# Abstract **(Most important part)**

NASA Control Room concept is an innovation strategy in Construction under the digital transformation strategy of smart city paradigm. By utilizing the NASA Control Room concept in Construction Industry, a remote working platform can be provided to enhance the collaboration between different stakeholders, managed the data effectively and provided insight to managers to set-up strategies and policy to enhance the construction safety during different stages of a construction project.

Model/Construction quality data….

With the emerging technology IoT (Internet-of-Things), the sensory data of the environment can be captured for making effective decision. The sensor data is collected from xx-July-2020 to xx-Aug-2020 in a local factory in Hong Kong to demonstrate the entire control room concept.

This dissertation researches different ways to visualise the data, which can act as a prototype to show how different parties in the AEC industry to make decisions in an innovative way.

It shows that the BIM360 working platform and web viewer can demonstrate the real time environment and collaboration of the site in a simple way. The VR Viewer can let us identify the site constraint remotely. And the power BI dashboard can provide insight from the construction quality and safety data.

The potential development of the control room can be much further investigated.

# Introduction

# Overview of Construction Sector

-> How big and its importance to economy?

Construction has long been one of the largest sectors in the global economy. There is about $10 trillion spent on construction-related activities globally every year, which is equivalent to 13 percent of GDP and about 7 percent of working population over the world are working for the construction industry (McKinsey & Company, 2017). However, 98% of infrastructure projects are over budget or delayed around the world. The productivity of Construction industry is also lagging the global productivity by over 30% (Changali et al., 2015).

-> Collaboration

Construction sector is complex and dynamic in nature (Mohd Nawi et al., 2014), it consists of many parties at various stages such as planning, design, construction, and operation. The parties are mainly client, designer, contractor, and manufacturer who are involved from the beginning until the completion of the project. Over the years, construction project delivery practice among these parties are poor in collaboration such as isolation of working and inadequate co-ordination. As the project is delivered in a sequential manner, it would significantly affect the quality and the progress of the works in future stages.

Information Management

Apart from poor collaboration, information management is very poor in construction sector. The construction sector is labour-intensive and generates enormous amounts of information. It mainly includes calculation, drawings, project reports, tender documents, ...etc which are produced in the planning stage to the operation stage.

According to a research in China (Xu & Luo, 2014), it has identified and discussed many consequence on the communication and information transfer among different parties, such as the loss and inconsistent of information caused by fragmentation of parties and unorganised information system. There is a comprehensive statistic shows that around 43%, 12%, 3% of the project time lost due to inconsistent information, dislocation, and ambiguity respectively on a construction project in average.

Safety

Safety is also one of the main concerns as compared to other sectors. The construction sector has long been recorded with the highest number of fatalities and accident rate among all industry sectors globally. For example, it is about 79,000 construction workers suffered from work-related ill health (new or long-standing) and 30 fatal injuries in 2018/19 (HSE, 2019). There was also about 2.1% of construction workers suffering from a musculoskeletal disorder that they believed they got it during working. This rate is statistical significantly higher than the rate for workers across all industries (1.2%) [ibid]

# Smart City and Digital Transformation

Nowadays, the development of smart city is a fundamental basis of our city. The smart city framework focus on integrating all these systems effectively with linking the interrelationships between multiple city systems, the output can be efﬁciency multiplied (Cosgrave, 2017). Besides, there are 3 elements highlighted for smart cities (Harrison et al., 2010), which are instrumented, interconnected and intelligent. Instrumentation means capturing the data from the physical world by sensors; interconnection means the data should be integrated from different source and they can communicate each other, while intelligent means the data should be visualised and provide insight for making better decision.

To resolve the long-established barriers in Construction sector, an initiative Project 13 has been risen under the smart city paradigm to develop a new business model for the infrastructural projects. It is an industry-led response to delivery models that fail not just the stakeholders as mentioned before, but also the operators and the citizens of economic infrastructure. It aims to develop a new business model to increase certainty, productivity and improve outcomes from the project life cycle. Digital transformation is a key enabler of this new business model. (Radford, Jamie; Macdonald, 2020)

The construction process should have a revolutionary change to solve the to build a smart city under this initiative.

# Scope of Research

Therefore, an integrated solution such as Control Room in construction will be investigated in this dissertation to optimise and effectively control the information generated and improve the project delivery in construction stage.

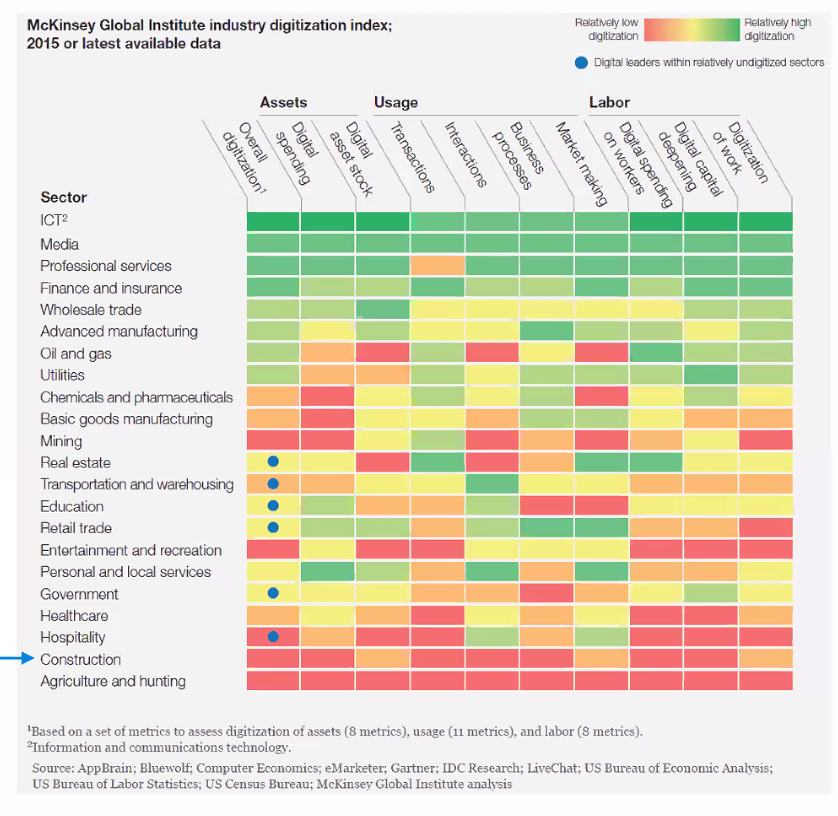
The scope of research of this dissertation is as follows:

* How the control room works in construction stage to solve the long-lasting problems of a construction project in different stages?
* What types of visualisation technique should be used to give insight and improve project delivery?
* What types of data should be captured and what data standard should be formulated?

# Literature Review

# Technology Implementation in Construction

Construction sector is slowly to adopt new technology and digitalisation compared with other industry. The digitalisation index of construction is very low as shown on below figure (McKinsey, 2015).



Although the sector has recognised the need for change and adopted many technological solutions, they are fragmented point solutions and disorganised (Woodhead et al., 2018). Instead, a key to improve the construction project delivery with a long-term advantage is to recognize a “planned IoT ecosystem” rather than combining different “point solutions”. Ecosystem means an integrated “layer” of hardware, software, connectivity, and information ﬂows linked to key decision-making activities.

Besides, the explosion of global pandemic COVID-19 is accelerating the development of digital transformation in different industry. With unprecedented consequences such as the disruption of manufactures and supply chains, the mitigation of the impact by COVID-19 requires new approaches and new forms of collaboration like a virtual platform for working from home to increase overall resilience.

# Control Room

There are so many researches focusing on facilities management at operational stage on the urban infrastructures but only few studies focusing on the construction stage, which is the fundamental part in the life cycle of an urban infrastructure. In response to this situation and the smart city paradigm, a Control Room concept for the construction stage is an integrated solution to fulfil this gap.

The control room concept was first applied in the 1970s during the Apollo 13 program by NASA, where engineers on the ground needed to be able to rapidly account for changes to their vehicle while exposed to the extreme conditions in space, and with lives on the line. When life support failed, NASA found they could no longer base corrective decisions on the original model because the actual module had undergone significant changes as the result of exposure to an extremely hostile environment. The original model needed to be updated to closely simulate the current state of the module. As a result, they use the “pairing technology” to simulate the outer space with the mathematical models so that the engineers and different professional can collaborate in the control room and make decision based on the mathematical model (Jarrett Hendricks, 2020). The same dynamics can also apply in different industries.

# Control Room in other Industry

There is an example in the financial services industry using the control room concept[[1]](#footnote-1). The Head of The Compliance Control Room at one of Africa's leading banks suggested that there's a growing awareness in the financial services industry have a need for a control room function as part of the larger compliance function due to the increased regulation and increased complexity in the day-to-day operations of the institutions" (StarCompliance, 2019).

The purpose of the Control Room in this case is to manage the flow of sensitive corporate information in a multi-service financial institution. Control rooms can act as a company’s nerve centre to monitoring the deals data such as mergers and acquisitions, equity offerings, debt offerings, …etc. The deals themselves are very complex and generate a deluge of data that must be rigorously monitored, and the deal data must be organized, recorded, and analysed. The volume of this deal data is immense and there is a need to keep track of who's involved in what and who said what to whom can be overwhelming, there is very little room for error and a premium placed on clearing deals quickly (ibid).

One of the importance of control-room is to use automated software to keep them working effectively in the fast-paced environment and there is a lot to keep track of data. Software can automate much of what previously could only be done manually but it also keeps data organized and up to date. If they are not cleared and response quickly enough, and lost reputation, if conflicts result in regulatory action (ibid).

During the construction stage of an infrastructural project, it generates enormous amount of information (Literature). A control room should also be used to enhance project management to reduce risk of project delay, within budget, and minimise contractual implication. Health and safety in construction are particularly important as the industry is prone to hazardous situations. The Control Room can help in making sure that all aspects of health and safety have been considered before and during the construction works.

# Gemini Principle

To build the control room, we must need the Gemini principle (Literature) as the basis.

A Digital Twin creates a digital representation of a physical building asset. It exists in the plan and design phase of a project as a method for better planning, design and construction of a project. It also plays a role at later phases of the lifecycle, especially after commissioning and provide long-term benefits for asset performance, optimisation, and reliability opportunities. Alternatively, Digital Twins can also be created after a physical version of it already exists, during its use phase. Physical assets can, therefore, be digitised when in operation.

In this approach, simulation and analytics from the digital representation can be tightly coupled with execution, which enable a cycle of continuous improvement and innovation. Measure performance, design based on current, data-driven observations, execute to design, and then measure execution to design; continuously adjusting and course-correcting to adapt to changing market conditions and to exploit emergent, potentially fleeting opportunities.

According to <https://www.intellias.com/digital-twin-technology-a-guide-for-2019/>, the three key factors that have made digital twin technology possible are:

**Velocity:** IoT devices can relatively easily collect massive volumes of data and transfer it to a digital twin in almost real time.

**Resolution:** Digital information helps us get a close look at the finest details of physical assets.

**Learning:**

Machine learning algorithms can analyze gathered data and make predictions, refining the digital twin based on gathered information and calibrating the general model and its details.

# Components of Control Room

Although there are so many report/marketing to describe the advantage of building a digital twin for an infrastructure, there is a lack of clear and entire manual to describe how to build it. This section is to outline the framework of the control room under this principle and investigate its essential components and visualisation techniques.

# Cloud & Collaboration Platform

A cloud-based common data environment should be used as a centralised collaboration platform, project data can be exchanged between different parties. Cloud computing changes the traditional way businesses to manage IT resources, which the delivery of computing services including servers, databases, analytics, and intelligence over the Internet (“the cloud”) and ensuring data security (Microsoft, 2020).

Besides, traditional tools such as email, project management software and telephone are just one-way communication activities. They lack the real-time collaboration elements which is for connected engagement, discussion and approval process (Levine, 2016). If different parties in the project can submit updates of information on a simple and real-time manner, it will be easier for all project team members as one and remain on the same pace as the project proceeds, so it would not make the progress delay in terms of scheduling and over-budget due to rework.

# Virtual Reality

Virtual Reality, known as VR, is widely used in the education and training purpose due to its potentials to stimulate interactivity and motivation (Freina & Ott, 2015). Furthermore, it offers an ideal approach to study and learn for those who prefer experiencing a visual or auditory learning style (Leite et al., 2010). VR can also be used in meeting with team members to work together within a 3D model for discussion, which is benefit for remote working (Brandon, 2020).

# Dashboard

Key performance indicators (KPIs) can be used to gauge and compare performance in terms of meeting both strategic and operational goals in a dashboard. Construction industry can also make use of the objective benchmarks and find a way to measure excellence across the industry. The analysis result of the data across the industry can help to improve the processes and lead to better performance and project delivery. It is the number one priority for Project Managers, Project Directors or any other person in charge of project planning to implement a planning process which will subsequently allow them to gain a clear view of each project’s status.

# Real-time Model Viewer

The viewer enables users to visualise 3D (and 2D) models in a browser. The digital twin of the building model created can be probably displayed it using this technology.

# Others

Apart from that, the data strategy of Control Room should consist of a common data exchange standards and Application Program Interfaces (API) for third-party developers to develop external applications so that many solution can be connected together and links to form a ‘bigger picture’ such as a connected smart city (Woodhead et al., 2018).

# Methodology

This dissertation frames the setting of the control room and will use a case study on a local factory in Hong Kong as prototype study to visualise the data of BIM model, anonymous construction performance data and sensory data. It provides an overview of the core visualisation technique of a control room that can be use. It focuses on three visualisation techniques with the data: VR, Dashboard and Web Application.

# Integration framework of NASA Control Room in Construction

To illustrate the idea of the NASA Control Room, existing solution and software available on the market will be used to build the conceptual integration framework as shown on the below figure. System components regarding the data repository, data services and application layer are investigated in this section.

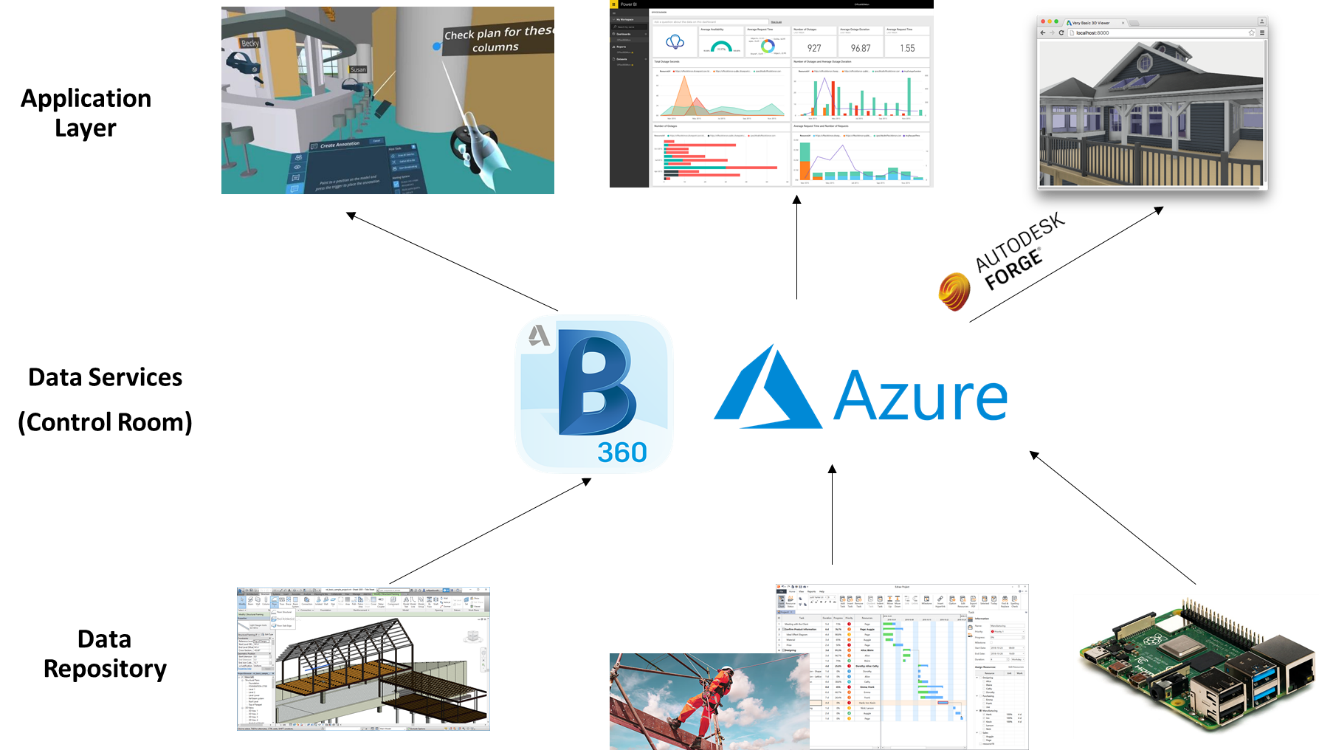
In the framework, three data repositories are considered:

Model Data: the virtual model of the physical configuration of the considered location

Construction Data: Safety and Progress Data

Sensory data: Working condition of the construction site

-> How the ecosystem works (charts)



Each of these data repository represents an aspect of the construction site and has a reflection on the construction performance. This dissertation focuses on providing an extensible framework for the Control Room to make it possible to add on other information whenever necessary. This enables the author to carry out my work even without capturing the detailed data requirements. The data will then be published in a standardised format using web services.

The construction of this information framework using Web services as Microsoft Azure Cloud Service to provide an integration service interface for the Control Room.

The engineers and managers can assess these web services to get the required data in a standardised format like in IFC,rvt and collaboration in BIM360. It is up to the client to process the retrieved data to feed into their specific applications for visualise by VR/ Dashboard or real-time web viewer (external application by open forge API).

# Source of Data

# Revit Model Data

->LOD,xxx, model info (ref to some execution plan)

# Project Performance Data

->

# Sensor Data

Low cost sensors raspberry pi has been selected as the prototype to capture the construction environment data. The technical details are given in the below Table:

-> how the sensor to collect the data (mechanism)

-> How the sensor send to microcontroller works

Table: Technical specification of Raspberry Pi

|  |  |
| --- | --- |
|  |  |
|  |  |

# Collaboration Platform (Backend)

# BIM360 Collaboration (CDE)

BIM 360 Design allows multi-users to work on the same model simultaneously on the cloud which can be extends worksharing to any parts of the world. Both modules must be activated in the Project services to allow proper implementation. When selected, Design Collaboration module will show the different drawing packages in a timeline format created by other Consultants and will allow them to decide whether to consume that package for their use.

# How your works related to ISO 19650 workflow

# Cloud Services

Azure….

# Data Capture and Storage (Backend)

-Web Server

Transmitting sensor data over the network can be used with the Microsoft Azure Cloud Services

-> How the Azure database build

->Table 1: Construction Data, Table 2 Revit Model Data, Table 3: Sensory

->How the endpoint to be build

-> how the cloud to get the sensory data

(->deployment of web to Azure)

# Collaboration / Visualisation (Front End)

Infrastructure for visualisation

-> How VR plug-in to be built and works on BIM360 platform

=> Joystick to control

-> How PowerBI Dashboard to be built

-> How Forge Viewer works + D3/Chart.js to be build (API to connect with BIM360,…..)

# Field Info

-Field Test and Data Collection **(physical)**

->Site Description

->how sensor set up and collect data in the factory

->Revit Model Specification

# Result

(Main point 🡪 demonstrate how to reflect your idea in practical case study)

(Originated from the Control Room as the center!!)

(Put video and the link of the Control Room)

-Description of your data collected first

-focus on how the visualization technique and control room give some surprise things

# BIM360: (how to collaborate with the BIM model)

(talk about the work flow to achieve a task!)

-Review + Approval Workflow

-ISO19650 WIP workflow

-RFI

In order to provide information support for the development of the RBIVS prototype, we mainly have worked on two tasks. First, we created the BIM for the BA building using AuotDesk Revit 2012 based the 2D floor plan.

We produced the BIM with details of the room/wall/window/door elements and sensors within the building which are sufficient for monitoring the building energy performance.

Clients, planners, site managers and engineers will be able to track real time project performance and take action based on insights. These stakeholders will, for the first time, be able to objectively compare 'what was planned' versus 'what has been delivered'.

(create card with the model on home)

# VR (what insight can get from the VR)

How VR enhance virtual meeting

<https://bim360resources.autodesk.com/connect-construct/how-paric-uses-virtual-reality-in-construction-to-streamline-workflow-and-reduce-risk>

<https://www.youtube.com/watch?v=vb7SmNdU8zo>

# PowerBI Dashboard

What insight on safety / progress data provided by PowerBI

# Sensory Data (what insight to get from it , e.g. CO2 , PM2.5,… )

To test whether the working condition is safe for the workers.

Second task is to publish the sensor data (e.g. temperature, lighting, noise, infrared etc.) through the? REST web service as part of the implementation of the integration information service framework.

The initial RBIVS prototype was developed as a desktop application using Visual C++ programming language and Openscenegraph (for 3D rendering). The RBVIS is acting as a client application of our integrated information service framework. It accesses sensor readings through web services and links the sensor information with the room/corridor defined in BIM. The energy consumption/temperature/lighting of indoor element is visualised in 3D in real-time as shown in Figure 2.

The system can monitor the building’s energy performance by both room-based query and sensor-based query.

It can dynamically display sensor readings using colour coding based on rooms with the default changing frequency of 5 seconds. The system also supports individual sensor query in text by clicking a sensor in the 3D model or choosing a sensor from a list. The system can display individual sensor and room’s historical reading in charts as shown in Figure 3.

# Discussion

(talk more your experience in BIM360, how it shd be improved)

(what existing solution provide, what not provided)

-depends on so much external plug-in

-no plug and play enough 🡪 many manual customisation

-learning path is quite long -🡪 not instant improvement

-Talk more about how the integrity can be improved

e.g. forge shd be more easily to use

e.g. PowerBI cannot insert as card on the BIM360 platform

-BIM360 shd with plug-in to display the sensory data

-Standardised database for all 3 types of data

-Limitation

-Future can do

->expansion of sensory data (capture by camera)

->Natural Language Processing from data

->Mobile apps function

# Conclusion

A good building process to build a connected city.

# Reference

Brandon, J. (2020). *VR is the future of remote working*. https://www.techradar.com/news/vr-is-the-future-of-remote-working

Changali, S., Mohammad, A., & Van Nieuwland, M. (2015). The construction productivity imperative. *McKinsey Quarterly*.

Cosgrave, E. (2017). The smart city: challenges for the civil engineering sector. *Proceedings of the Institution of Civil Engineers - Smart Infrastructure and Construction*. https://doi.org/10.1680/jsmic.17.00012

Freina, L., & Ott, M. (2015). A literature review on immersive virtual reality in education: State of the art and perspectives. *Proceedings of ELearning and Software for Education (ELSE)(Bucharest, Romania, April 23--24, 2015)*. https://doi.org/10.12753/2066-026X-15-020

Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for Smarter Cities. *IBM Journal of Research and Development*. https://doi.org/10.1147/JRD.2010.2048257

HSE. (2019). Work-related stress , anxiety or depression statistics in Great Britain , 2019. *Annual Statistics*.

Jarrett Hendricks. (2020). *Rise of the Digital Twin: How Lessons Learned from NASA Are Changing the Way Supply Chains Are Managed*. https://info.expeditors.com/horizon/rise-of-the-digital-twin

Leite, W. L., Svinicki, M., & Shi, Y. (2010). Attempted validation of the scores of the VARK: Learning styles inventory with multitrait-multimethod confirmatory factor analysis models. *Educational and Psychological Measurement*. https://doi.org/10.1177/0013164409344507

Levine, T. (2016). *Using Communication and Collaboration Technology to Keep Construction Projects On Schedule and On Budget*.

McKinsey. (2015). The MGI Industry Digitization Index. *McKinsey Global Institute*.

McKinsey & Company. (2017). Reinventing Construction: A Route To Higher Productivity. *McKinsey & Company*.

Microsoft. (2020). *Azure Cloud Services*. https://azure.microsoft.com/en-us/overview/what-is-cloud-computing/

Mohd Nawi, M. N., Baluch, N., & Bahauddin, A. Y. (2014). Impact of fragmentation issue in construction industry: An overview. *MATEC Web of Conferences*. https://doi.org/10.1051/matecconf/20141501009

Radford, Jamie; Macdonald, J. (2020). *Project 13 Digital Transformation Workstream: Infrastructure industry benchmarking report*.

StarCompliance. (2019). *Compliance Control Room: What Is It And Who Needs It?* https://blog.starcompliance.com/control-room-what-is-it-and-who-needs-it

Woodhead, R., Stephenson, P., & Morrey, D. (2018). Digital construction: From point solutions to IoT ecosystem. *Automation in Construction*. https://doi.org/10.1016/j.autcon.2018.05.004

Xu, S., & Luo, H. (2014). The information-related time loss on construction sites: A case study on two sites. *International Journal of Advanced Robotic Systems*. https://doi.org/10.5772/58444

# Appendix

Coding, github

1. https://www.youtube.com/watch?v=oYzqpfinyvc [↑](#footnote-ref-1)