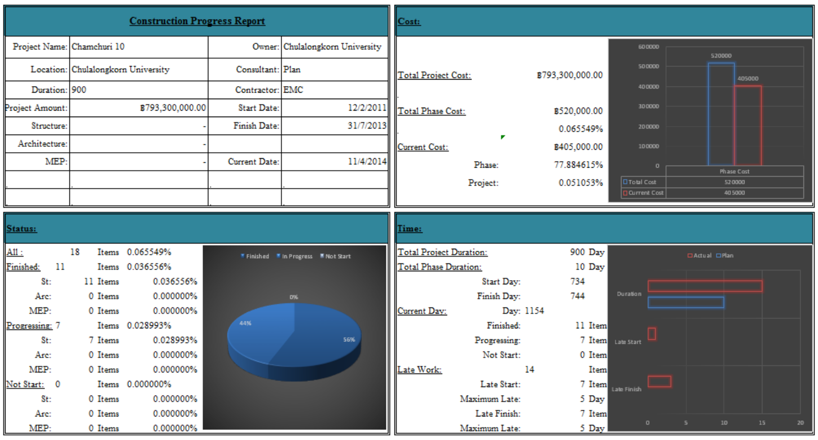


Figure 5.6 User interface of Microsoft Excel

5.2.4 Monitoring equipment

The construction work progress was monitored through Lenovo IdeaPad Yoga 13, which is a convertible laptop. The Yoga 13 gets its name from its ability taken on various form factors due to its screen being mounted on a special two-way hinge.

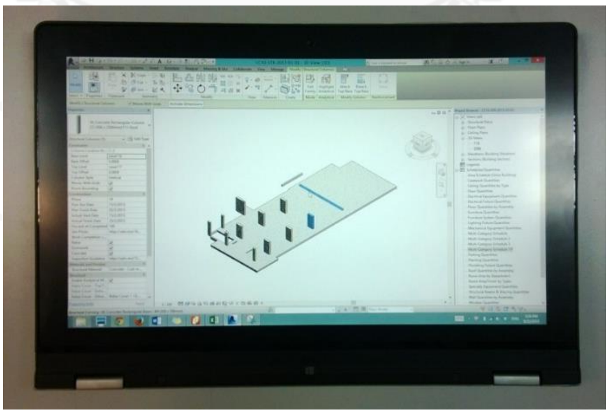


Figure 5.7 Lenovo IdeaPad Yoga 13 notebook

5.3 Pre-Construction

As discussed in Chapter 4, the pre-construction stage is divided into two parts: the design part and the project monitoring preparation parts. The design team is responsible for the design part. The team comprises the three main disciplines: architect, structural engineer, and MEP engineer. Meanwhile, the construction management (CM), which is the representative of the owner, is responsible for the project monitoring preparation part.

5.3.1 Design part

In this part, the owner first identified and informed necessary information for project monitoring to the design team. Such information can be categorized into three groups, namely, the planning and design group, the construction group, and the operation group. The planning and design group contains basic information of the construction project, including identity data type, design data, and planning data, as shown in Figure 5.8.

The design team then used the necessary information provided by the owner to create parametric information on the BIM-design model, as shown in Figure 5.9. After all the BIM models were created, they were checked by the owner. These models subsequently provided information for project monitoring.

Planning and Design

- Identity data
  - ID Code
  - Mark Number
  - OmniClass Number
  - Work discipline
- Desing data
  - Category(Family)
  - Name(Type)
  - Dimension
  - Materail
  - Cost
  - Level
- Planning data
  - Phase
  - Plan start date
  - Plan finish date

Construction

- Construction
  - Actual Start date
  - Actual finish date
  - Percent of complet
  - Site photo
  - Comment

Operation

- Facility management (FM)
  - Room
  - Space
  - Funtion

Figure 5.8 Three groups of important information

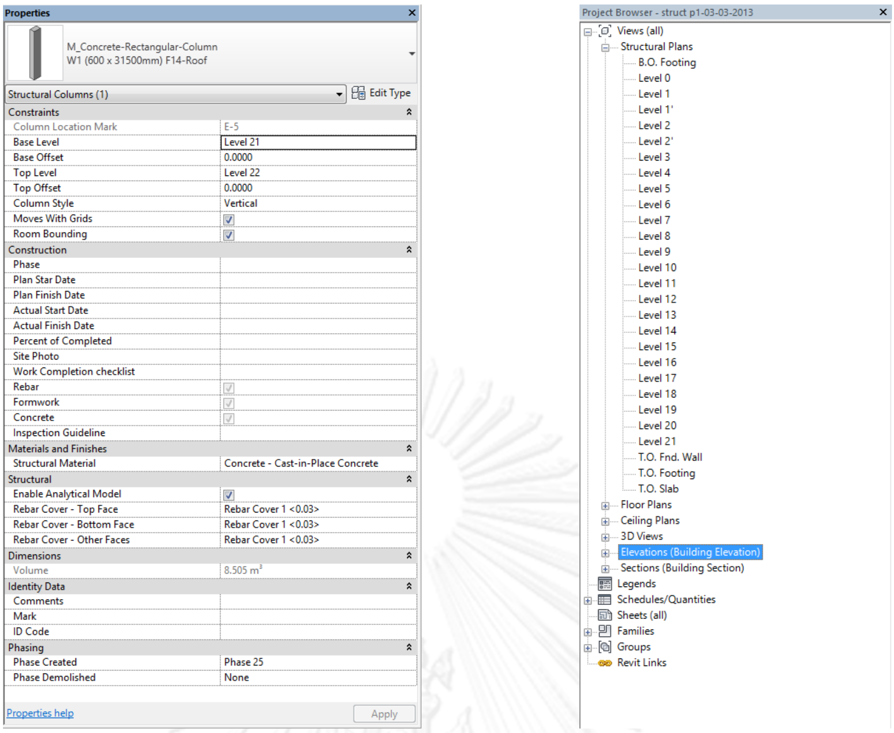


Figure 5.9 Parametric information on BIM-design model

The BIM-design models were transferred from the BIM-design database (Figure 5.10) to the BIM-construction monitoring database in the owner office.

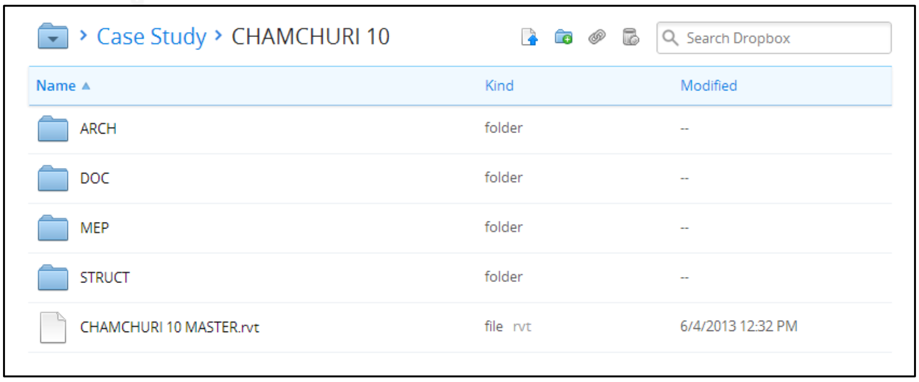


Figure 5.10 BIM-design database

5.3.2 Project monitoring preparation part

The CM was responsible for the project monitoring preparation part. The CM managed the BIM-design models (e.g., Figure 5.11) that were transferred from the designer to the BIM-construction monitoring database (BCMD) in the owner office. The CM first created a new BIM project folder in the BCMD. The BIM-master model was then created in the BIM project folder. The BIM-design models were linked to the BIM-master model and construction phases were established, as shown in Figures 5.12.

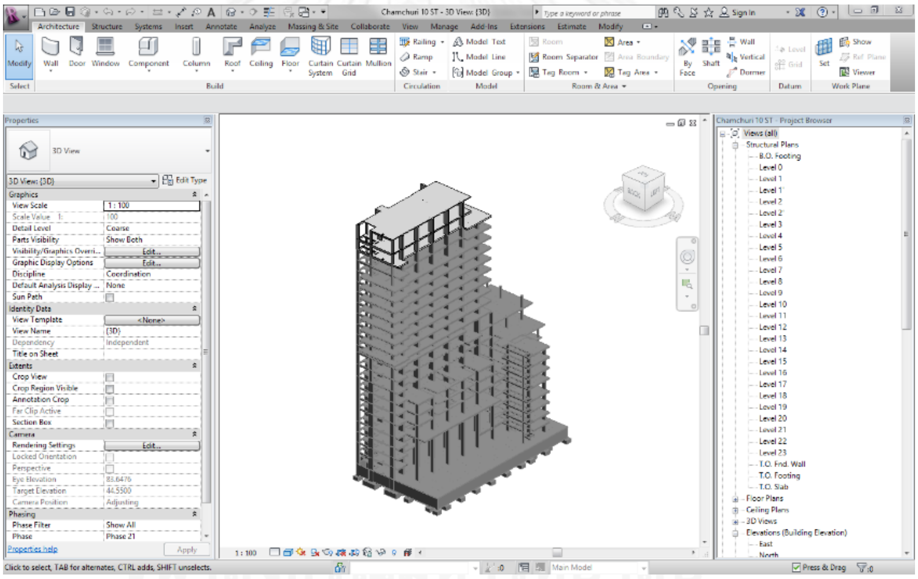


Figure 5.11 BIM design model

PAST

	Name	Description
1	Existing	Existing
2	Demo	Demo
3	Phase 1	Completion plan: Janueary 30, 2011
4	Phase 2	Completion plan: March 1, 2011
5	Phase 3	Completion plan: March 31, 2011
6	Phase 4	Completion plan: April 30, 2011
7	Phase 5	Completion plan: May 30, 2011
8	Phase 6	Completion plan: June 29, 2011
9	Phase 7	Completion plan: July 29, 2011
10	Phase 8	Completion plan: August 28, 2011
11	Phase 9	Completion plan: September 27, 2011
12	Phase 10	Completion plan: October 27, 2011
13	Phase 11	Completion plan: November 26, 2011
14	Phase 12	Completion plan: December 26, 2011
15	Phase 13	Completion plan: January 25, 2012
16	Phase 14	Completion plan: February 24, 2012
17	Phase 15	Completion plan: March 25, 2012
18	Phase 16	Completion plan: April 24, 2012
19	Phase 17	Completion plan: May 24, 2012
20	Phase 18	Completion plan: June 23, 2012
21	Phase 19	Completion plan: July 23, 2012
22	Phase 20	Completion plan: August 22, 2012
23	Phase 21	Completion plan: September 21, 2012

Figure 5.12 Construction phases in the BIM-master model

Figure 5.13 shows the components of the BCMD, which comprises three main folders, namely, architecture (ARCH), structure (STRUCT), and MEP. These folders were accessible by the staff members who were responsible for monitoring the work progress, as shown in Figure 5.14.

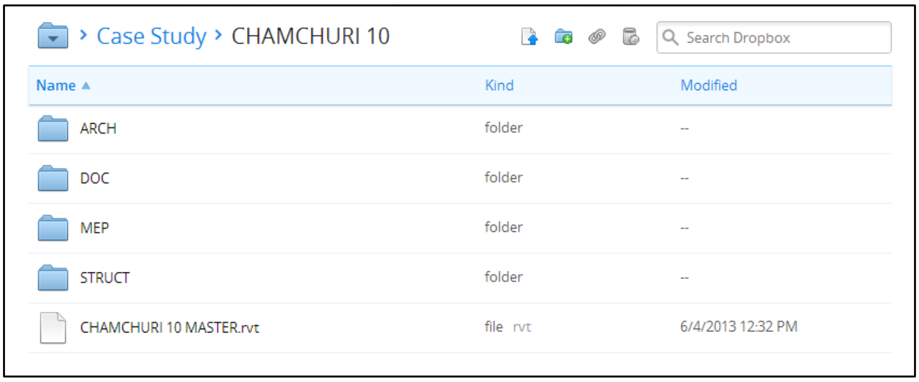


Figure 5.13 Components of the BIM-construction monitoring database

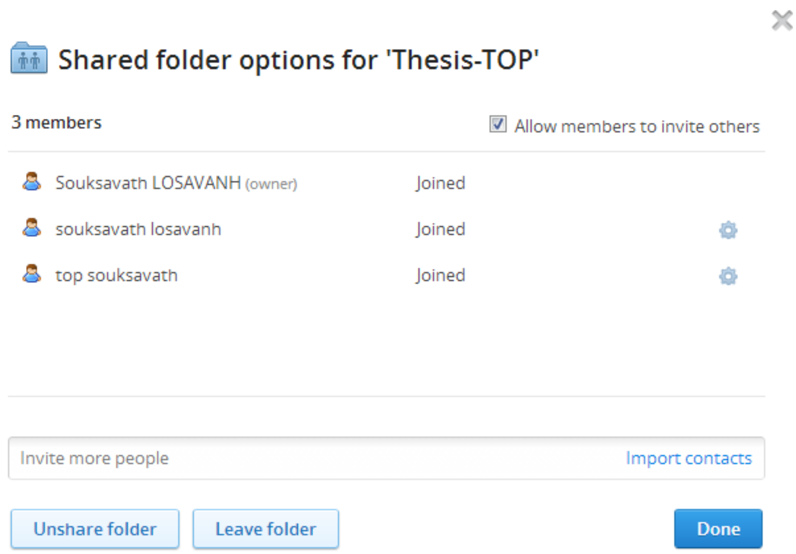


Figure 5.14 Accessibility of the BIM-master model

5.4 Construction

As discussed in Chapter 4, the construction stage was divided into two parts: data collection and project updating part and the project progress report part.

5.4.1 Data collection and project updating

In this part, the CM collected relevant data concerning construction work progress and update the project status on the weekly basis. All the BIM-master model files were imported from the BIM-construction monitoring database (BCMD) in the construction site office to a tablet PC, which was used as a data collection tool on the site. To collect the data, the CM first chose the object and the updated construction data were filled in, as shown in Figures 5.15 and 5.16.

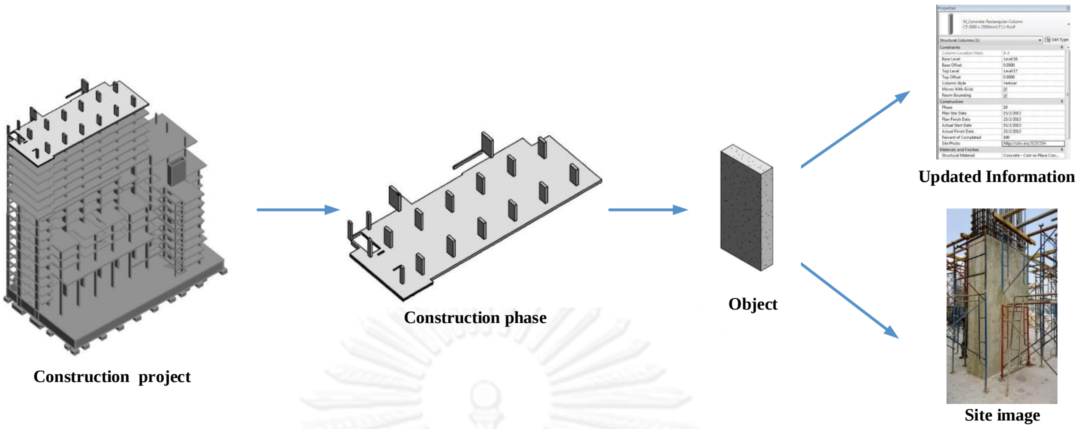


Figure 5.15 Data collection at the site

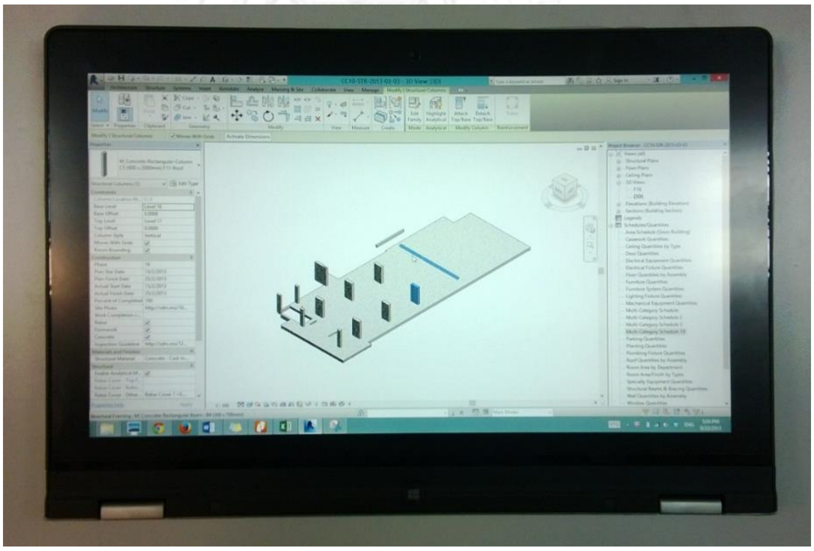


Figure 5.16 Tablet PC for collecting data at the construction site.

The BIM-record model contained updated information and images of current construction progress. The updated information entailed construction phase, object ID, object location planned start and finish dates, actual start and finish dates, and planned and actual duration. Figure 5.17 shows an example of updated construction information.

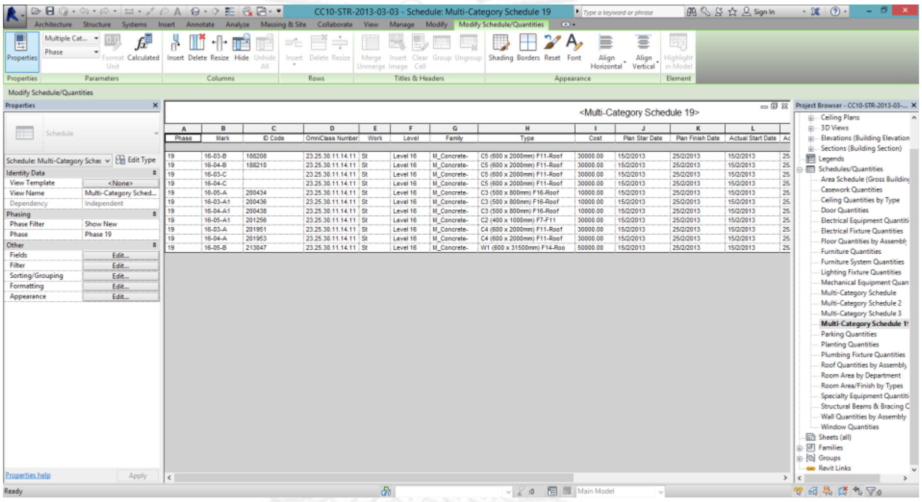


Figure 5.17 Updated construction information on the BIM-record model

5.4.2 Project progress report

The project progress report part is the final step of the system implementation. It combined and analyzed updated information that was gathered in the previous parts, as shown in Figure 5.18. In this step, the BIM-master model combined the updated BIM-record model files in the three disciplines (e.g., Figure 5.19) and analyzed them using Microsoft Excel (e.g., Figure 5.20). The current status of the project were presented in the form of percent of completion, in-progress items, total cost, and actual site images.

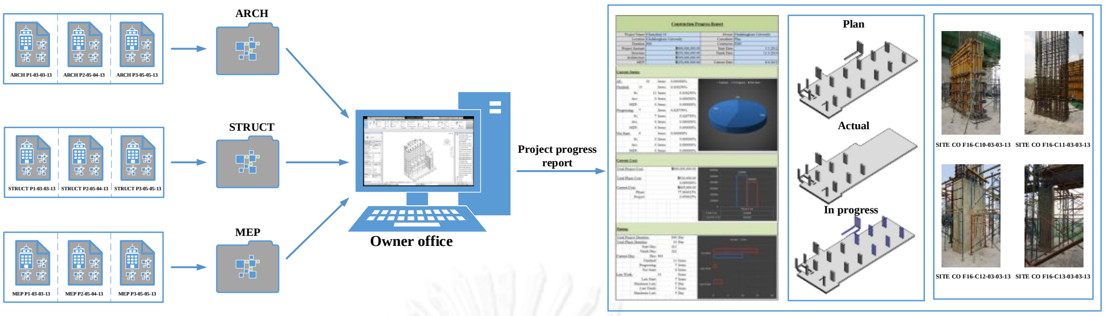


Figure 5.18 Workflow of the project progress report part

The most updated BIM-record model files were transferred from the site office into a directory in BIM-construction monitoring database in the owner office. The BIM-central model analyzed such project information to report the current status of the project, as shown in Figure 5.21.

Multi-Category Schedule 4

Phase	Mark	ID Code	OmniClass Number	Work	Level	Family	Type	Cost	Plan Star Date	Plan Finish Date	Actual Start Date	Actual Finish Date	Percent of Completed	Site Photo
19	16-03-B	188208	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C5 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/10FofGq
19	16-04-B	188210	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C5 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/X13COH
19	16-03-C		23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C5 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/10FoscI
19	16-04-C		23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C5 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/ZgWf7n
19	16-03-D	188216	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C5 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	20/2/2013	2/3/2013	50	http://sdrv.ms/XkXxSK
19	16-04-D	188218	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C5 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	20/2/2013	2/3/2013	50	http://sdrv.ms/ZgWkrD
19	16-03-E	188220	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C5 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	20/2/2013	2/3/2013	50	http://sdrv.ms/ZvuoyO
19	16-04-E	188222	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C5 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	20/2/2013	2/3/2013	50	http://sdrv.ms/10Fpx4o
19	16-05-A	200434	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C3 (500 x 800mm) F16-Roof	10000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/X13v5D
19	16-03-A1	200436	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C3 (500 x 800mm) F16-Roof	10000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/XEoE9B
19	16-04-A1	200438	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C3 (500 x 800mm) F16-Roof	10000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/XEo9fz
19	16-05-A1	201256	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C2 (400 x 1000mm) F7-F11	30000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	
19	16-03-F	201947	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C4 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	20/2/2013	2/3/2013	50	http://sdrv.ms/ZgXmUz
19	16-04-F	201949	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C4 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	20/2/2013	2/3/2013	50	http://sdrv.ms/Yorxa5
19	16-03-A	201951	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C4 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/XEp5AG
19	16-04-A	201953	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	C4 (600 x 2000mm) F11-Roof	30000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/X13qyG
19	16-05-B	213047	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	W1 (600 x 31500mm) F14-Roof	50000	15/2/2013	25/2/2013	15/2/2013	25/2/2013	100	http://sdrv.ms/X13BtV
19	16-05-E	213049	23.25.30.11.14.11	St	Level 16	M_Concrete-Rectangular-Column	W1 (600 x 31500mm) F14-Roof	50000	15/2/2013	25/2/2013	20/2/2013	2/3/2013	50	http://sdrv.ms/Yfw81o

Figure 5.19 Updated information in text file.

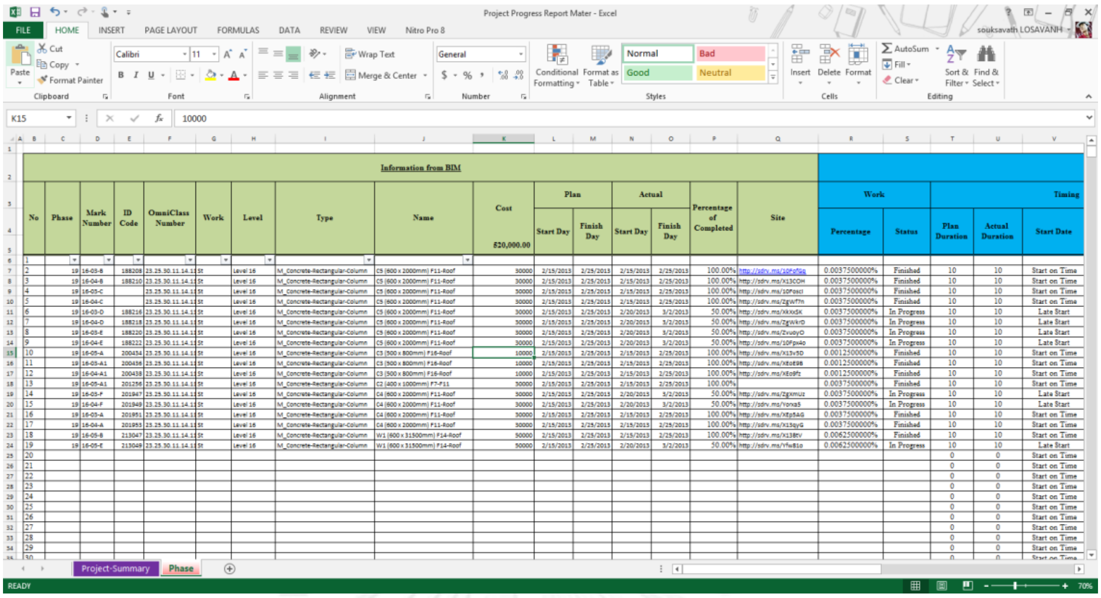


Figure 5.20 Import updated information for analyzing project status

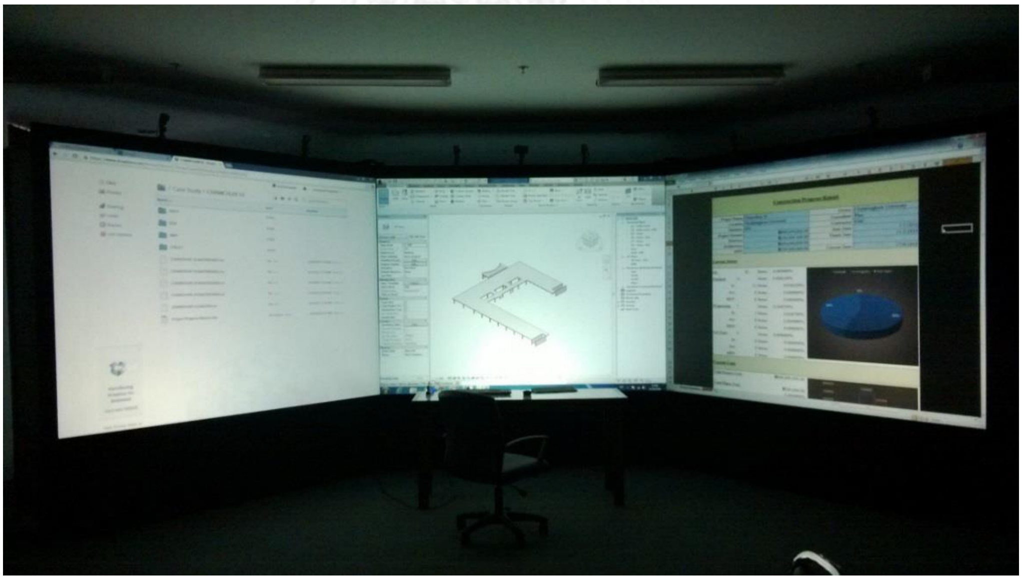


Figure 5.21 Project progress report in the owner office

5.5 Conclusion

This chapter presents the application of the proposed BIM-based construction project monitoring system in an actual high-rise building project. The practicality of the proposed system was tested by applying it to Chamchuri 10 building project, a new high-rise academic building of Chulalongkorn University, Bangkok. Chamchuri 10 building is a 21-floor reinforced concrete structure that houses graduate classrooms and the offices of international units of Chulalongkorn University. In this case study, the additional approach was compared with the system. BIM-based construction project monitoring system was improved additional construction project monitoring process such as time, accurate, error and documentary.

CHAPTER VI

SUMMARY AND CONCLUSION

This research has developed a framework of BIM-based construction monitoring system for the high rise building construction project to the owners that can be used by the owner to monitoring project progress. The purpose of this framework is showed the BIM-based construction monitoring system that reduce errors and omissions in paper on the paper-based modes of communication.

6.1 Conclusion

The framework of BIM-based construction monitoring system for the high rise building construction project to the owners is divides the construction project life cycle in three stages. First stage is the pre-construction stage that is included of programming phase, conceptual design phase and documentary phase. The owner has to clearly and identify of information that is consisted in BIM-model. In this research is divided BIM-model in multi-layer as shown below. Information is compost of 3d, data and documents that separated into three types of information. Second stage is Construction stage that is the main stage of the framework. The owner has to input and update information which consisted in BIM-model. The last stage is Post-construction stage. The information that record in the BIM-model is used as As-built BIM-model for building facilities management.

The BIM-Design part workflow consists of fifth steps. The significant information for design is contained three groups that are planning and design group, construction group and operation group. The planning and design information group are the basic information of the construction project that is included of three types of data such as identity data type, design data type and planning data type.

The project monitoring preparation part is main responsibilities of the construction management (CM) that a representative of the owner. The CM has to manage BIM-models that are transferred from the designer into the BIM-construction monitoring database at the owner office.

The data collection and project updating information part is mainly part of this framework for monitoring construction progress. In this part, the CM has to collect and update the information every week. The CM use tablet PC that carries of BIM-master models into construction building and selects construction project phase that constructing. After that selected object to fill-in updated information.

The BIM-record model is contained updated information and image of current construction progress such as planned start and finish date, actual start and finish dates, planning and actual duration, construction phase, cost, present of completed, object direction, object ID, actual site image and etc. The BIM-record model is almost the same function as As-built drawing, but the BIM-record model is represented in 3D-Model that is accurate more than As-built drawing.

The project progress reports part is the last part of the framework that show the result of combined and analysis information that is updated in the previous parts. The project progress report is using BIM-master model file to combine the updated BIM-recorded model file from three disciplines and using Excel for analysis the information to present current statue of the project such as a percent of completed, percent of uncompleted, in progress items, total cost, actual site image and etc.

The practicality of the proposed system was tested by applying it to Chamchuri 10 building project, a new high-rise academic building of Chulalongkorn University, Bangkok. Chamchuri 10 building is a 21-floor reinforced concrete structure that houses graduate classrooms and the offices of international units of Chulalongkorn University. In this case study, the additional approach was compared with the system. BIM-based construction project monitoring system was improved additional construction project monitoring process such as time, accurate, error and documentary.

6.2 Limitations and future research

The result of this research currently established the information pack of requirement information for development high rise building construction project on the BIM-based construction monitoring system. Actually, it has the illustration of the framework and guideline for applies to other project, but it does not totally monitoring totally system of construction project. The result of this research were based on the reinforcement concrete structural system and only one case study that own by

Chulalongkorn University. Therefore, this study has some limitation, and it should be improve in future research.

The future research. Here are some suggestion for future research. First of all, this research data collected only reinforcement concrete structural system that included column, beam and slab. Therefore, the measurement of complete is not totally applicable because of they used cast in place system as a result the formwork, Rebar and concrete are counting in separate cost but in this BIM-base using of item system. Secondly, this research were developed after project start. According to the framework, this research should be apply into earlier stage of construction project to complete the BIM-model and all requirement information before the construction project start. Finally, the software this research were use Autodesk Revit 2013 to made the BIM-model and Microsoft Excel 2010 were used to analysis and report construction progress that two software can not directly exchange information. Moreover, Autodesk Revit 2013 is not fully functional with Smart-PC that were used to collect data in construction site.

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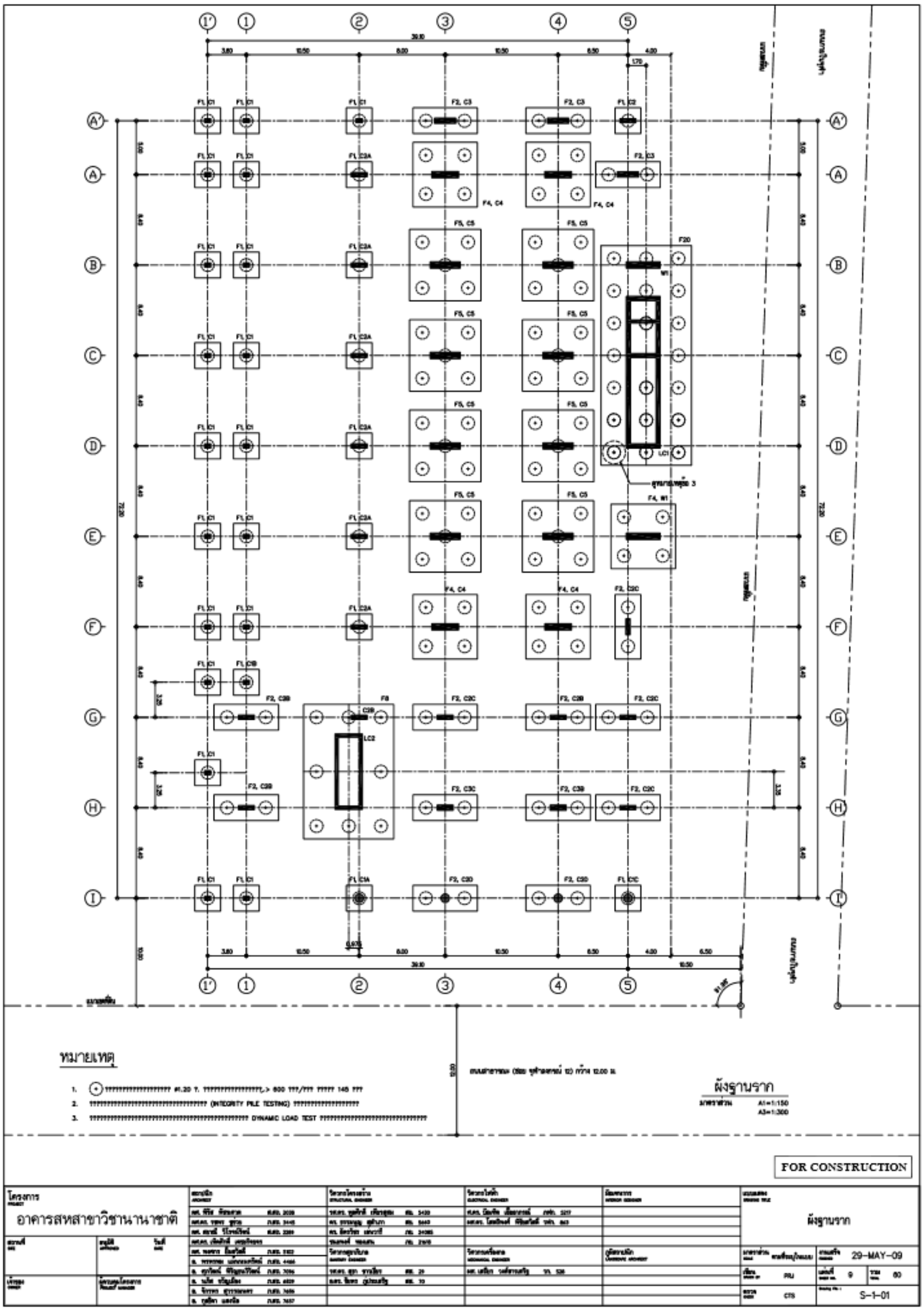
APPENDIX

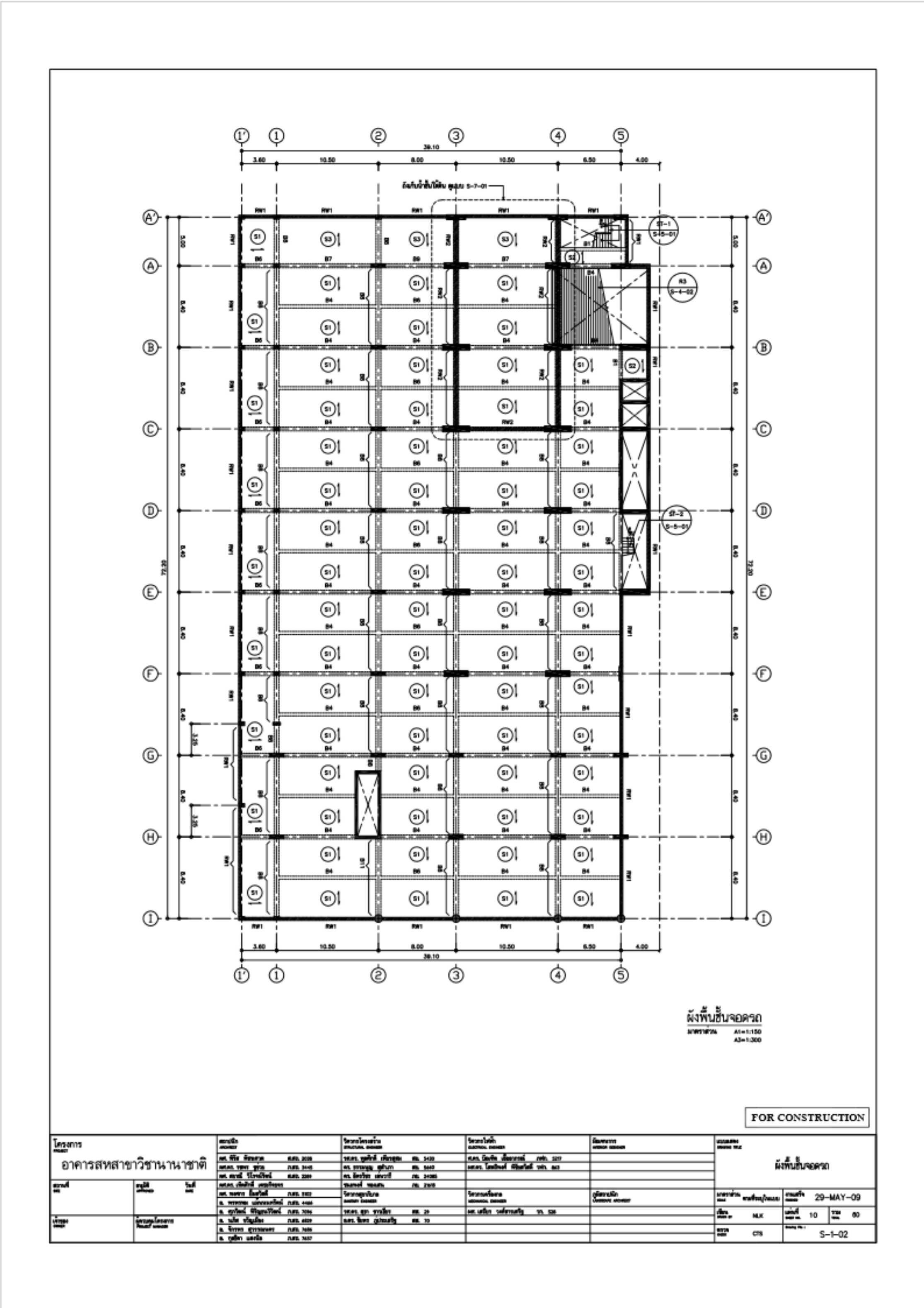
Appendix A

Structure plan of Chamchuri 10

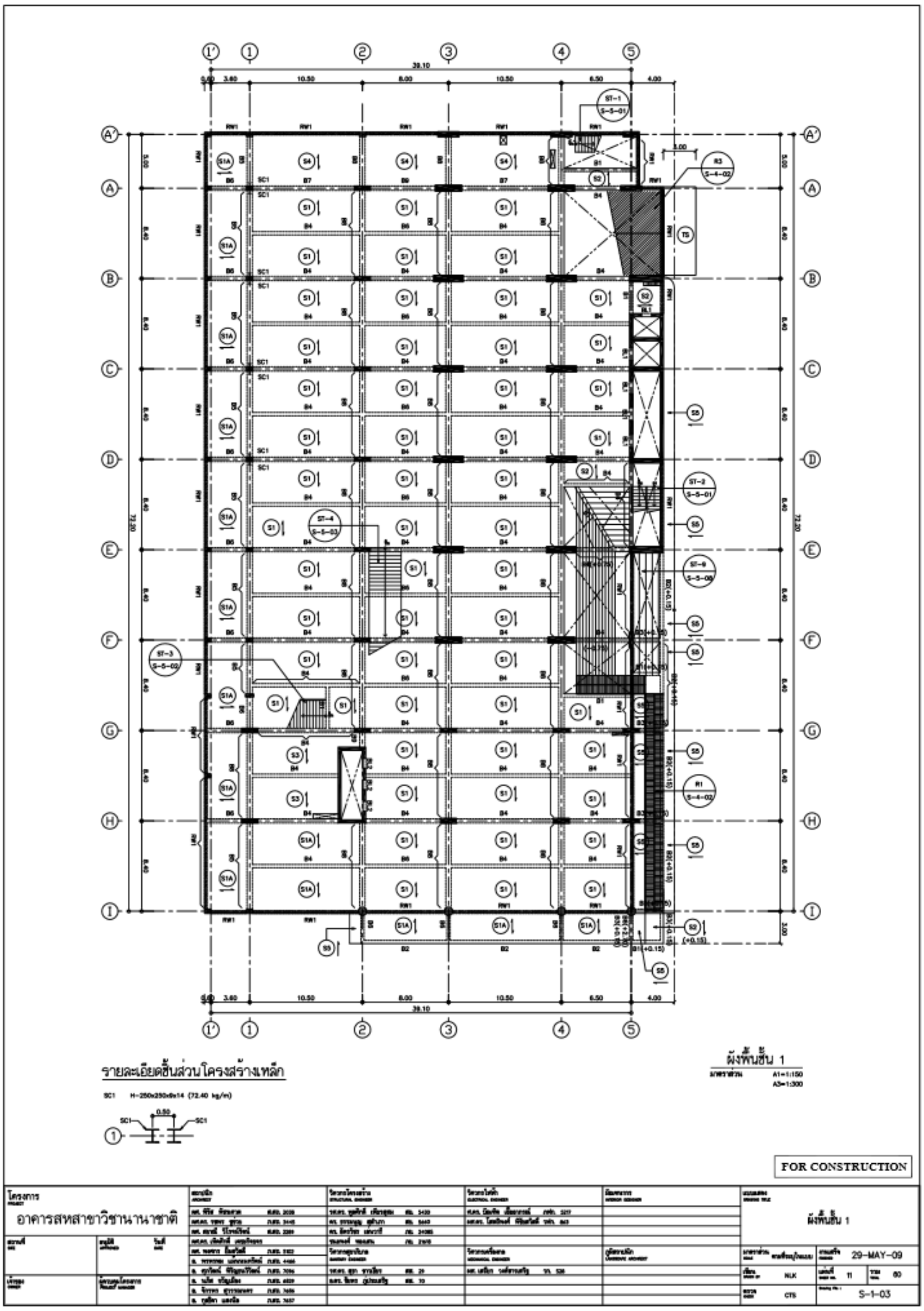
A1. Foundation plan of Chamchuri 10



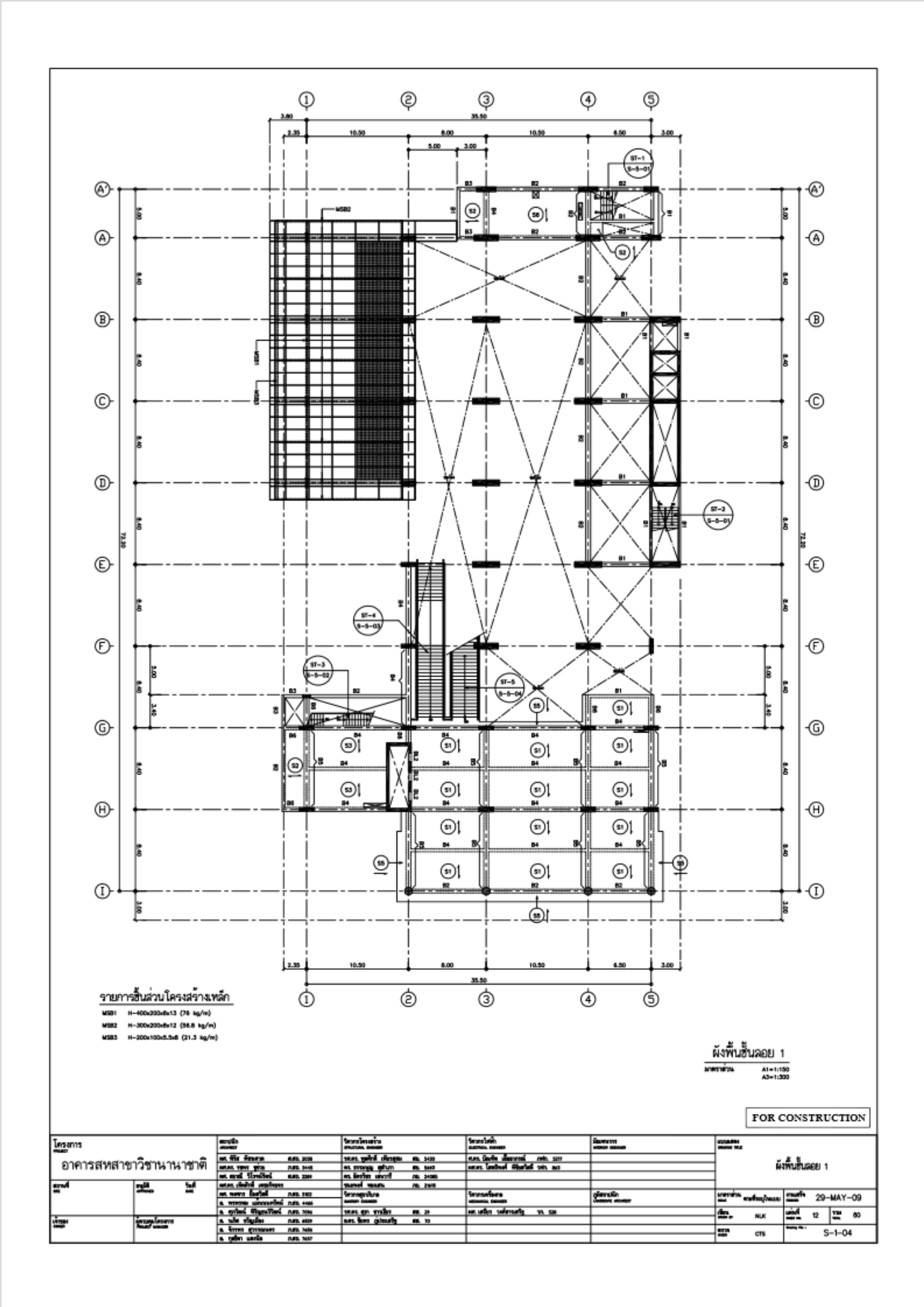
A2. Parking floor plan of Chamchuri 10



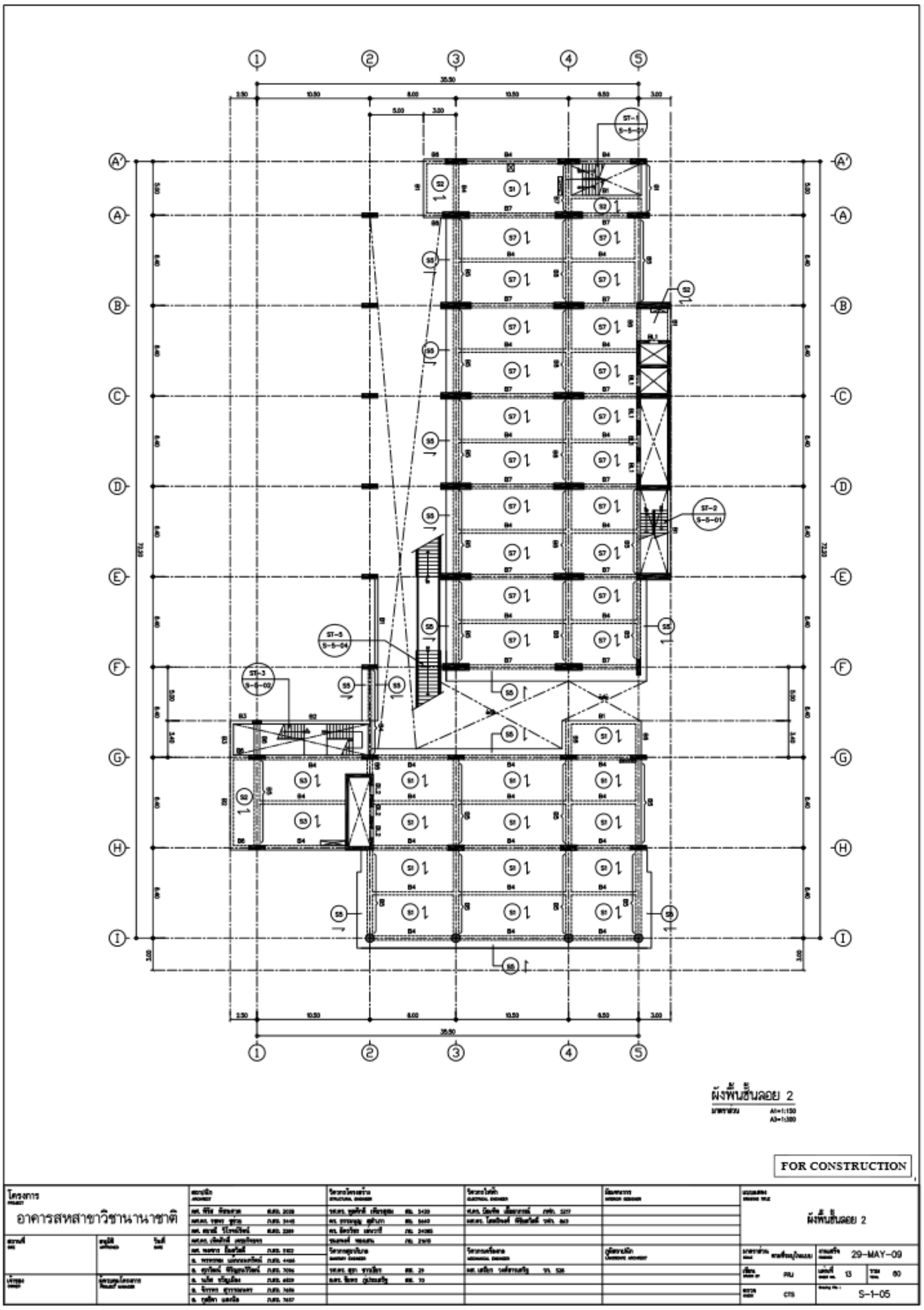
A3. Floor 1 plan of Chamchuri 10



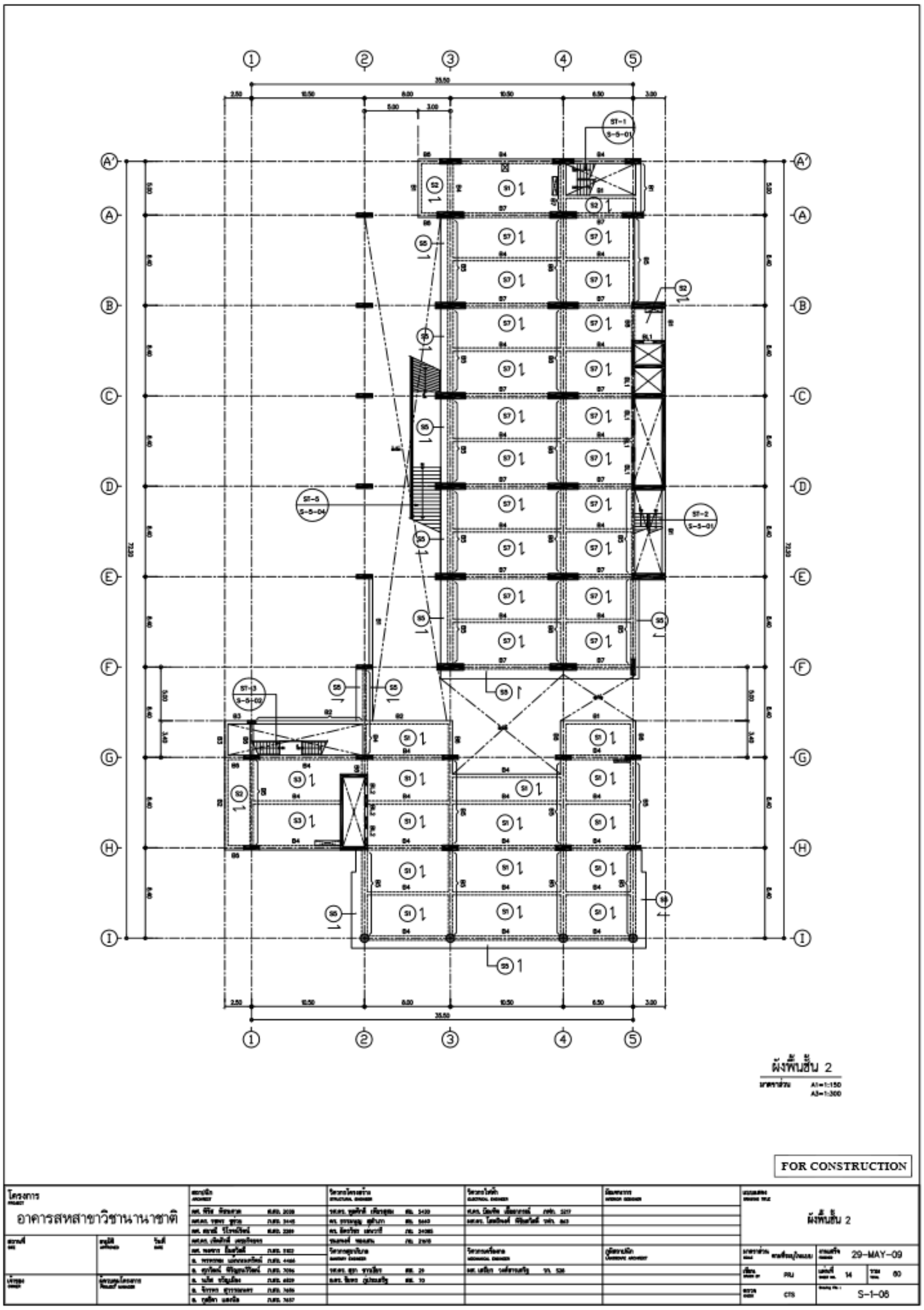
A4. M1 floor plan of Chamchuri 10



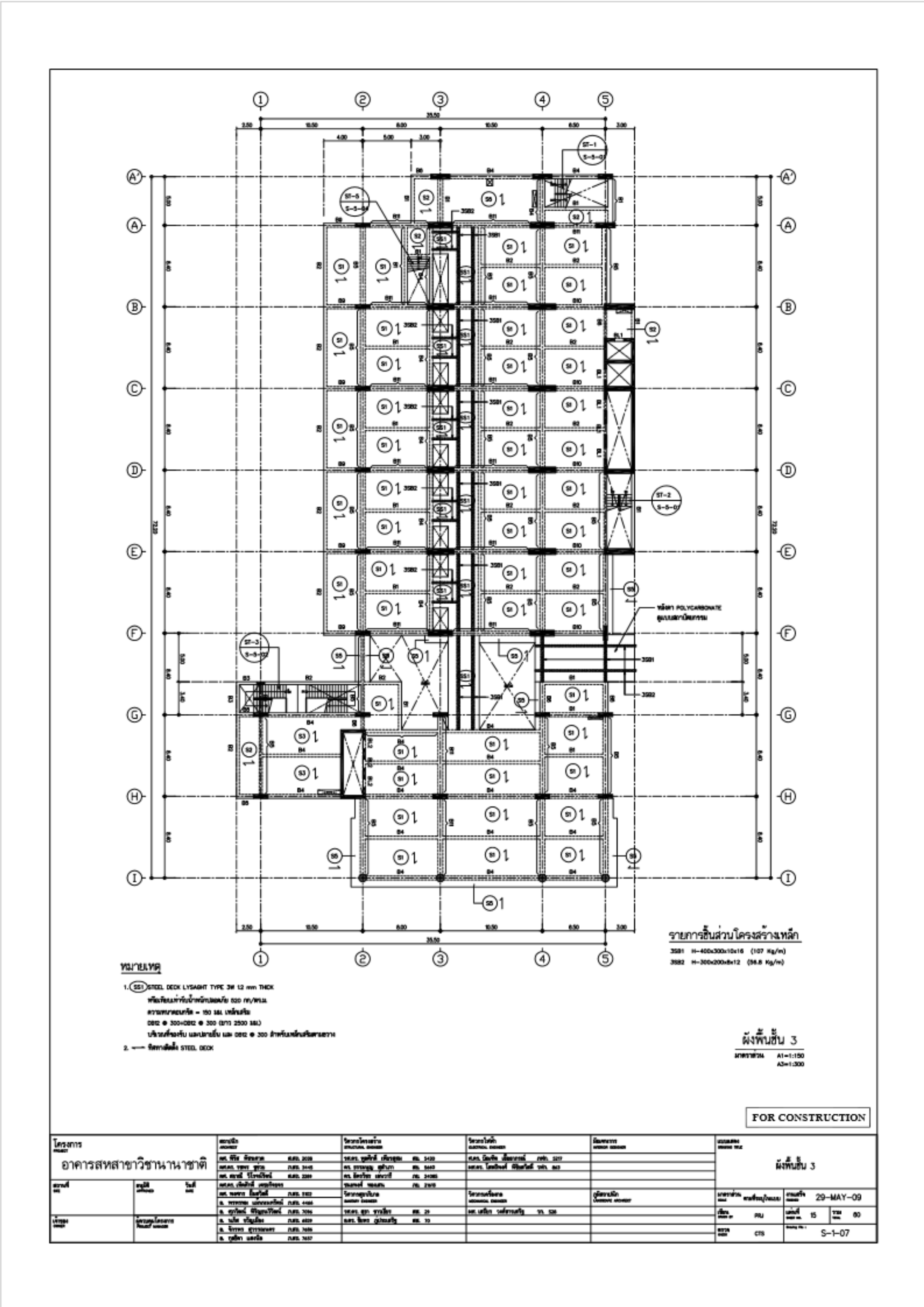
A5. M2 plan of Chamchuri 10



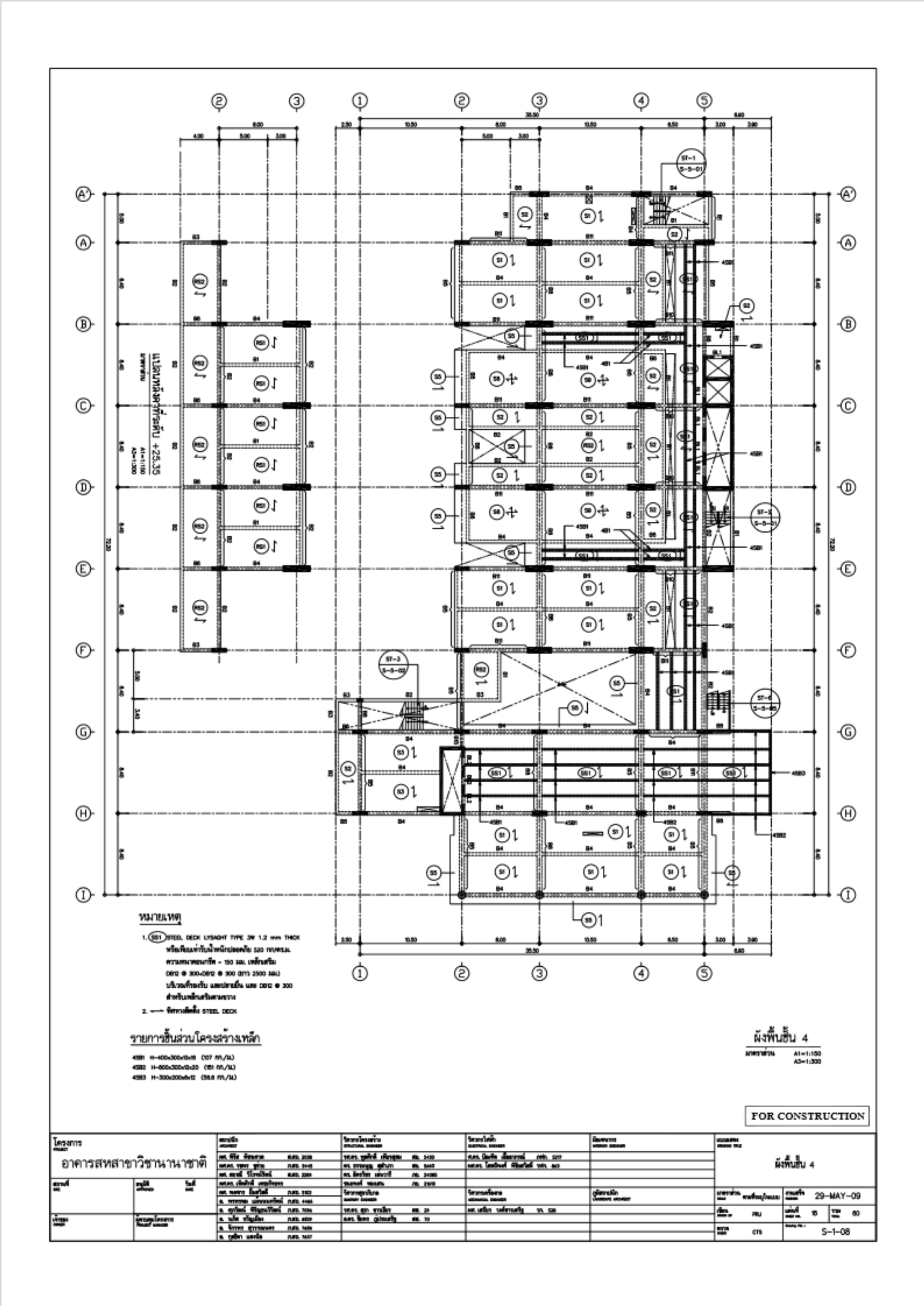
A6. Floor 2 plan of Chamchuri 10



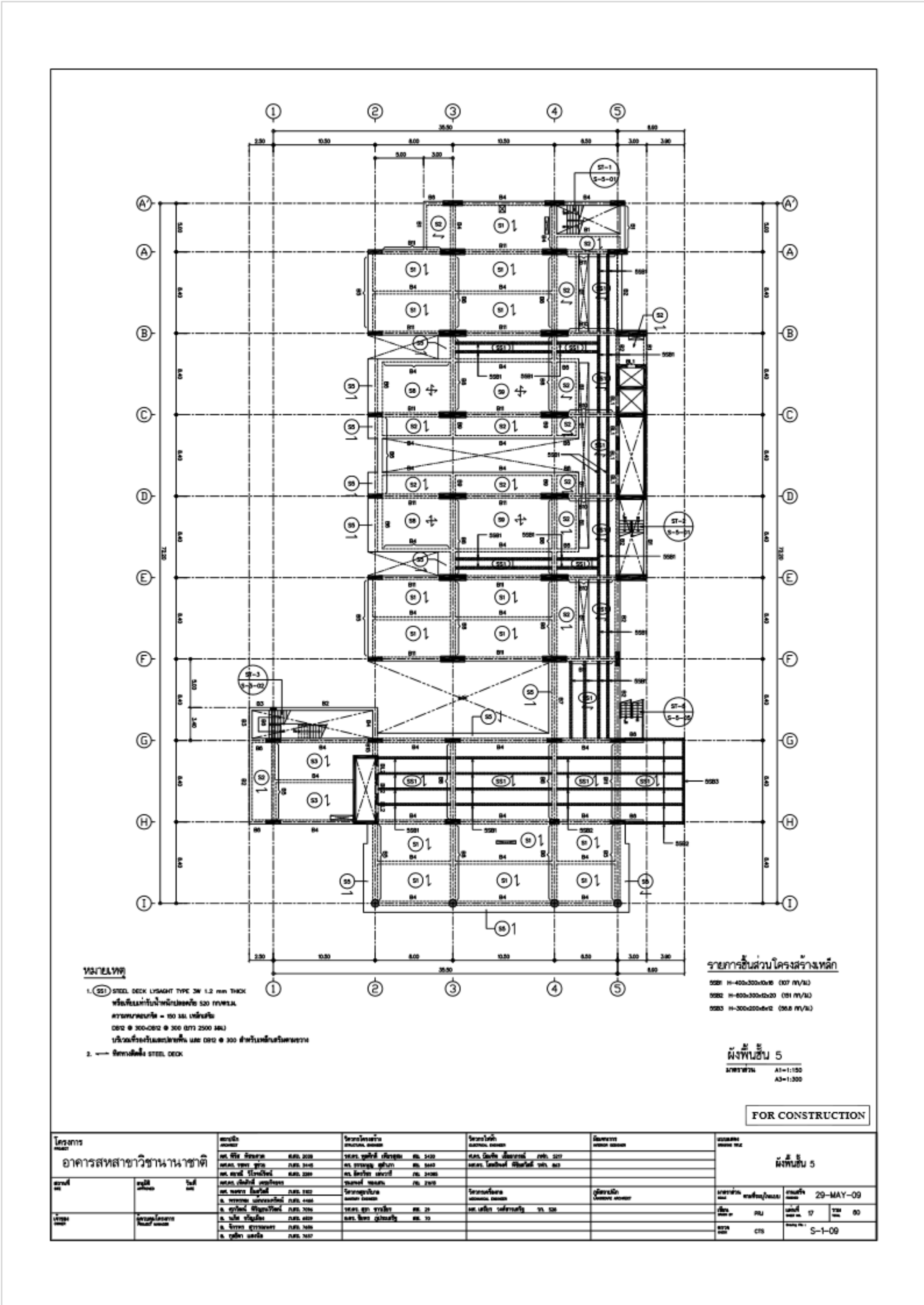
A7. Floor 3 plan of Chamchuri 10



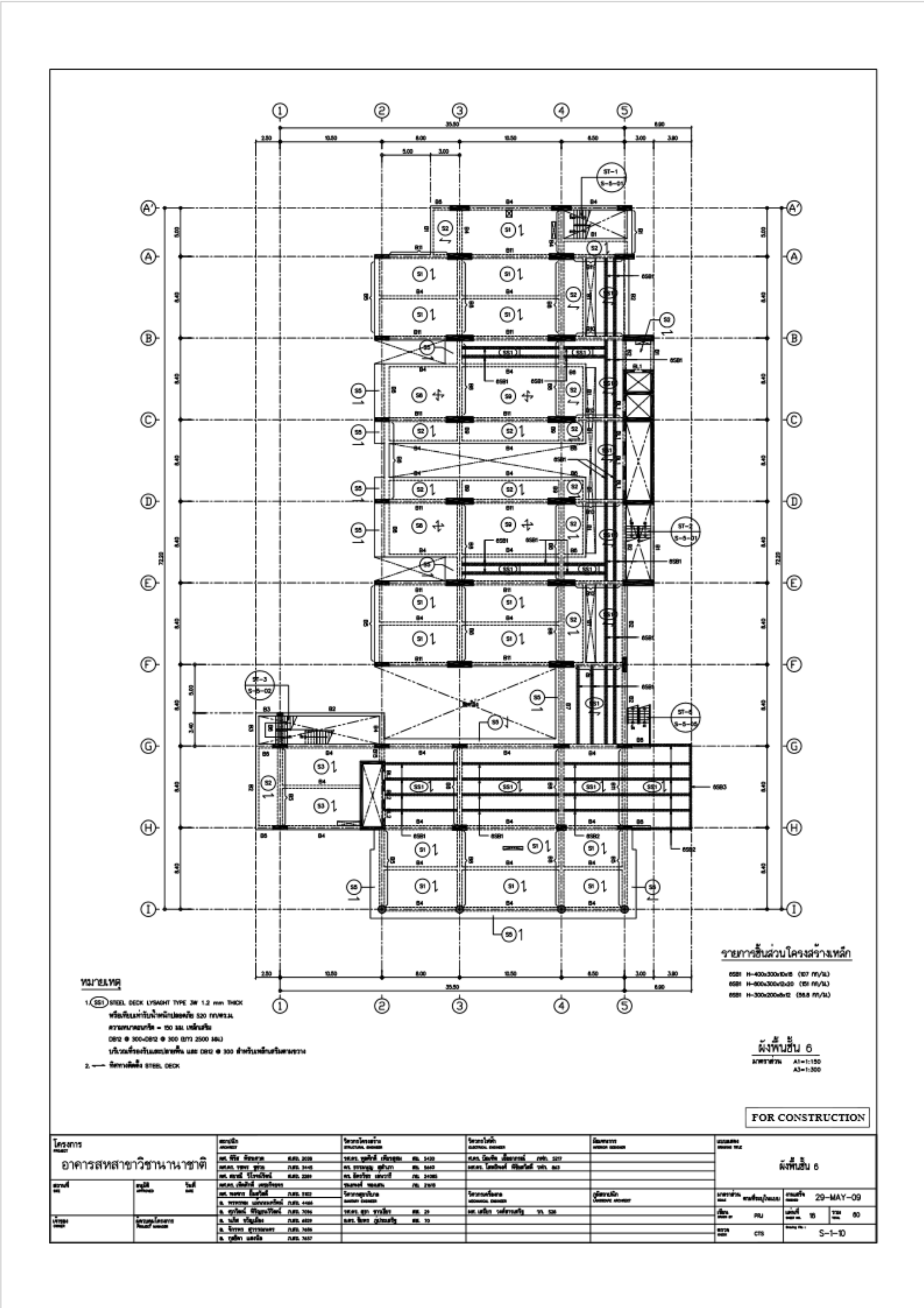
A8. Floor 4 plan of Chamchuri 10



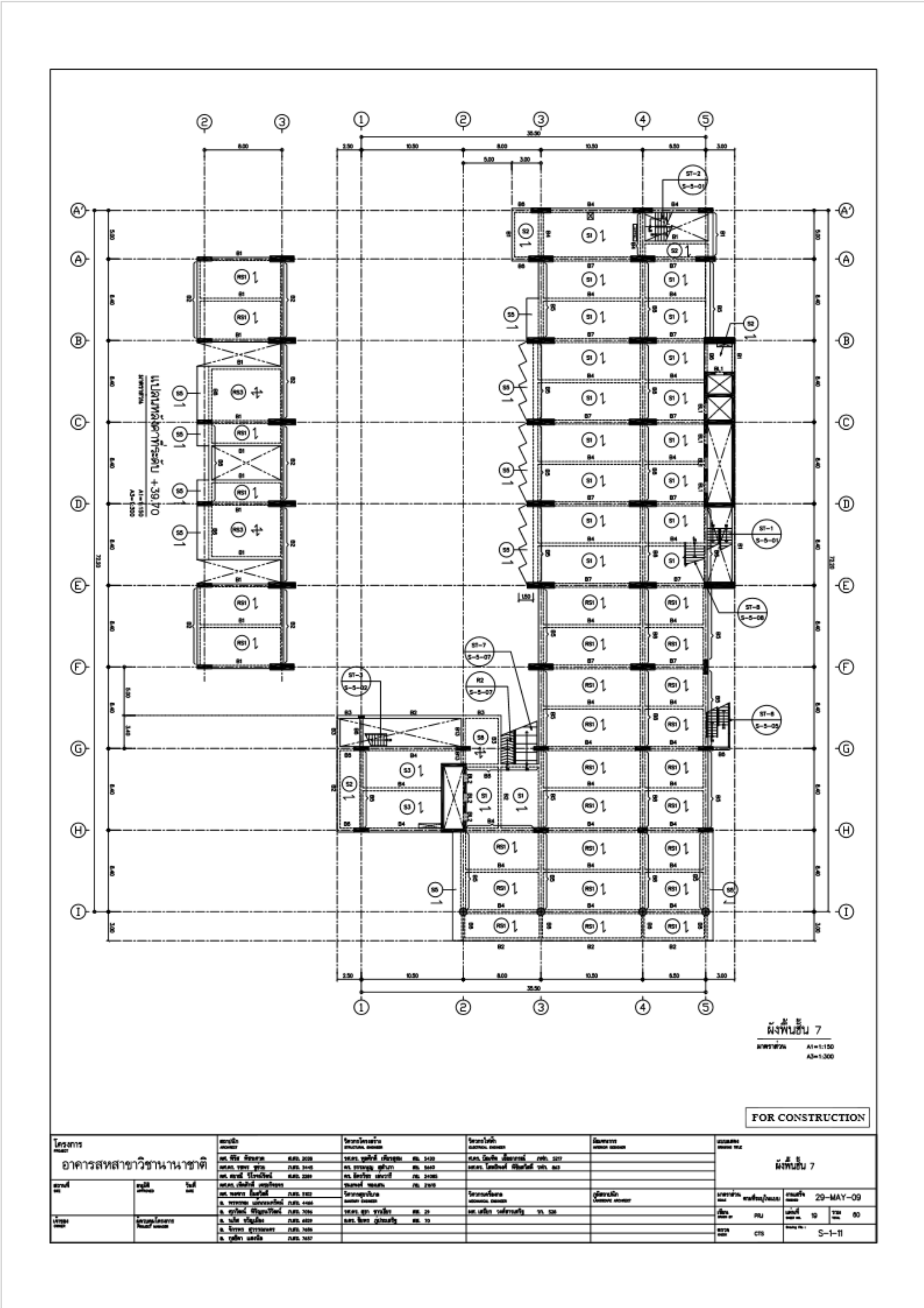
A9. Floor 5 plan of Chamchuri 10



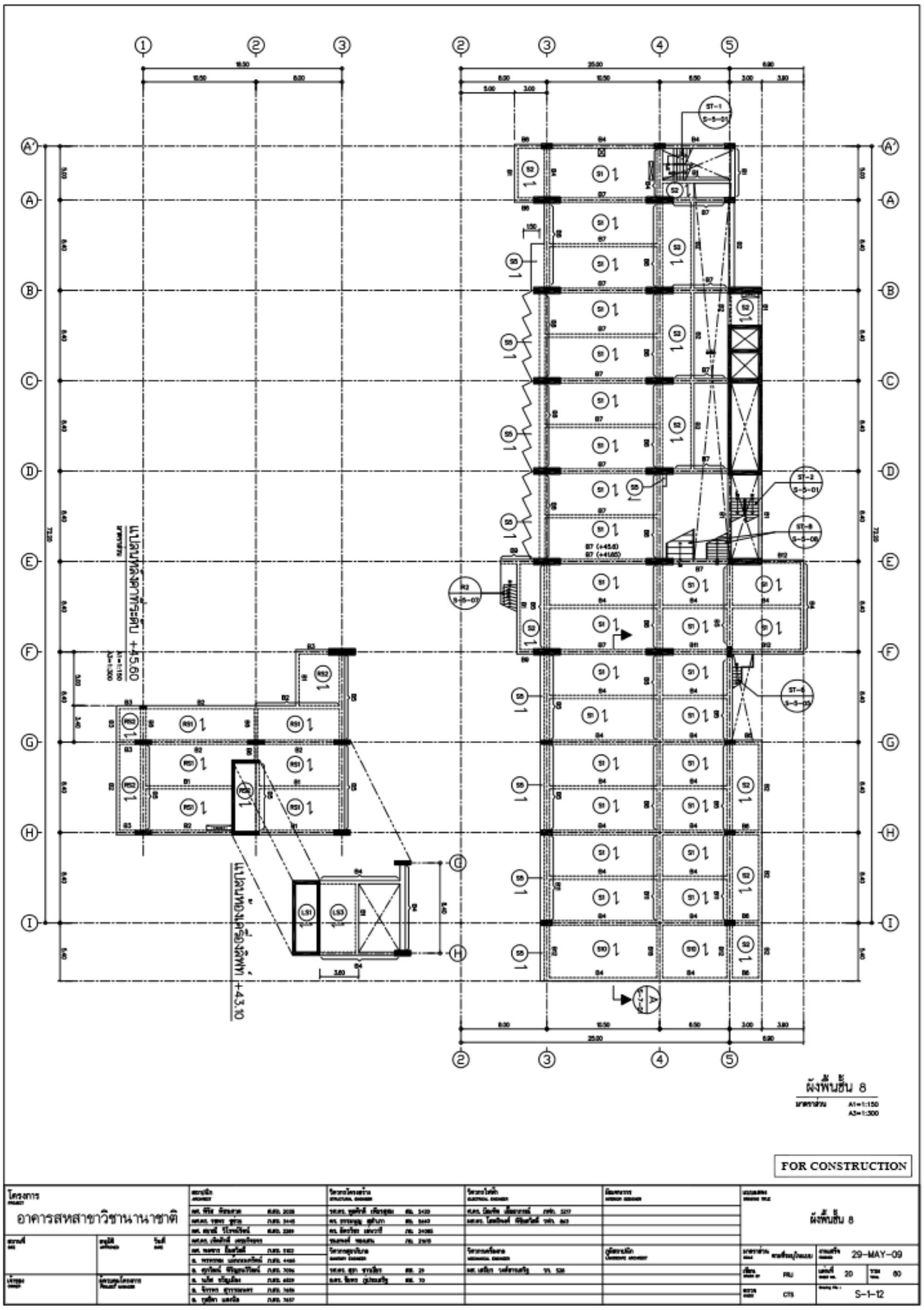
A10. Floor 6 plan of Chamchuri 10



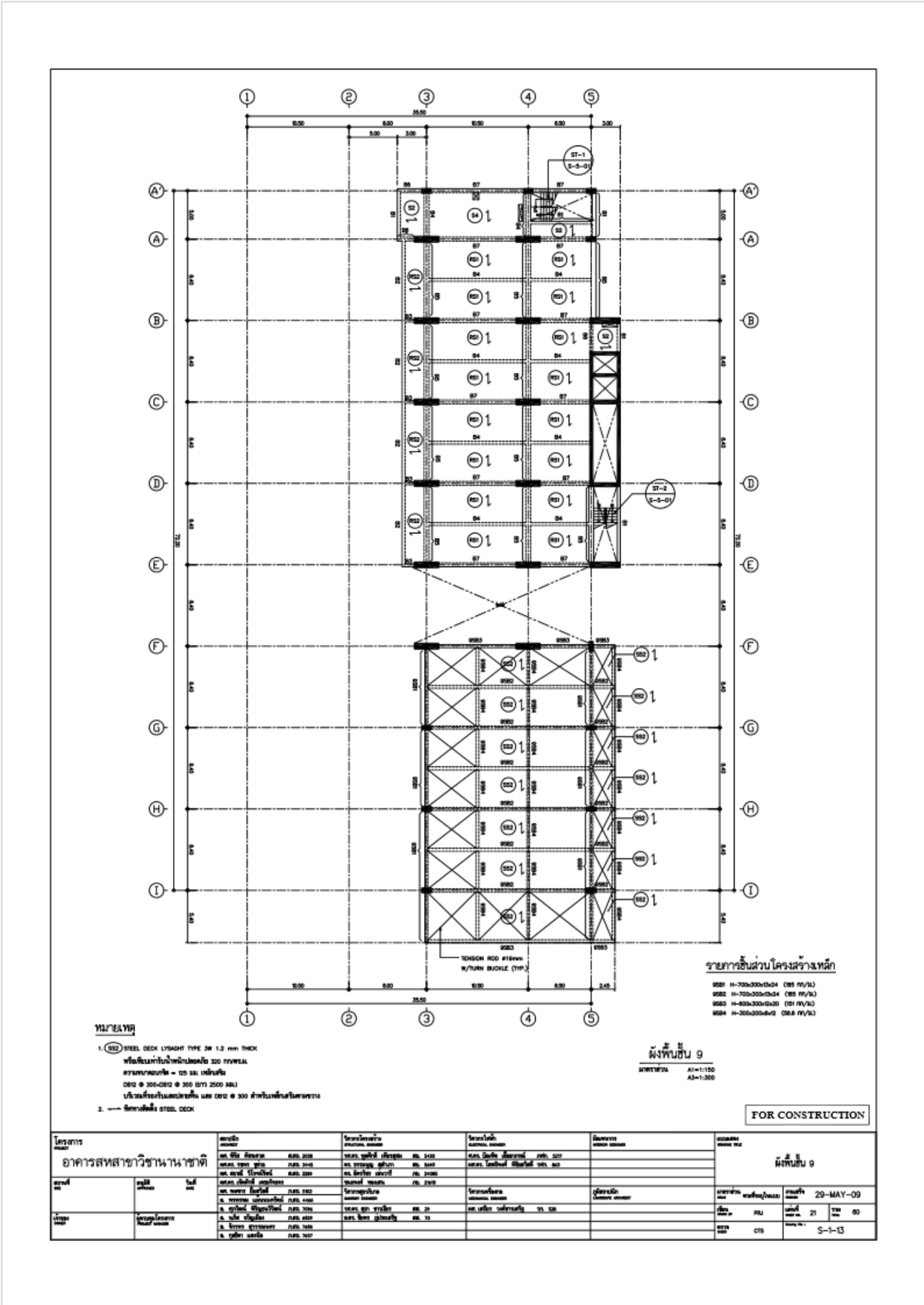
A11. Floor 7 plan of Chamchuri 10



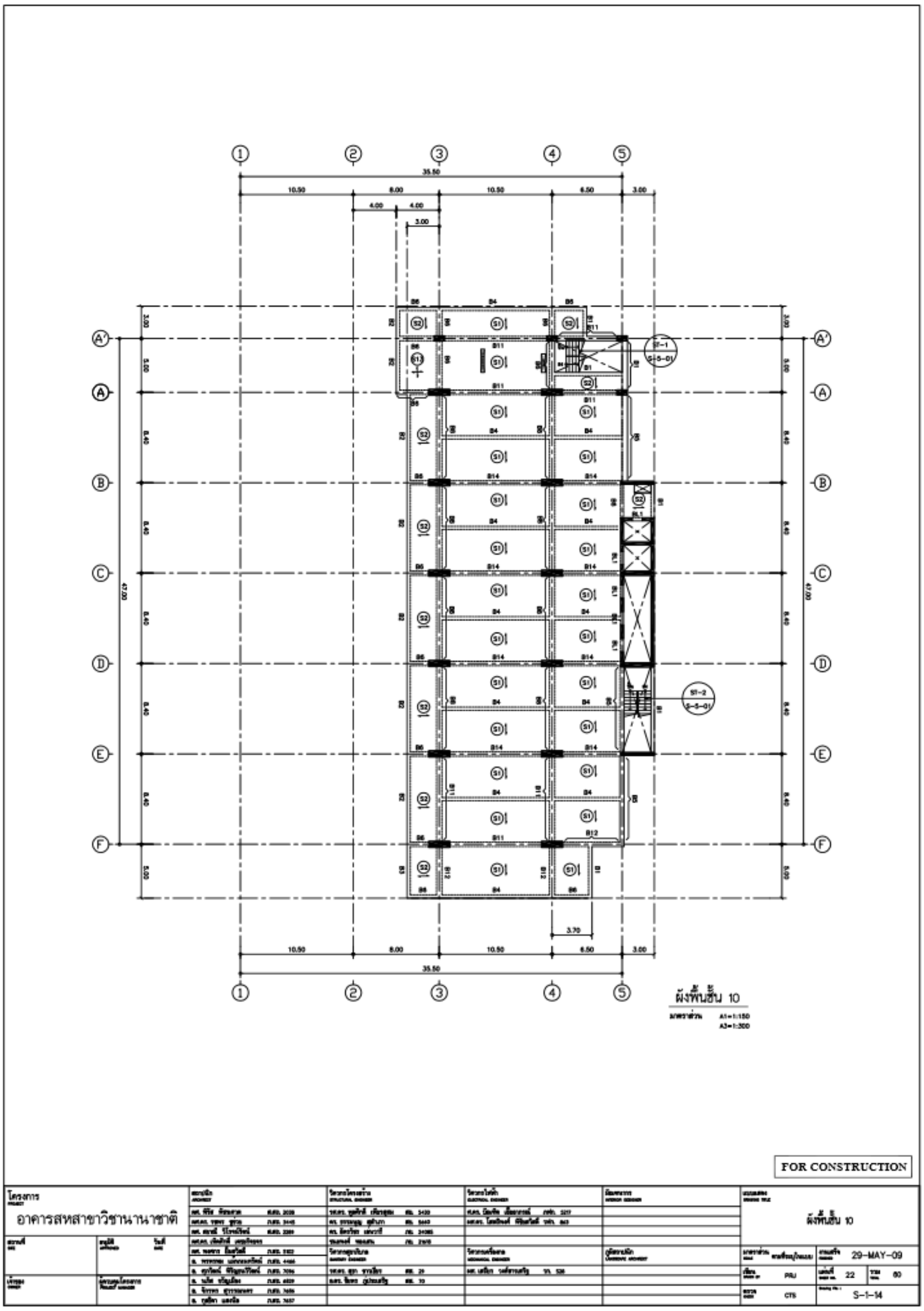
A12. Floor 8 plan of Chamchuri 10



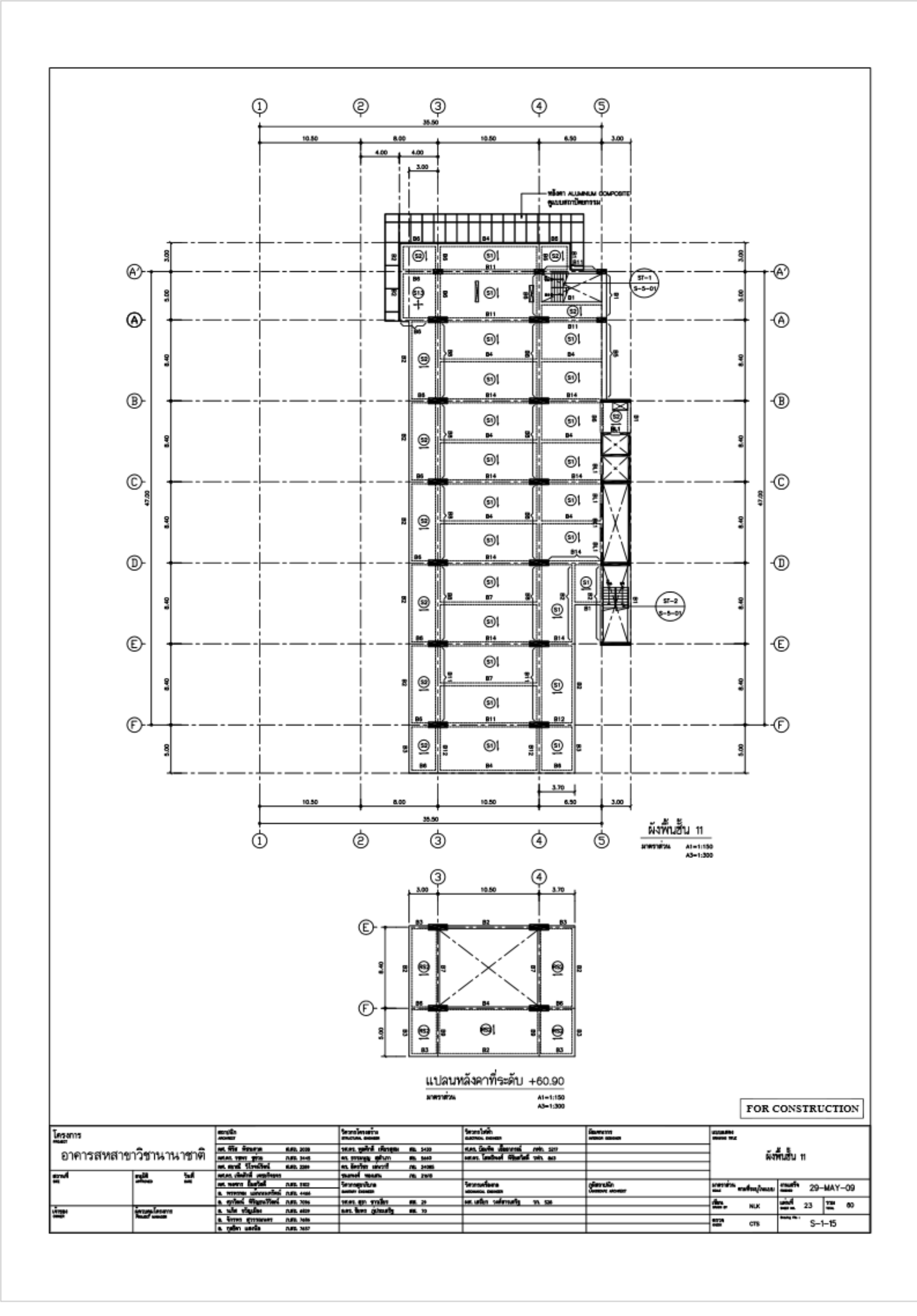
A13. Floor 9 plan of Chamchuri 10



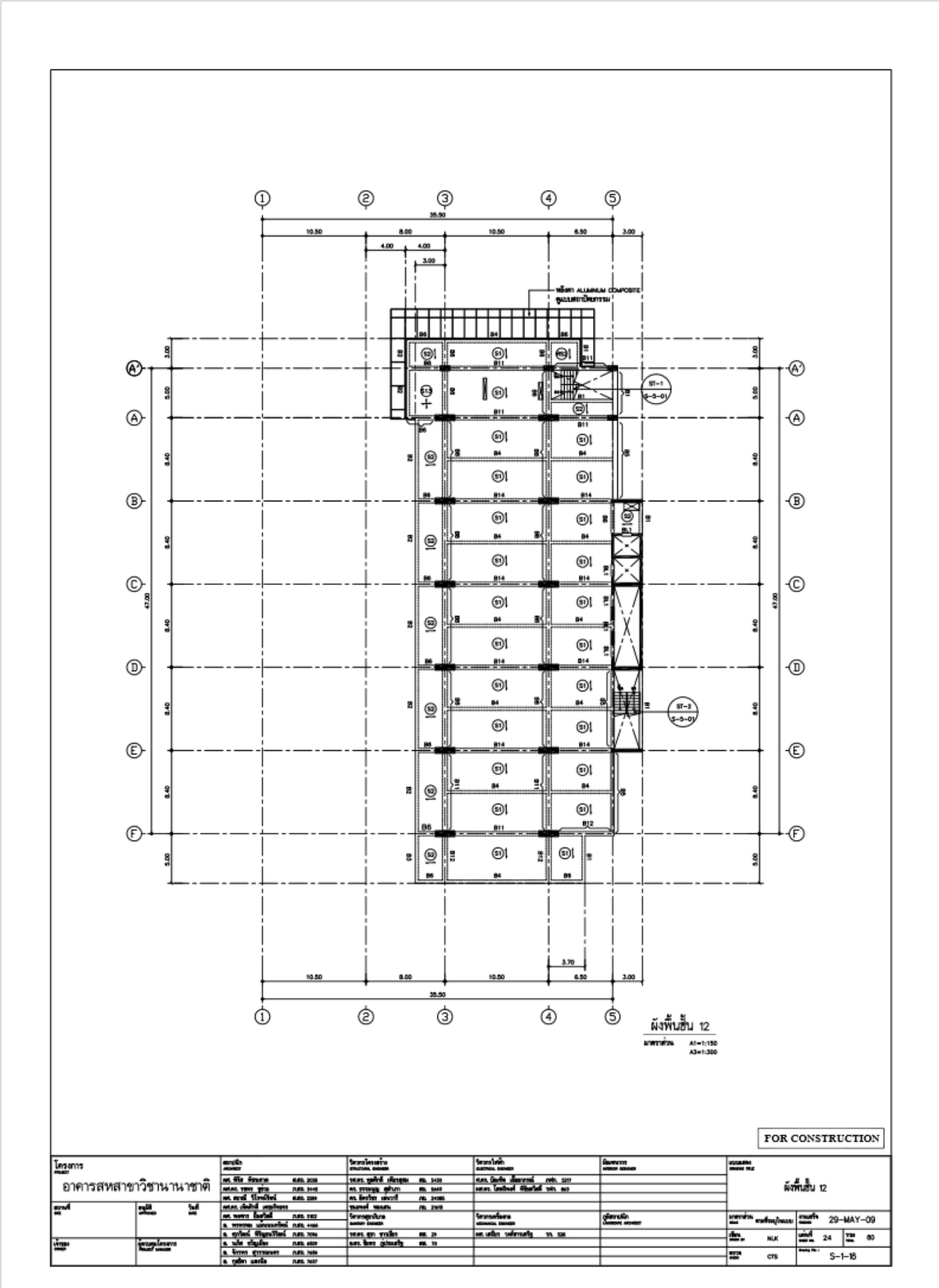
A14. Floor 10 plan of Chamchuri 10



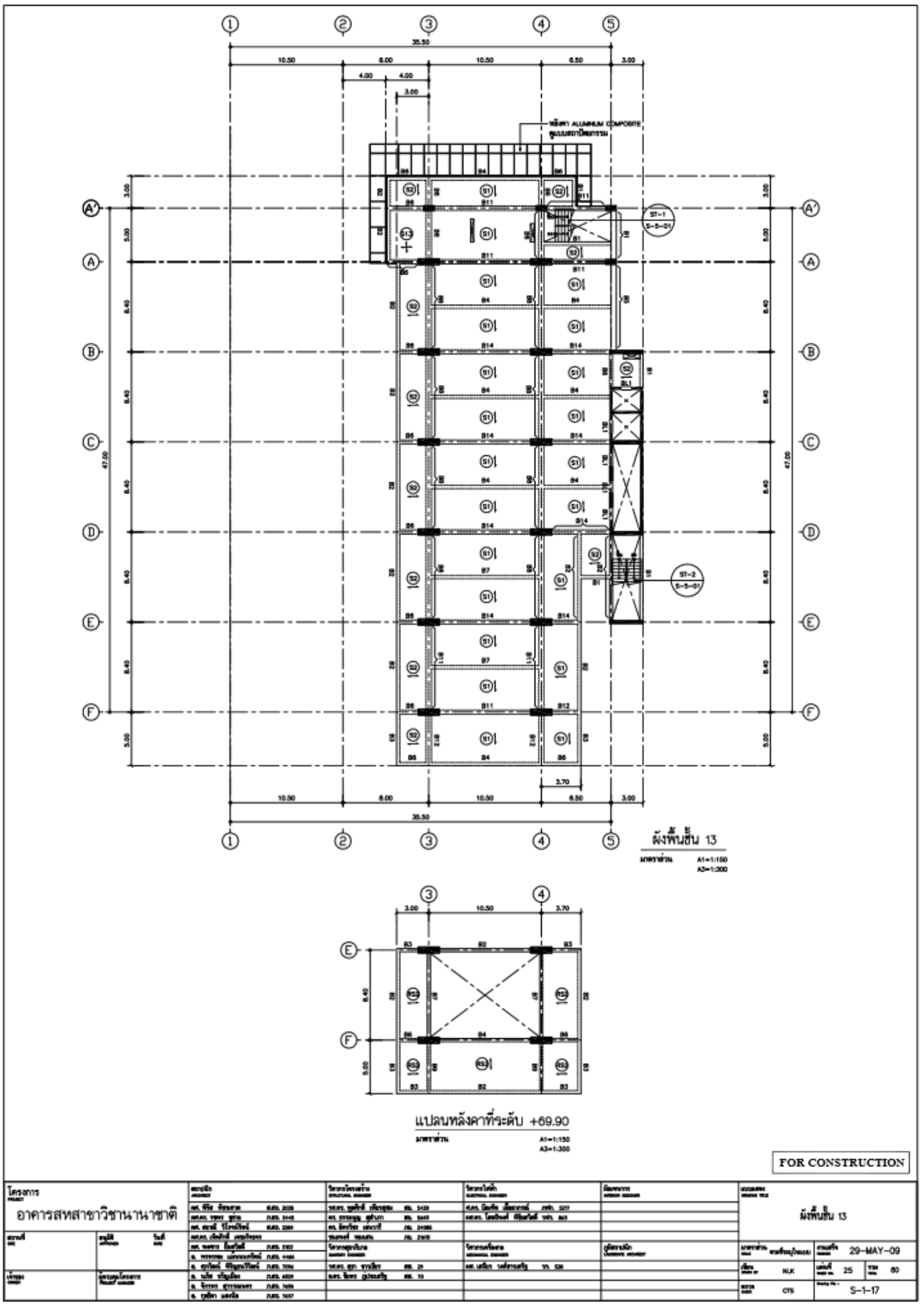
A14. Floor 11 plan of Chamchuri 10



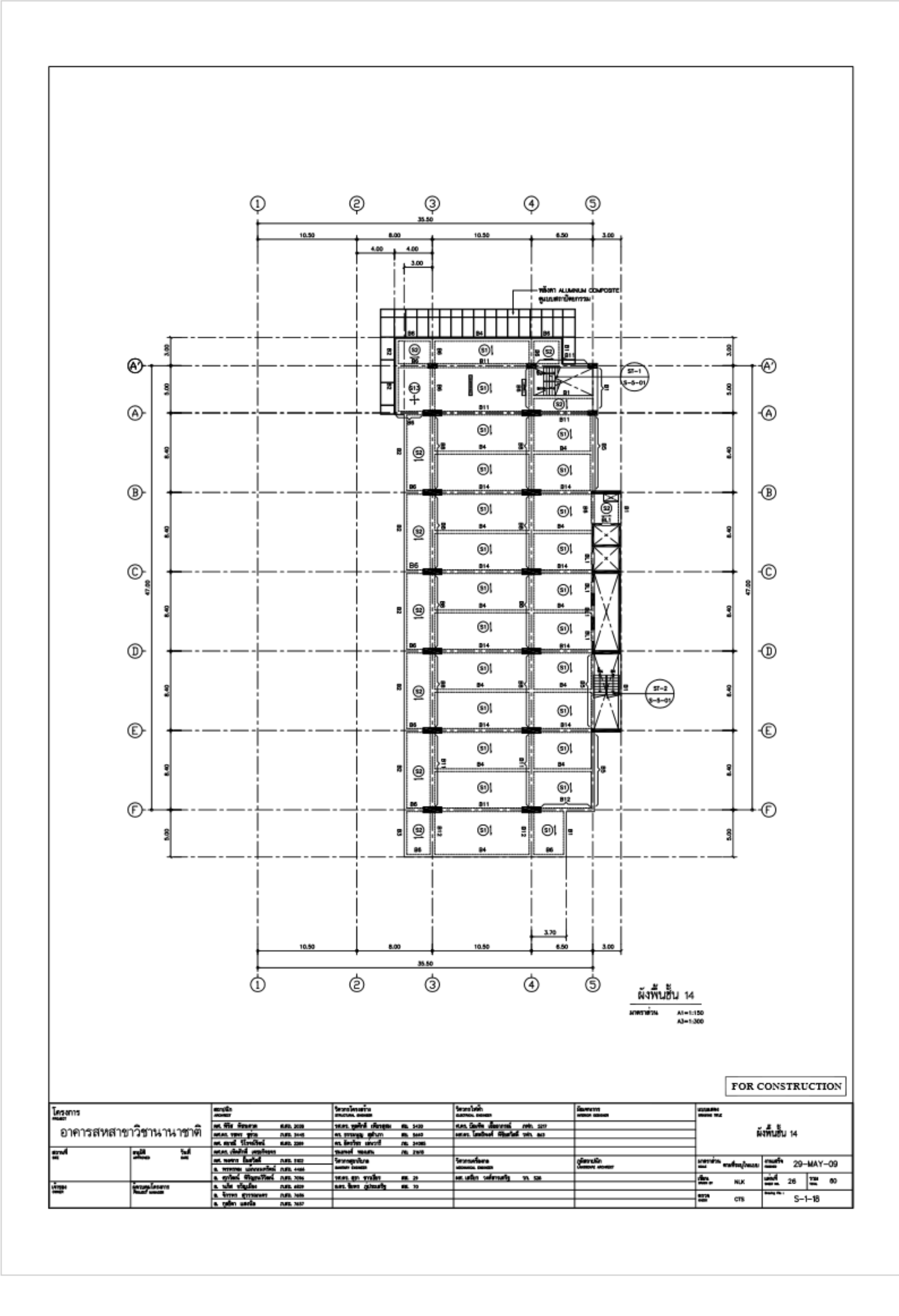
A16. Floor 12 plan of Chamchuri 10



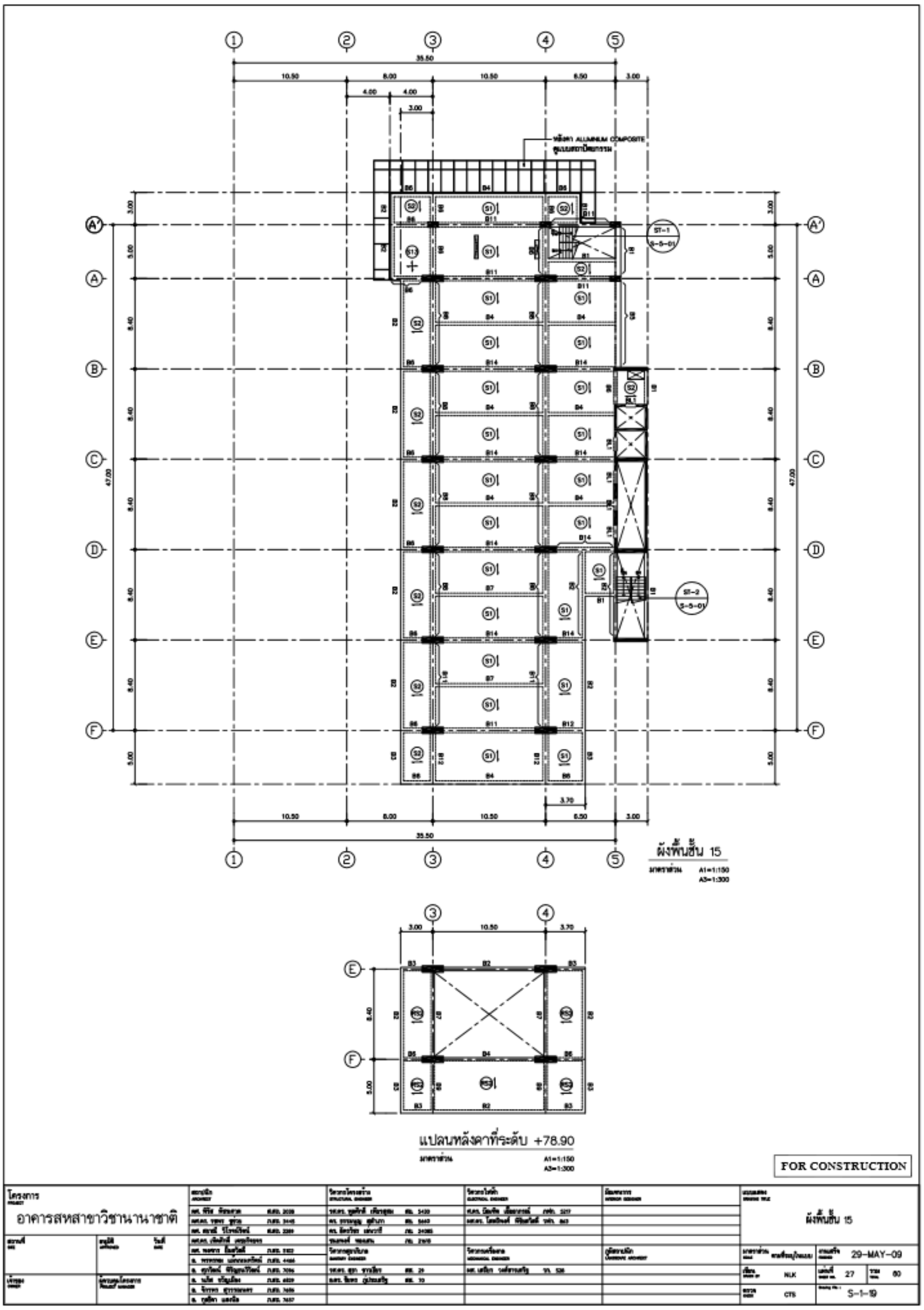
A17. Floor 13 plan of Chamchuri 10



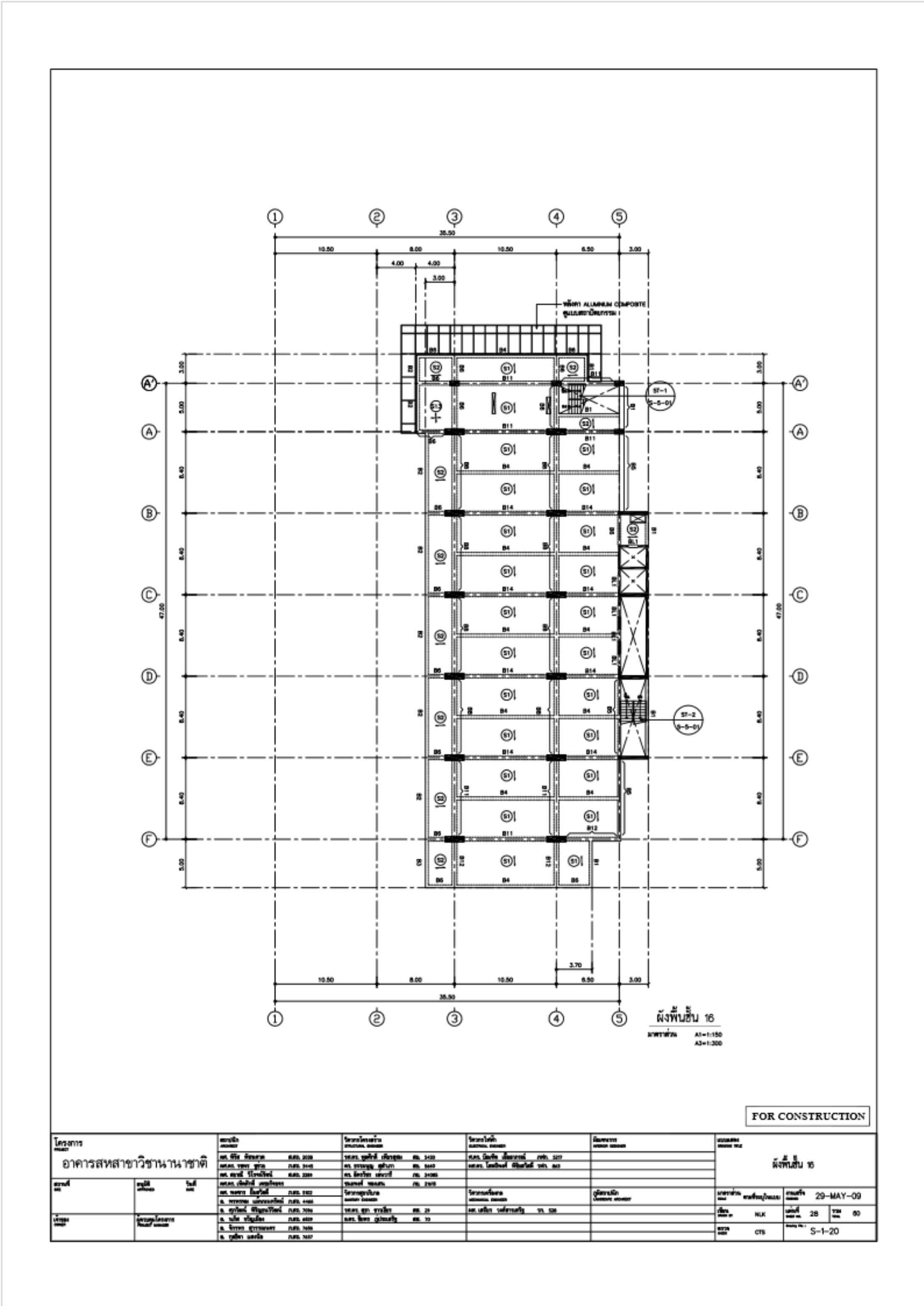
A18. Floor 14 plan of Chamchuri 10



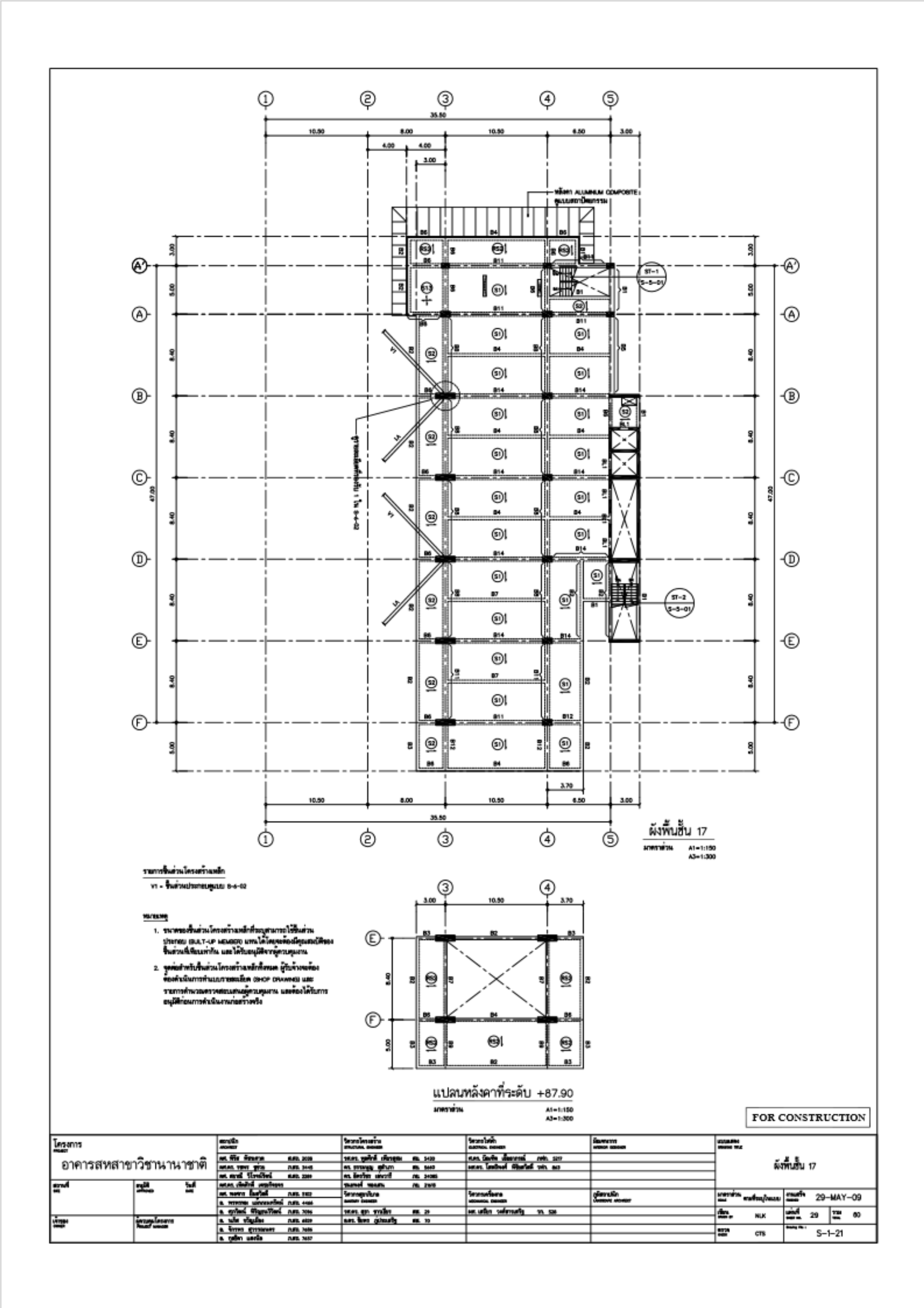
A19. Floor 15 plan of Chamchuri 10



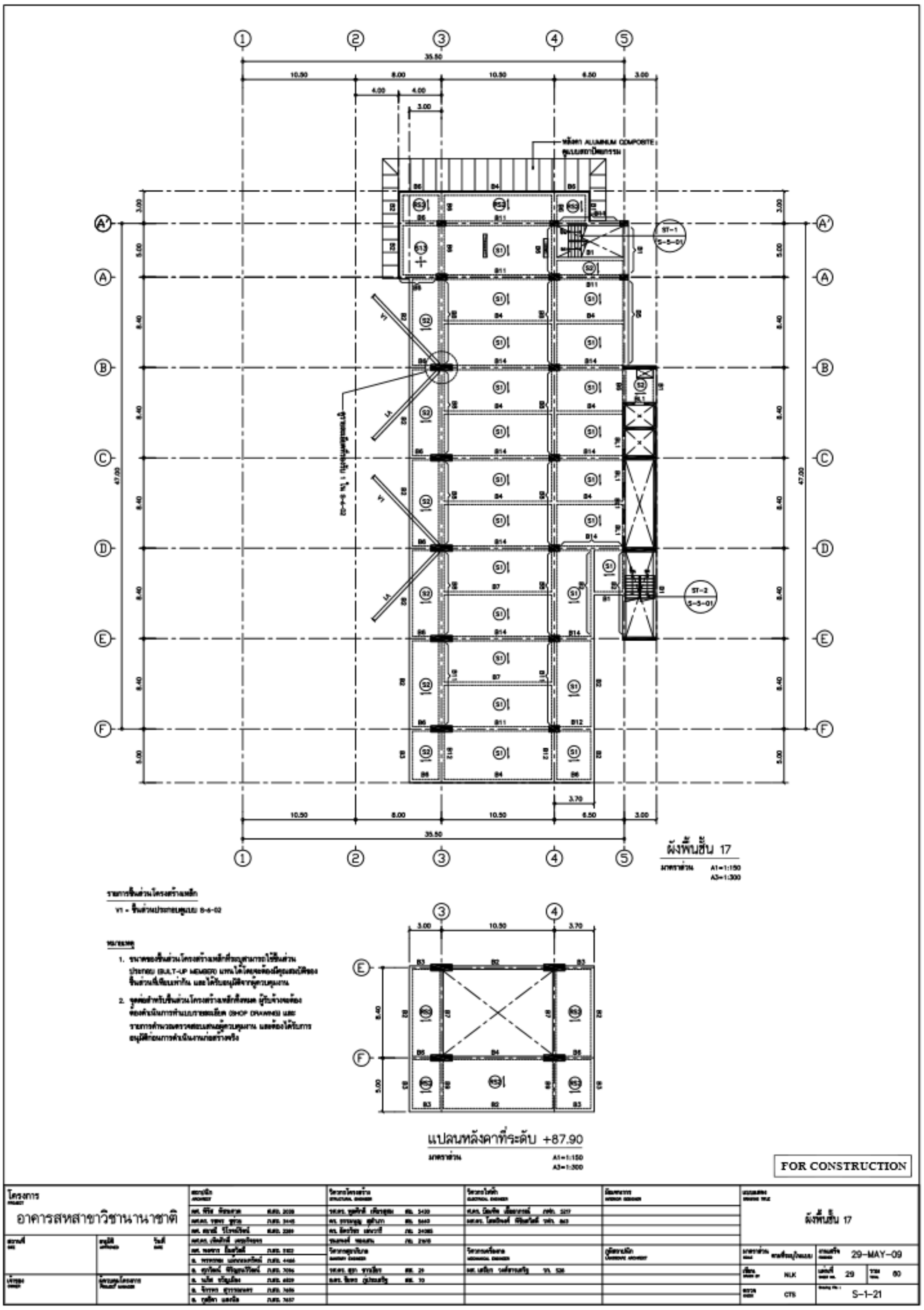
A20. Floor 16 plan of Chamchuri 10



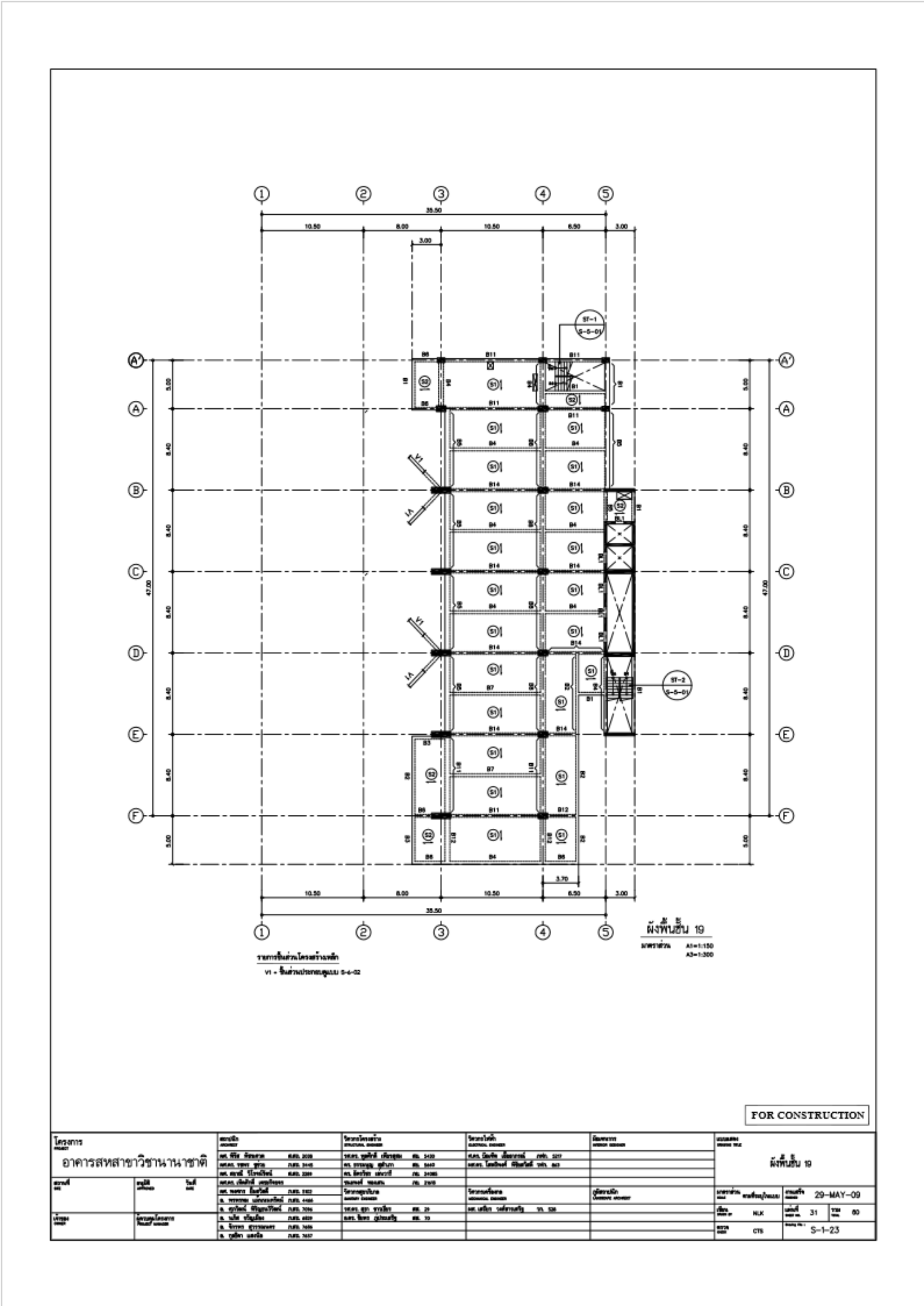
A21. Floor 17 plan of Chamchuri 10



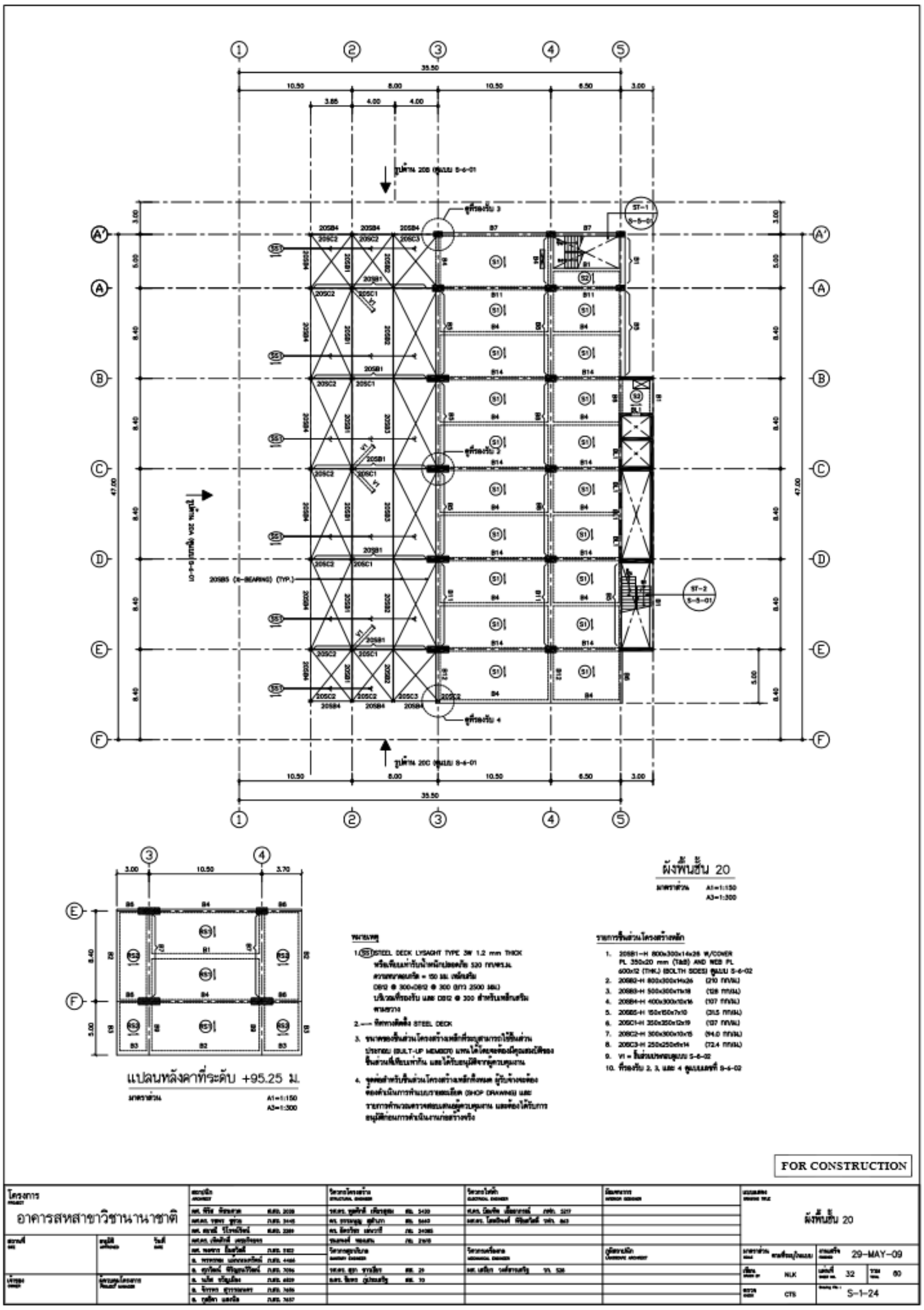
A22. Floor 18 plan of Chamchuri 10



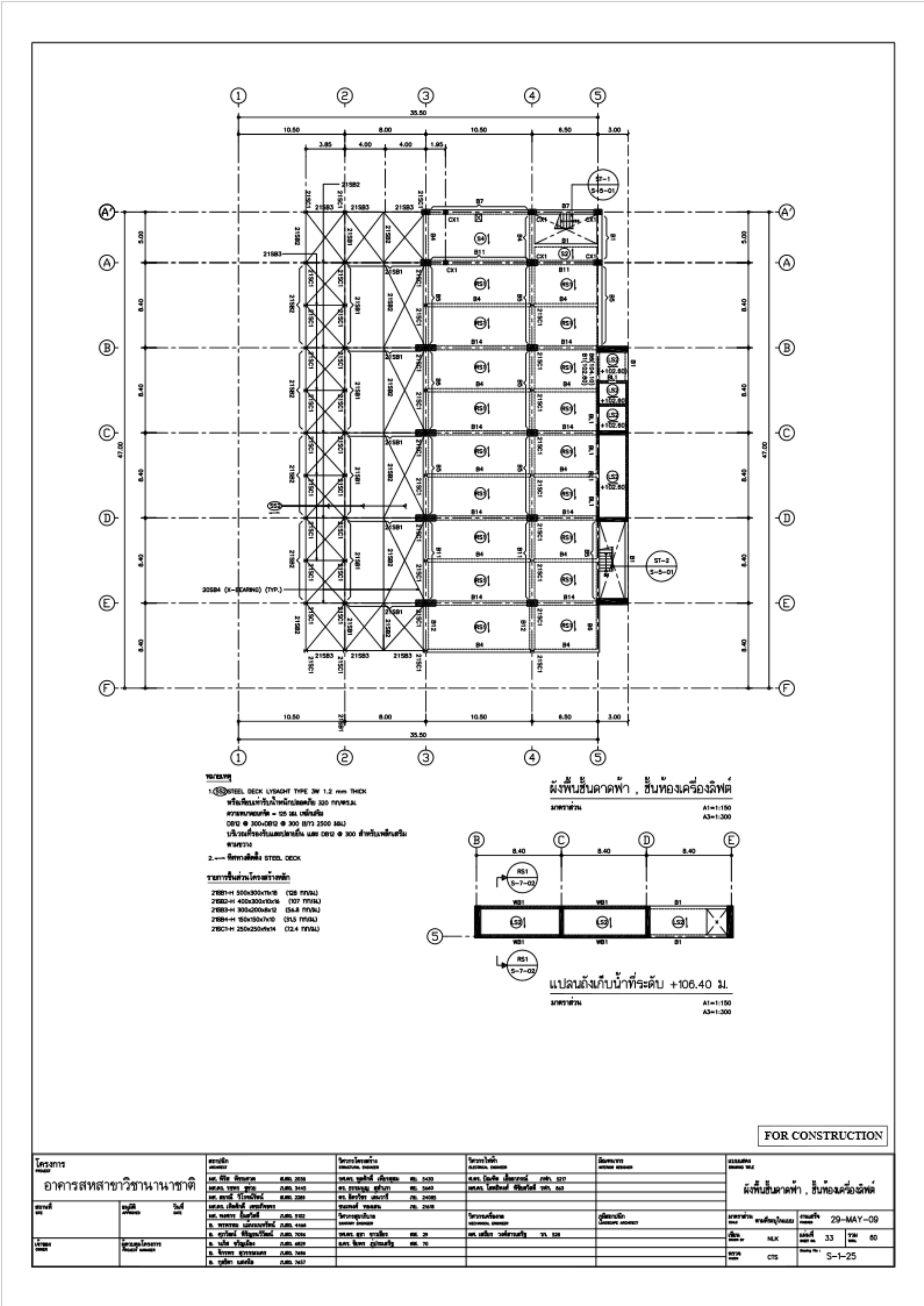
A23. Floor 19 plan of Chamchuri 10



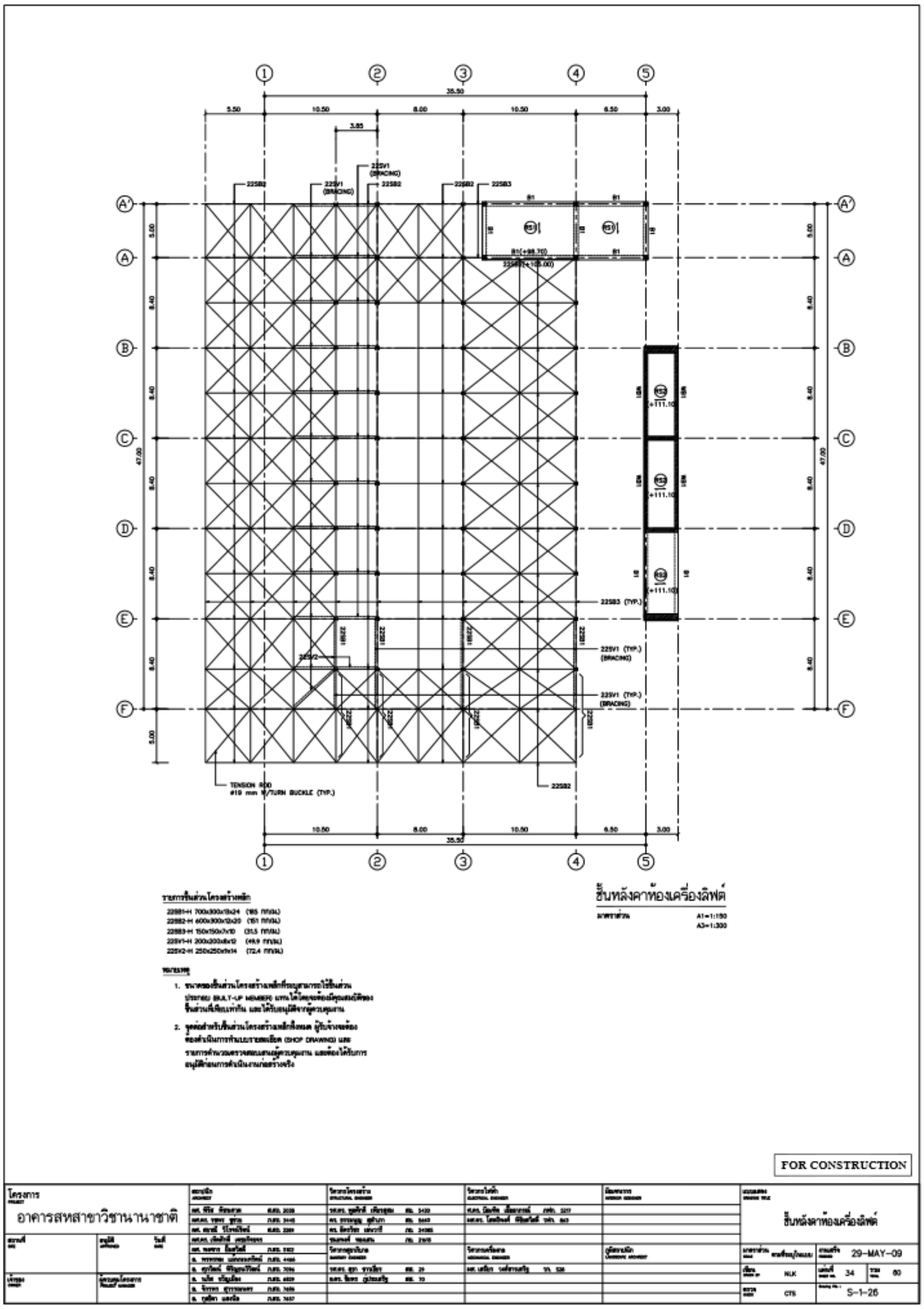
A24. Floor 20 plan of Chamchuri 10



A25. Desk floor plan of Chamchuri 10



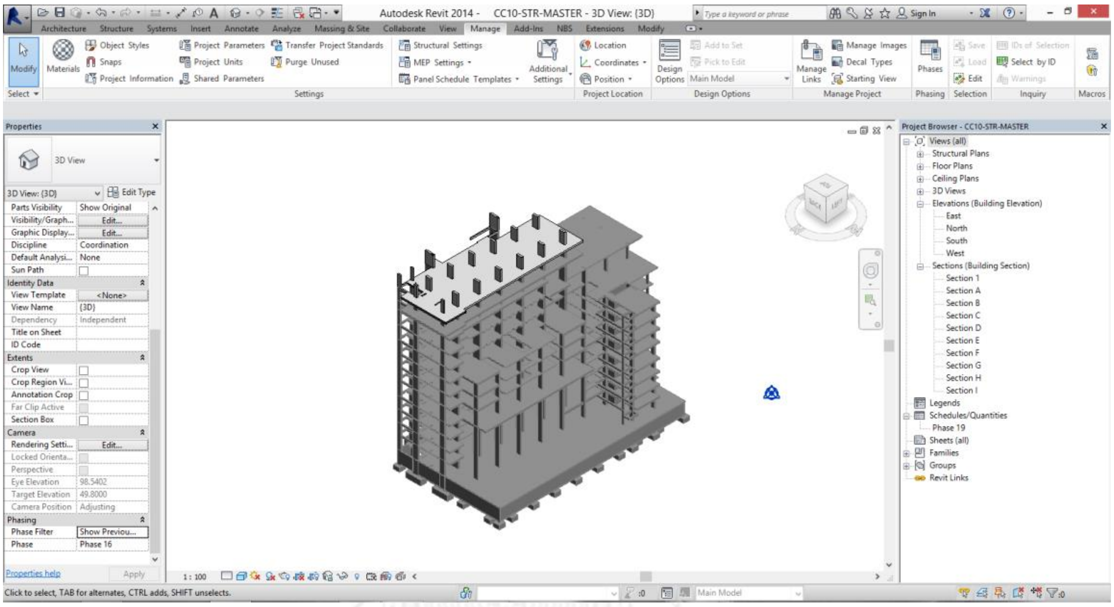
A26. Roof plan of Chamchuri 10



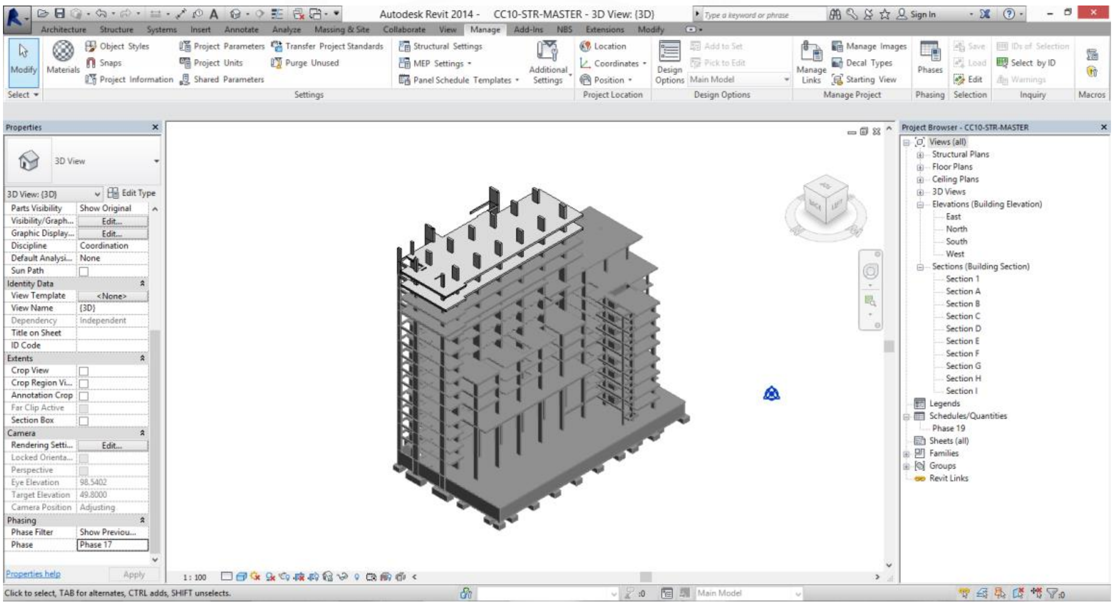
Appendix B

Construction phase in BIM-Master model file

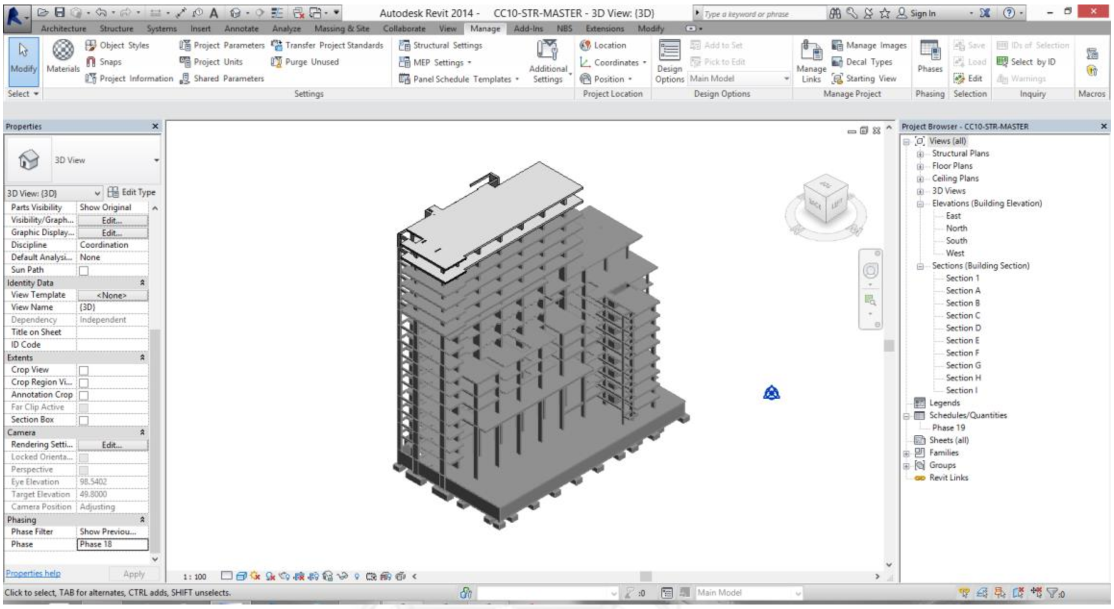
B.1 Construction phase 16



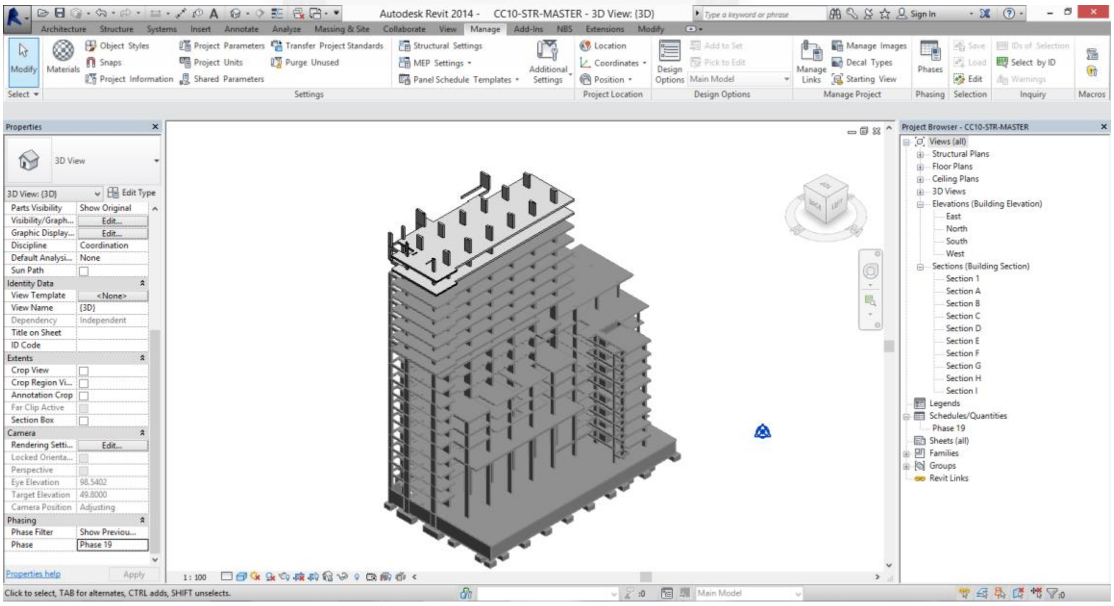
B.2 Construction phase 17



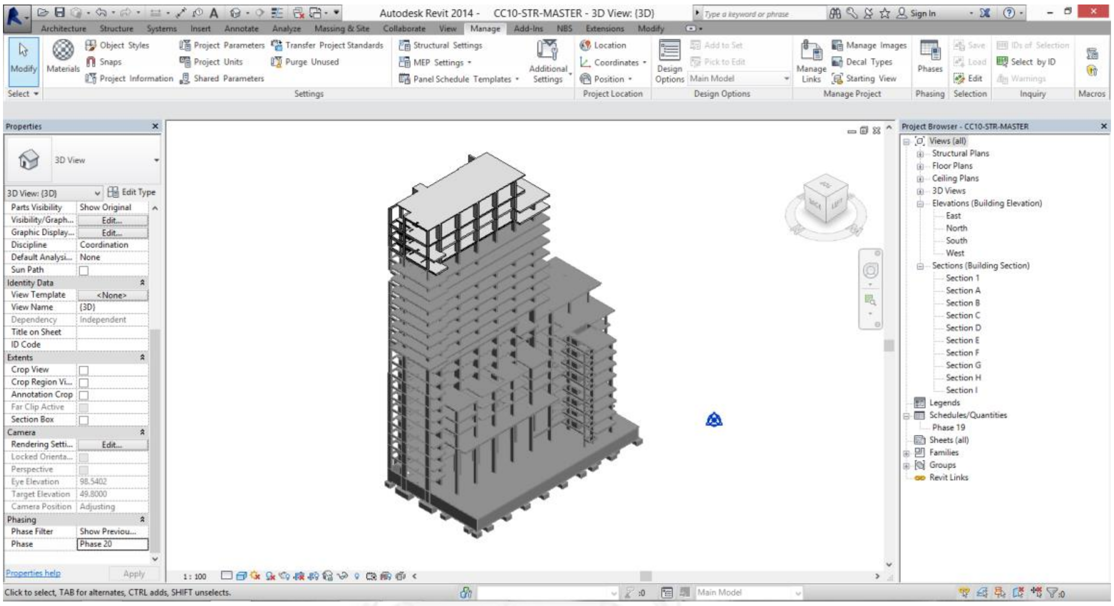
B.3 Construction phase 18



B.4 Construction phase 19



B.5 Construction phase 20



Appendix C

Actual site image in construction phase 19

VITA

Souksavath Losavanh was born in July 29, 1988 in LuangPraBang, Laos. He finished high school at Sun Ti Phap high school in 2005, he graduated Bachelor Degree of Civil Engineering at National University of Laos (NUOL) in 2010. He was awarded by CU-Neighboring country scholarship to continue his Master's study in field of construction engineering and management, Department of Civil Engineering, Faculty of Engineering, Chulalongkorn University, Thailand in 2011. The future plan after this studying, he would like to improve Lao construction industry.