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Declaration

Abbreviation

Acknowledgement (to different software/ service provider)

# Introduction

# Overview

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

As AEC sector is complex and dynamic in nature (Mohd Nawi et al., 2014), it consists of multiple disciplines and teams 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, the project delivery practice among these parties are notorious for poor in collaboration such as isolation of working and inadequate co-ordination. As construction projects can involve thousands of work tasks which are interrelated, so if one individual task happened with quality and safety deficiency, it would significantly impact the progress and the budget control of works in future stages.

Apart from that, the information management in construction is not effective enough. The AEC Sector is labour-intensive and generates enormous amounts of information including 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 poor collaboration 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 of two typical sites in middle and North China, it 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.

Health and safety deficiency are also one of the main concerns as compared to other sectors. The AEC Sector has long been recorded with the highest number of death and accident rate compared with other industry sectors globally. For example, it is about 79,000 workers in the Construction sector in Great Britain suffered from work-related ill health such as depression and musculoskeletal disorders and 30 fatal injuries in 2019 (HSE, 2019). There was about 62% of construction workers suffering from musculoskeletal disorder. The rate is statistically significant higher compared with the rate for workers across all other industries, which is only 1.2% [ibid].

# Technology Implementation in AEC Sector

As the AEC sector is embracing the digital age, the processes involved in the design, construction and operation should be enhanced by technologies dealing with value-added monitoring of data and optimisation of engineering systems. However, the AEC Sector is notorious to adopt new technology and digitalization much slowly compared with other industry. The digitalization index of construction is very low as shown on below figure (McKinsey, 2015).

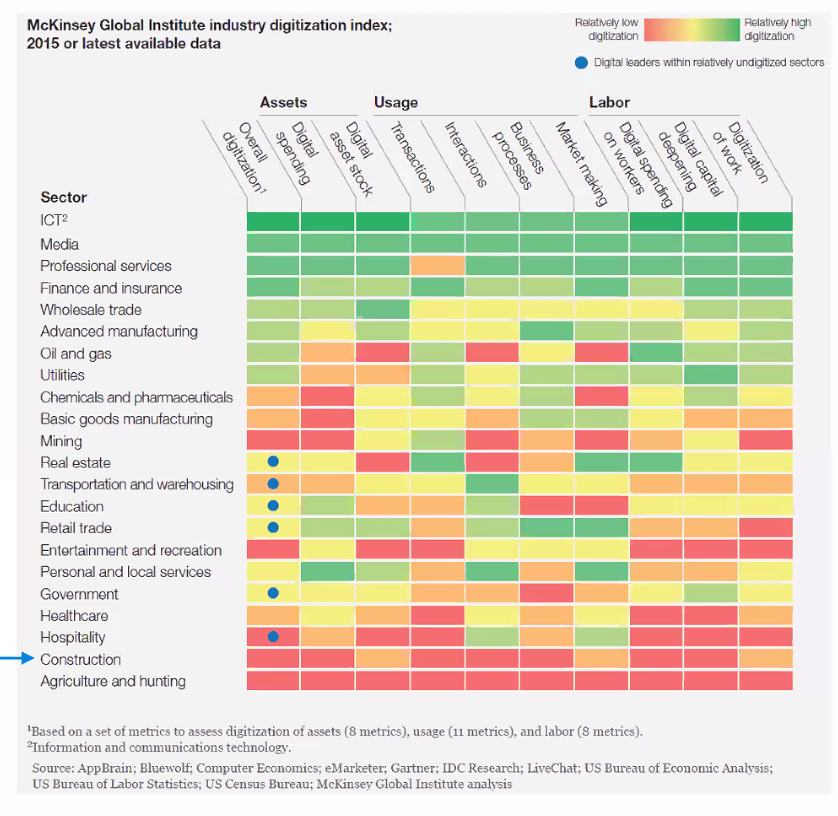


Figure 1 Digitalization Index extracted from McKinsey, 2015

Although the sector has recognised the need for change and adopted many technological solutions such as Building Information Modelling, Virtual Reality, ..etc , they are fragmented point solutions and disorganised (Woodhead et al., 2018). To improve the construction project delivery by technology with a long-term advantage, a “planned IoT ecosystem” approach rather than combining different “point solutions” is recognized. This system should be with high connectivity between hardware, software and making key decisions based on data (ibid).

Besides, as 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 manufacturing and supply chains, the mitigation to the impact by COVID-19 requires new approach of working and forms of collaboration such as remote working among team members to increase overall resilience of the business by using technology.

# Development of AEC Industry under Smart City Paradigm

Nowadays, the smart city paradigm is embraced over the world. It proposed that the technology developed should be citizen-focused, the developer must understand their citizens and develop appropriate technologies which will be beneficial to them. This framework of smart city research is described as “citizen centric” (Lara et al., 2016). This citizen-centric value defines the initiative Project 13 in AEC industry, which aims to develop a new business model for delivering high performing infrastructure to the ultimate user (i.e. the citizen). There is an ‘Integrator’ character which can be a single company or a collective party which plans and delivers the infrastructure programme, manages the suppliers and advisors, oversees design, construction, maintenance and operations as requested by the owner (Engineers, 2018). Most importantly, it pointed out that the Integrators should bring together capabilities to deliver effective solutions through production systems and enables a platform approach to deliver the project under the “Integration” pillar of the five pillars in the initiative (ibid).

Regarding to this, an integrated platform such a control room platform should be developed so that we can effectively control and get insight from the data generated during the construction process to improve the project delivery.

# Scope of Research

The major scope of research of this study is as follows:

* Explore why the Control Room can help to improve the project delivery in AEC industry and the framework of it

* Explore how the control room to improve the project delivery based on available collaboration tools and visualisation techniques in the market
* Explore the challenges and improvement on a control room platform based on the evaluation on current available solution

# Statement of Ethics

All the data used in this dissertation do not contain any personal information. Therefore, no ethics approval was required.

# Literature Review

# Control Room

The control room was originated in 1920s, which is for production control and monitor the physical facility in a central space (Bennett, 1993) . In 1970s, the launch of Apollo 13 program by NASA make use of the control room for monitoring the outer space condition (Jarrett Hendricks, 2020). The engineers on the ground control room needed to response the changes swiftly to the space vehicle and the astronauts exposed to the extreme conditions in outer space. Later, NASA identified that they can no longer make corrective decisions based on the original modelling method because the actual module had subjected to significant changes due to the exposure under extremely hostile environment. It was necessary to update the original modelling method so that the actual state of the module could be closely simulated. As a result, they used the “pairing technology”, which is  the precursor to digital twin technology, to simulate the outer space with the mathematical models so that the engineers and different professional could collaborate in the control room on ground and made decision based on that mathematical model (ibid). The core idea of the digital twin paradigm is to create a virtual asset to represent the physical assets, which helps to make better-informed decisions to improved outcomes in the real-time (Bolton et al., 2018).

It shows that the framework of the control room approach as follows. First, it should be a platform which can enhance collaboration. Second, it should include digital models paring with the physical facility and the data obtained can be visualised and analysed. Third, there is protocol of the digital model that exchange data with the physical facility. This framework of control room is related to the concept of digital twin, which various industries are embracing.

# Control Room Approach in Industries

In the product manufacturing industry (Yi et al., 2020), a digital twin based production management and control approach has been used. The product digital twin acts as a single data source for the vendors to collaborate each other throughout the product lifecycle such as product design, process planning, product assembly, product use and maintenance. In an assembly shop-floor scenario, data visualisation and integrated management of shop-floor data based on digital twin is achieved. For example, the assembly shop-floor digital twin is composed of shop-floor production elements’ geometric models and physical models such as shop-floor model, production line models, assembly station models, manufacturing resource models, product models, and environment models. These 3D geometric models are constructed by Pro/E, CATIA, SolidWorks, AutoCAD and so on.

In the financial industry, an Africa’s bank used the control room approach to monitor the sensitive corporate information flow from a multi-service financial institution. It acts as the company’s nerve centre to monitor the deals data such as mergers and acquisitions, equity offerings, debt offerings, …etc. The deals themselves are very complicated and generate an enormous amount of data that must be monitored closely to ensure the deal data can be organized, recorded, and analysed. It keeps track on who are involved in the deal, what are their deal and who agree with that deal, there is extremely little room for error for the deal data (StarCompliance, 2019).

It shows that the control room approach can address the need and problems in different industries by enhancing the collaboration, data visualisation and getting insight from the data.

# Control Room in AEC Industry

AEC industry has similar nature as the above-mentioned industry, the infrastructural generates enormous amount of data during the entire project life cycle, if any data got error or inconsistency between the documents such as the design information is not consistent in different drawings, the project progress and productivity would be greatly affect. It also involved multi-discipline stakeholders for collaboration in the projects. As a result, a control room should also be used to enhance project management and reduce risk like project delay, over-budget and minimise contractual implication and safety deficiencies.

Besides, to utilise the digital twin paradigm for the control room in AEC Industry, many professionals embrace that Building Information Modelling (BIM) plays an important role with it to form an integrated approach (Boje et al., 2020). It also pointed out that BIM should be integrated with another application such as control systems such as IoT devices although BIM lack semantic completeness due to its legacy data format.

# Research Gap

Most of these literatures has just pointed out the conceptual framework and the advantages of using the digital twin-based control room approach. However, there is less organised research on how these control room solutions should be implemented practically, the technical challenges and clear case study to show how does it work. For example, the details on using what types of sensors, the architecture to form the control room and how to link them all together to solve problem practically are omitted. Unlike those studies, this study will outline the practical application framework of the control room and will evaluate the functionality, limitation and whether it is easy to adopt this solution in the industry.

# Framework of Control Room

# Cloud Service and Collaboration Platform

The control room should be a cloud-based common data environment and a centralised collaboration platform to foster the collaboration and information exchange between different disciplines. One of the examples on the market is BIM 360, which is developed by the cloud service Amazon Web Service. It allows easy access to all project information from anywhere. Information like Drawings, models and other documents uploaded during the design phase can be continuously developed into the next phase such as supporting requests for information (RFIs), submittals, inspections.

In addition, cloud computing changes the traditional way of businesses to manage IT resources, which the services such as servers architecture, databases, analytics and business intelligence over the Internet (“the cloud” ) and ensuring data security (Microsoft, 2020). Cloud Computing also eliminates the requirement of using local hardware to handle and process data, thus no need to pay extra cost to buy hardware with high computation power (Stergiou et al., 2018).

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 on a single platform to create a single source of truth, 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.

# Visualisation – Immersive Virtual Reality

Immersive Virtual Reality (VR) can give the user feel like physically presenting in a computer-generated environment simulating places in the real or imagined worlds. It is common used in the education and training purpose by its potentials of provide an interactive and motivated environment (Freina & Ott, 2015). Besides, many publications have identified that VR technologies have been implemented to enhance safety in many areas (Alizadehsalehi et al., 2019), such as risks identiﬁcation, workforce training, skill transfer and ergonomics in the AEC industry (Li et al., 2018). While VR can also be used for meeting with team members to work together within a 3D model for discussion, which is benefit for remote working (Brandon, 2020). All these literatures showed that VR device is an effective tool for enhancing the interaction between human experiences and building environments.

# Visualisation - Dashboard

Dashboard visualisation is a cognitive tool to improve our “span of control” over the business data. This help the user to identify trends, patterns, and anomalies from the data. Managers can figure out the reason about what they observe and as a guideline for them to make effective decisions. It also let non-technological users to combine multiple data sets easily to customize a dashboard and generate data visualizations. Besides, Key performance indicators (KPIs) is commonly used to benchmarking and compare performance by meeting both strategic goals with a dashboard in different industry. Construction industry can also make use of the objective benchmarks and to measure excellence across the industry. The analysis results can help to improve the building processes and risk identification for project delivery. It is the topmost priority for Project Directors, Project Engineers and any other person responsible for planning management to implement a better planning process by having a clear view of the project’s status.

# Visualisation - Real-time Web-based Model Viewer

As suggested by (Boje et al., 2020) , Digital Twin should be based on a semantic web approach to accelerate digitalization by narrowing the gap between the physical and virtual world. Semantic web approach is to enable IT systems to process information by connecting web sites and data resources such as IoT devices so that the relationships and dependencies between pieces of data can be recognised (Keil et al., 2019). As a result, a web site approach to link the digital model data and the data from IoT device will be investigated.

# Open API

Under the context of smart city, the availability of information can create opportunities to get insight from the city's activities through modeling and analysis of data from different domains (Belizario & Berardi, 2019). This smart data solution can be used to get insight and able to manage cities data strategically (ibid). As a result, the control room platform should open Application Program Interfaces (API) such that the third-party developers can develop external applications and able to utilise the function of the control room platform. It motivates more developers to improve the functionally of the entire control room system and make good use of the data.

# Methodology

# Use of available data, software, and service

This study will make use of services and software currently available on the market to develop a prototype for the Control Room system and evaluate its usefulness with the available data. Originally the author intended to invite different construction professionals to use these applications of the control room in this study so that more feedback and comments from different perspective. However, under the current disruption by the COVID-19 pandemic, there is a great disruption on everyone form of working and working time, so it is hard to carry out such activity.

As a result, the functionality and visualisation techniques of the system will be evaluated by the author himself. The usefulness of all the software and services will be evaluated based on the author’s personal experience such that a clear view on how a Control Room should be developed on the perspective of collaborating, information management, analysis and visualisation of the data can be discussed further.

# Framework of Control Room in Construction

Available service and software in the market has been allocated into different layers of framework for the Control Room as below figure. It composed of 3 layers which are the Data Layer, Data Services and Application layer.

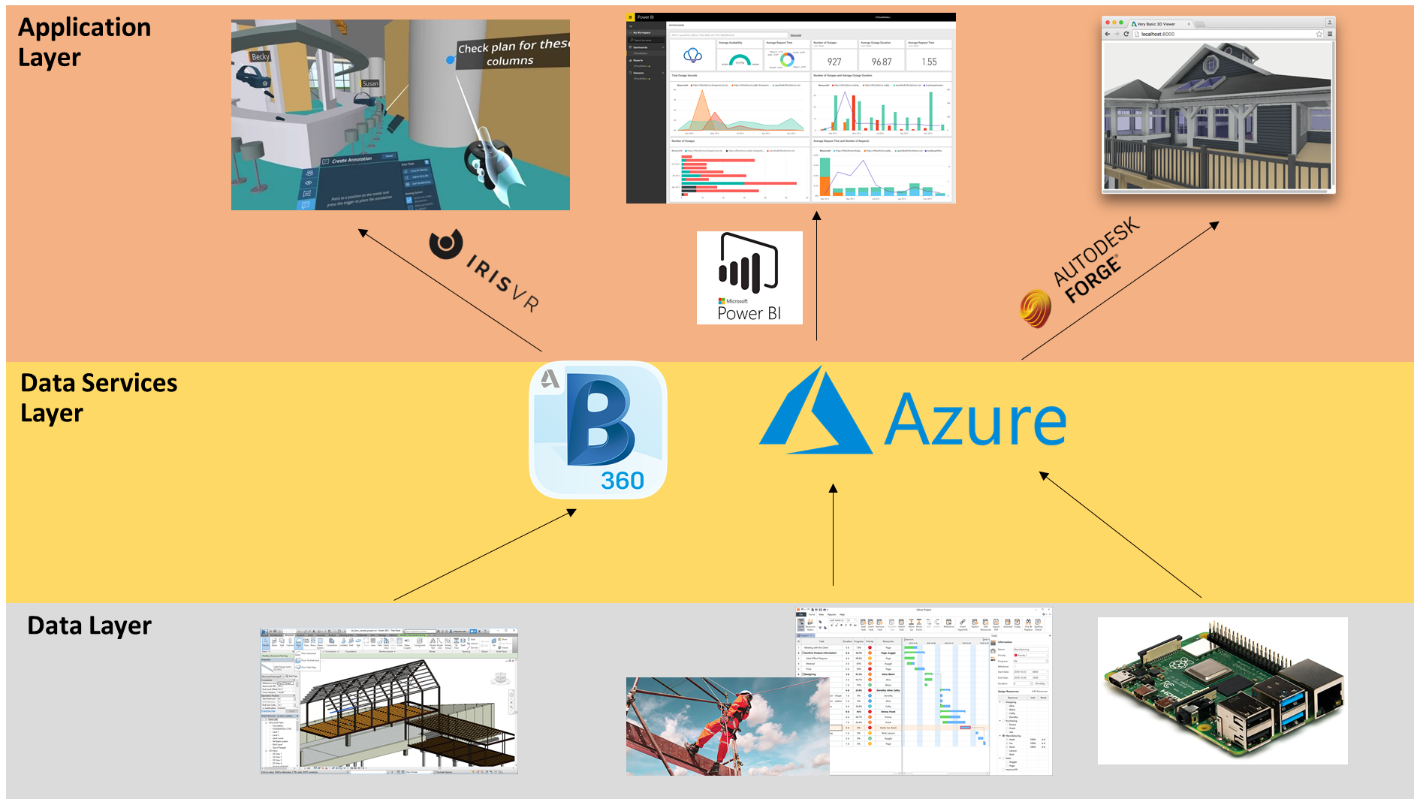


Figure 2 Proposed Application Framework of Control Room

# Data Layer

Each of the component (from left to right) in the data layer represents an aspect of the construction site to reflect the performance.

1. Model data: the virtual model of the physical configuration of the building or infrastructures
2. Project performance data: Safety data
3. Sensory data: Working condition of the construction site

# Data Services Layer

It forms the core part of the Control Room. The model data can be published to the BIM 360 cloud platform for collaboration so that different project team members can work remote and modify the model data on a single source of environment. Besides, the Microsoft Azure Services provide a platform to storage and process the data. The project performance data and sensory data will be stored in a SQL Server database which is created with Azure Services. The data can be retrieved to feed into the elements in application layer for visualisation.

# Application Layer

The Application layer is for data visualisation. Model data in BIM 360 will be visualised in VR environment with the software “Prospect” developed by IrisVR. The project performance data will be visualised as dashboard by Microsoft Power BI. While the sensory data will be visualised with the model data on BIM360 by Autodesk Forge API. There details will be discussed in Section 3.3 to 3.5.

# Source of Data

A case study of a residential house construction project will be used to evaluate the different functions of the control room. All the data used in this study will be modified to fit into the novel of this case study.

# Model Data

The model data is a digital prototype of a residential house, which is a template file provided by Autodesk Revit 2020 with format of “.rvt”. The 3D model can be visualised as the below figure:

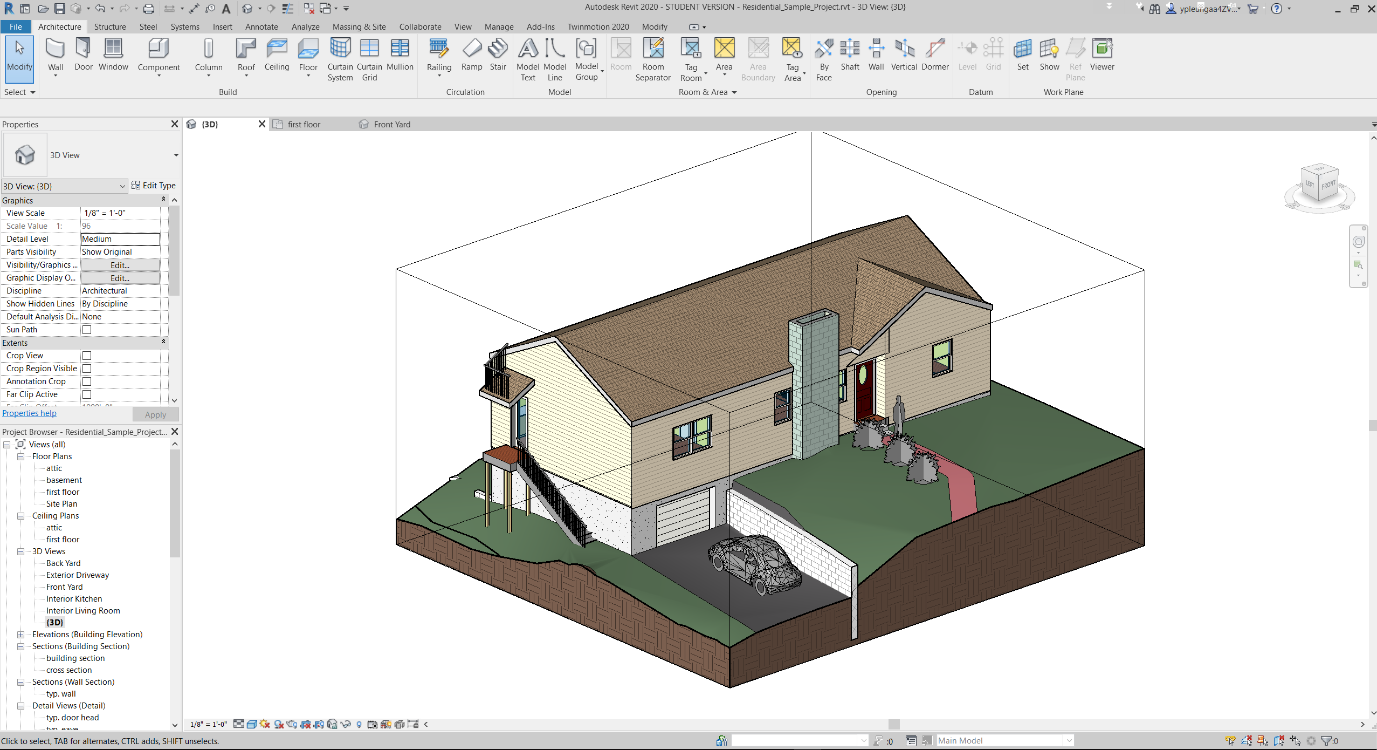


Figure 3 BIM Model visualised in the Autodesk Revit

The model contains objects data relating to the architectural and structural elements. All objects in the model contained information such as object name, type ID, furniture name, material information and major dimensions in object property. All the model data would be processed by Autodesk Revit first and would be published to BIM 360 online to simulate the collaboration between the structural and architectural team.

# Project Performance Data

One dataset of project performance data used for this study is modified from the data provided from the ‘Project Hack 5[[1]](#footnote-1)’ hackathon organised by Project Data Analytics Community. It contains all incident record during the construction of the residential house from 2016 to 2020, it includes detailed information with 139 rows and 15 columns, such as date of accident, accident category, nature of injury and damage classification and type of contact.

# Sensor Data

Low cost microcontroller Raspberry Pi (RPi) has been selected as the prototype of IoT devices to capture the construction environment data. RPi is a Linux-based platform. It is a credit card-sized computer and can be as an alternative of a desktop computer. As it is low cost and support different operating systems, it is suitable for ranges of projects such as acting as IoT device. The version used in this study is the Raspberry Pi 4 Model B which is newly released on the end of May 2020. The RPi can connect with local area networks with WIFI and transfer the data received from the sensors to Microsoft Azure IoTHubs services, which will be explained in Section 4.4.1. The technical details are given in the below Table:

Table 1 Technical Specification of Raspberry Pi and Sensors

|  |  |  |  |
| --- | --- | --- | --- |
| **Component** | **Image** | **Relevant Technical Data** | |
| Raspberry Pi 4 Model B | Raspberry Pi® 4 B 4 GB 4 x 1.5 GHz Raspberry Pi® | Conrad.com | Cost:  RAM  Processor  Operating  Voltage | 68 pounds  8GB  Broadcom BCM2711, Quad core Cortex-A72 (ARM v8) 64-bit SoC @ 1.5GHz  5V DC via USB-C Connector (minimum 3A) |
| SHT20 | SHT20 溫濕度傳感器模組I2C 通訊- 台灣物聯科技TaiwanIOT Studio | Cost  Interface  Temperature Range  Humidity  Range  Operating Voltage | 3 pounds  I2C  -40oC to +125 oC  0 to 100%  3.3V |

Figure to show final configuration of the Raspberry Pi with sensor installed.

# Field Condition

Under the current disruption of COVID-19, it is hard to find an actual construction site for capturing the data for our study. As a result, the sensory system had installed on a local factory which manufactures hanger in Hong Kong to simulate the working condition of a construction site and the ability of the sensor to collect the empirical data. The usable area of the factory is around 75 sq. feet and height 12 feet. One worker will be work in this factory to keep on monitoring and maintenance the machineries which produce the hangers and processes the raw material inside the factory. The working environment will be impacted when the machineries are operating. As a result, it is a reasonable location to be chosen to simulating capturing data in a construction site.

-> general layout of site (photos)

# Sensor set up

For this study, only 1 sensor box will be installed at the factory for demonstration purpose. The experiment will run for a duration from xx:xx:xx to xx:xx:xx on xx August 2020. The data obtained will be processed as discussed in Section 3.5 and will be used to visualize with the BIM data.

(photos)

# BIM 360

# BIM 360 Collaboration

BIM 360 will be used to simulate the collaboration function of a control room. The modules of this cloud platform such as “Document Management”, “Design Collaboration” will be used for exploring the functionality on multi-disciplinary coordination on all project information. Drawings, model data and relevant files uploaded on BIM360 support version control will be uploaded to the module Document Management. Design Collaboration module can show different drawing packages created by different parties on a timeline and will allow them to decide whether to consume that package for their further amendment. The data also supports requests for information (RFIs), submittals, inspections and more will the module Project Management. As the author only able to get the trial offer of BIM 360 from Autodesk, it has been chosen for this study.

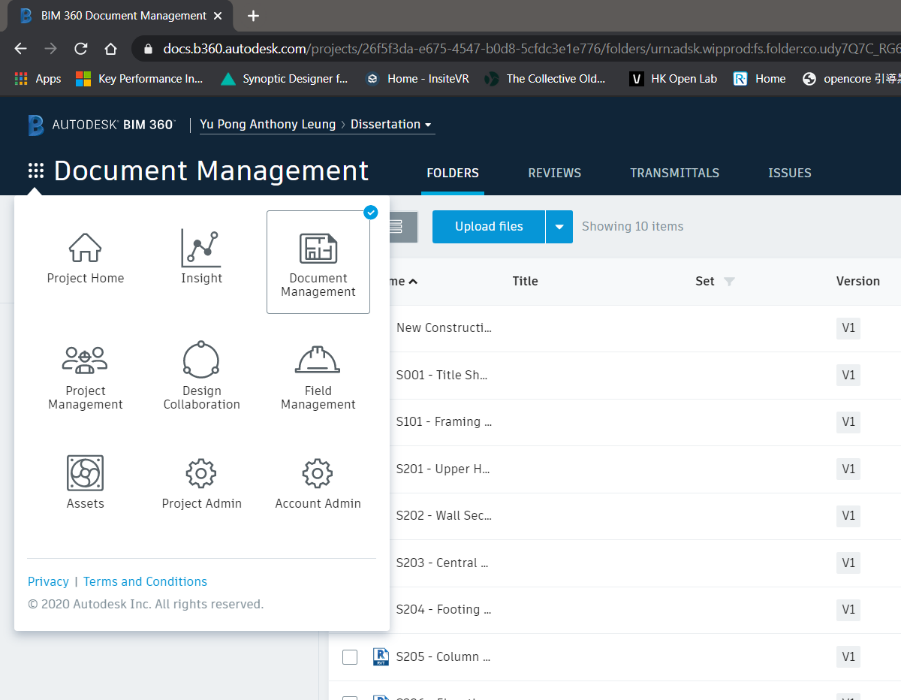


Figure 4 Modules in BIM360 cloud platform

# Forge API

To retrieve the data from BIM 360, there is only one open API – Forge API provided by Autodesk. It comprised of multiple APIs for retrieving different kinds of data for specific group of tasks related to the Autodesk cloud ecosystem. The data in BIM360 such as model data, checklist, issues can be further developed for automated processes, workflows, and data visualisation. All the available API can be explored on [forge.autodesk.com](file:///C:\Users\vmone\AppData\Roaming\Microsoft\Word\forge.autodesk.com).

# Microsoft Azure

Microsoft Azure offers cloud service in three main categories: Infrastructure as a Service (IaaS), Platform as a Service (PaaS), and Software as a Service (SaaS). PaaS will be focused on this study. Platform as a service (PaaS) is a cloud-based development and deployment environment, with resources to deliver our own applications.

PaaS not only includes the elements of IaaS such as servers, storage, and networking, it also provides middleware, development tools, business intelligence (BI) services, database management systems and so on. It is designed to support the full development of the lifecycle of a web application like building, testing, deploying, managing, and updating. Compared with other cloud service, the Microsoft Azure also provides a user-friendly environment and tools for the developer to build their own application, the building blocks is clear to build the new application quickly.

Besides, Azure cloud services is the only one in the market to offer a free tier one-year subscription for students. As a result, it has been chosen for this study.

# Data Capture and Storage

Data has been sent over to Azure for interception and storage in a database for management, analysis and visualisation. For the sensory data, the sensor with the microcontroller Raspberry Pi (RPi) act as a node and registered as an ‘IoT devices’ in Azure. By using the IoTHubs services as the gateway, the data can be further processed as below figure referenced from the Microsoft Azure Cloud.

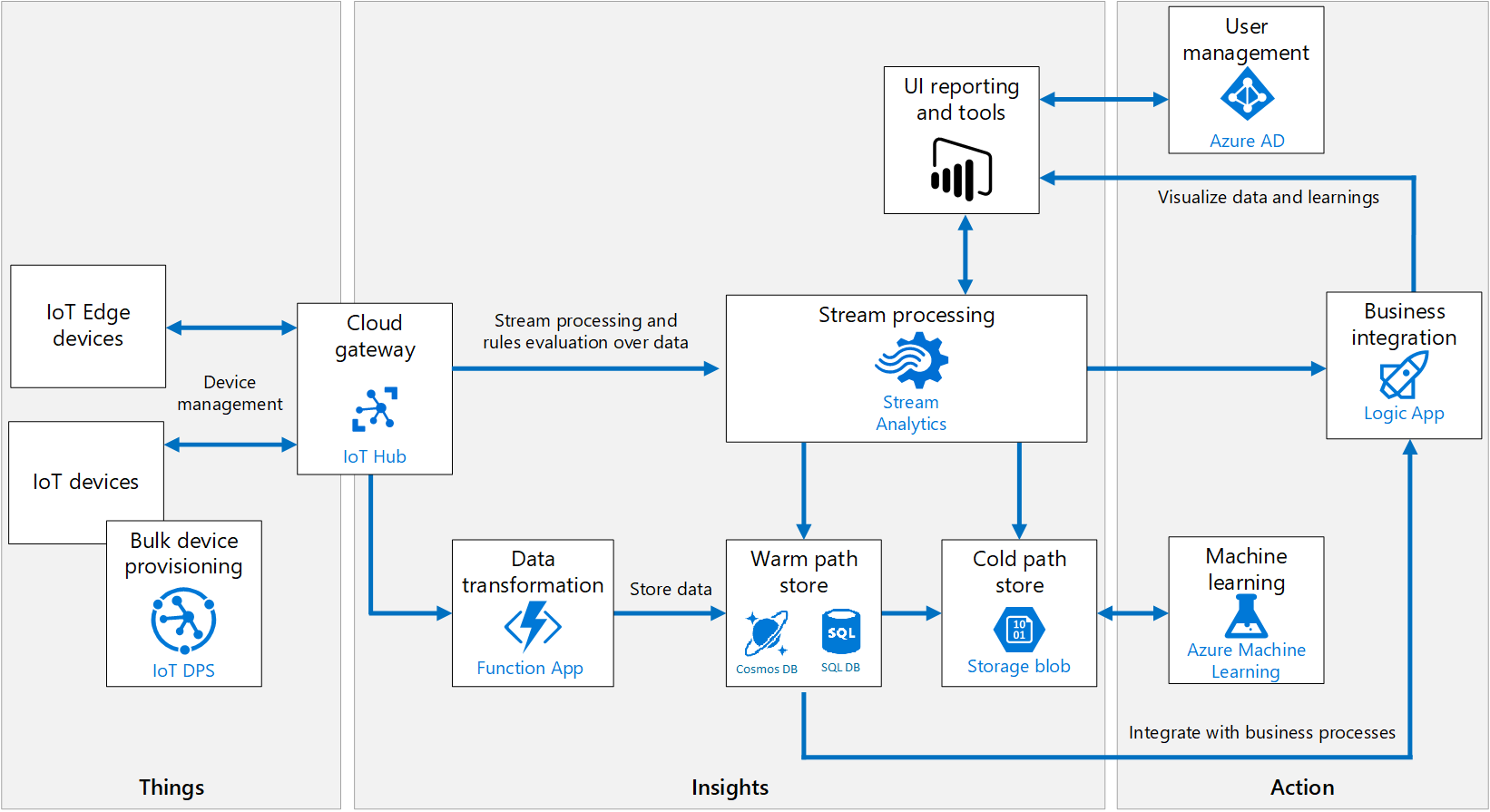


Figure 5 Azure IoT Ecosystem extracted from Microsoft Azure Cloud Service

# Database Management

Azure SQL Database is a fully managed PaaS database engine that handles most of the database management functions such as upgrading, patching, backups, and monitoring without user involvement. With Azure SQL Database, a highly available and high-performance data storage layer for the applications and solutions can be created. It also allows the process of both relational data and non-relational structures, such as graphs, JSON, spatial, and XML. Data in file format like .csv can be moved to an Azure SQL Database using a Bulk Insert SQL Query. A python script (Appendix XX) was used to insert the performance dataset which is in .csv format. It established a connection to the SQL Server with the required credentials and perform inserting to the database. Python Libraries such as panda and pyodbc will be used for data processing and building connection with the SQL Server.

Table 2 Table Summary of Construction Performance Data in SQL Server Database

|  |  |  |  |
| --- | --- | --- | --- |
| **Table Name** | **Field** | **Type** | **Description** |
| SAFETY |  |  |  |

# Streaming of Sensory Data

Besides, Azure Stream Analytics is a real-time streaming engine that is designed to process high volumes of fast streaming data from multiple sources simultaneously.

Once the relationships between input sources RPi in IoTHubs and output sources such as SQL Database has been formed, it will trigger the streaming of real-time sensory data from IoT device to SQL Database. The Python script (Appendix xx) has executed on the RPi to connect with the IoTHubs. RPi is set to send data every 10 seconds. The parameters obtained are the microcontroller device id, timestamp, temperature, humidity, CO2\_level and PM2.5\_level. These parameters are added as a new row in the Azure SQL Server database.

In summary, there are 3 tables which are the safety data, progress data and sensory data of the data layer for the control room.

Table 3 Table Summary of sensor data in SQL Server Database

|  |  |  |  |
| --- | --- | --- | --- |
| **Table Name** | **Field** | **Type** | **Description** |
| SENSORY |  |  |  |
|  |  |  |
|  |  |  |

# API Endpoint

Azure App Service is an HTTP-based service for hosting web applications, REST APIs, and mobile back ends. Node.JS application has been developed to retrieve the data from the SQL Server Database. The script is on Appendix XX. It defines an URL endpoint for triggering GET request from the tables in SQL database and returned as a JSON object for live data visualisation and analytics. Data can be retrieved from these API for the visualisation applications. The API documentation can be found on the studies GitHub page.

# Visualisation Techniques

# VR

The plug-in of Autodesk Revit called “Prospect” which is developed by IrisVR will be used for VR visualisation, the model data in BIM360 can be opened in Revit and the model will be converted for VR visualisation by using this plug-in. The 3D Views of the model can be imported directly into VR and automatically become viewpoints. It can create a narrative for the VR experience which is in 1:1 scale. Besides, Prospect is the Prospect is the only one that include all utility features such as measurement, mark-up, snapshot, section view and object information in a single add-on compared with others in the market and it provided free-trial for 14 days, so it has been chosen for this study.

The immersive VR headset Oculus Quest will be used for this study. It is a completely wire-free, PC free and with all the sensors built in. The specification is as follows:

Table 4 Specification of Oculus Quest

|  |  |
| --- | --- |
| Display panel | OLED |
| Display resolution | 1440 x 1600 per eye |
| Refresh rate | 72Hz |
| CPU | Qualcomm Snapdragon 835 processor |
| RAM | 4GB RAM |
| Battery | Lithium-ion battery with 2-3 hours playtime, depending on what you are playing |
| Degree of Freedom | 6 degrees of freedom head and hand tracking |
| controllers | Two touch |
| Weight | 571g |

# Dashboard

A dashboard application was built on top of Azure SQL Server Database to provide data visualisation and analytics. Microsoft Power BI will be used to visualise the construction performance data as a dashboard. As Power BI can get data from a large numbers of source data can be retrieved from Azure SQL database after the connection has been set up. Also, whenever the data has been sliced or another field has been updated in the data source, one can just click the refresh button in Power BI to make a new query to the database to update data. It is easy to use and free for its desktop edition, so it has been chosen for this study.

# Web Viewer

The Web-Application was to provide a plug-n-play tool for user from any background to understand the working environment of the construction site with the visualisation of a digital model and sensory data. The viewer application aims to visualise the model data in BIM360 by means of the BIM 360 API of Forge API. The viewer application is a WebGL-based, client-side JavaScript library for 2D and 3D model rendering. The model data will be first translated to SVF using the [Model Derivative API](https://forge.autodesk.com/en/docs/model-derivative/v2/) of BIM360 APIs. Once the process has completed, the viewer will be able to visualise these translated files.

Besides, the real-time sensory data will be visualised with JavaScript library D3/Chart.js on the page with the model. New data streams can be added dynamically. The chart will automatically update the new data series into the available space in the SVG.

Then, the website will be deployed to Azure. (details…..)

(Github link: )

# Result & Discussion

(Put video and the link of the Control Room)

(focus on 3 or 4 key observations that you want to discuss and explain why they are important on the scaleability or implementation of this kind of technology.!!!!)

# BIM360

# Document Management

The module “Document Management” provides ways **to identify the change of information effectively.** It provides version control function for model data, it can show all the record of what have been updated in each version and tracking who have modified the model data in each version. Besides, different types of model data can be compared together and the difference between them can be highlighted.

Under the case study of the Residential house Project, the structural team members want to find out what additional architectural features has been added in the model file, they can compare the versions of the model and all the additional features can be highlighted as below figure. The features which are highlighted in green is the additional elements added by other team members and the part highlighted in yellow indicate the structural that has been modified.



Figure 6 Comparing the difference between models by BIM 360 Document Management

The quality assurance process of information can be enhanced by workflow approval function. The workflow is a set of rules that the engineer should fulfil to make the document such as design drawings can be approved.

After the structural engineer have identified the changes of model by Architect and added the respective structural elements to support the Architect’s change, he would like to submit to his designated team members to review, he can select the model and choose the desired workflow and assign to other team members for review. An email notification window will be automatically sent to the team members afterwards. Then, the reviewer can make mark-ups and add comments to the model. And the reviewer can give back to the project engineer for amendment and the workflow only can go to the next step only when all the comments has been resolved.

This ensure the quality of the information that it should be compromised and go to the next step and no need to spend extra-time to return to previous step to re-do the works under the traditional working practice as there is no strict workflow approval procedure before. Also, it can record who have already received the notification for review the document and who need to answer the queries by other team members, so it push the team members act on time to increase the productivity in the project delivery.

# Design Collaboration

The “Design Collaboration” module **provides a clear way to enhance the collaboration with different team members**.

After the structural team member have finalised their changes of model data, they can publish the model data to BIM 360 for the architectural team further amendment. For example, they have modified the model with extra structural elements such as beam, columns and walls based on that model. Once they have completed the modification, the structural engineer can synchronize and publish the model data to the BIM 360. On the web-platform of BIM 360, the structural engineer can create a package in the timeline as shown on below figure so that the packages can be shared to other team such as the architectural team to consume this model and keep on modify it.

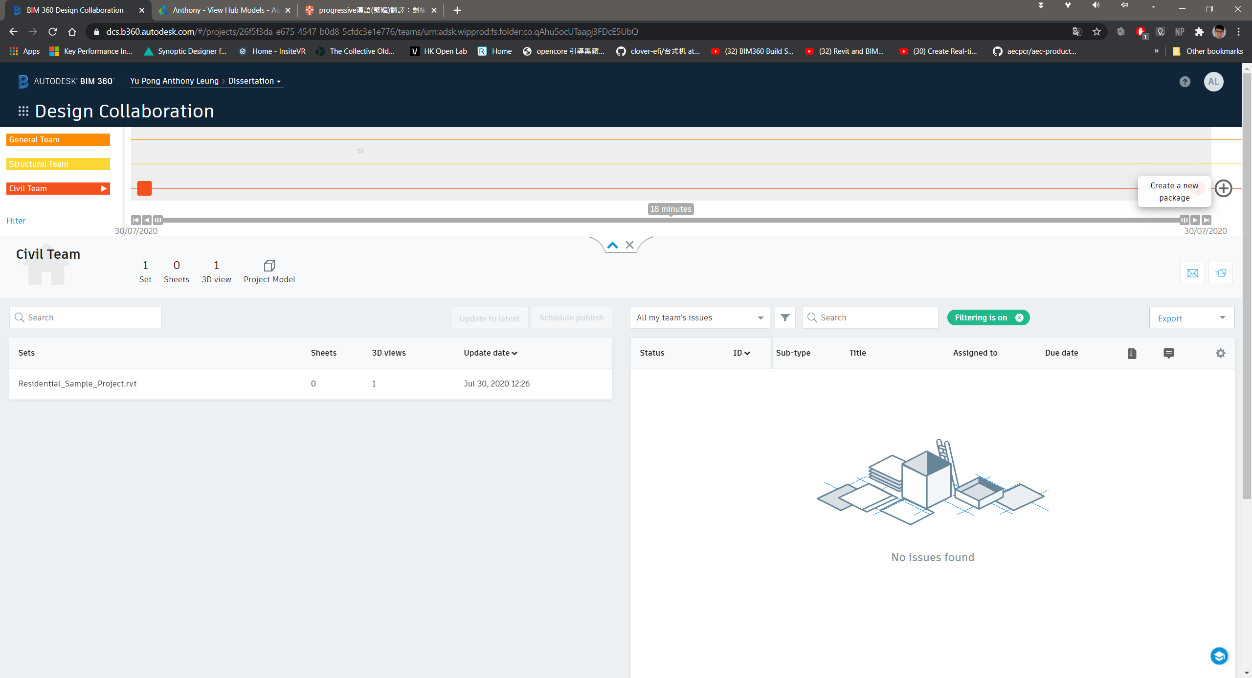


Figure 7 Overview of BIM 360 Design Collaboration Module

This is the concept of the design collaboration loop which is a set of collaboration procedure can achieve a continuous and smooth handover of the model data between different team members.

# Comments & Feedback

These module features play a good illustration of how the collaboration and ensure the information management should be of a control room. However, the “design collaboration” module is a bit complicated and it created multiple model data files which may lead to confusion.

For example, after the publish of the model data by one team member to the BIM 360, the model will be saved in the folder of “WIP (Work in Progress) folder”, which is created automatically under the work breakdown structure of the design collaboration module. Besides, as the user need to create a package to share to other team members, the model data will be saved in “Shared” folder for sharing to other team members for consume. And finally, after the model has been consumed, the model will be saved in the folder named “Consume”. As a result, multiple model data files have been created by using this design collaboration loop concept and it may make confusion to the beginners that they do not understand which model they should be used to work with if they are not familiar with the design collaboration concept.

# VR

# Project Coordination

The VR visualisation shows a great enhancement in collaboration for different team members. First, the residential house model data has been parsed with the software “Prospect”. Different team members can either fully immerse in the 3D models data with the VR headset (figure on right) or visualise the 3D environment with the computer (figure on left). It gives a great perception for the project team members to understand how the construction environment would be instead of imagination from the traditional drawings.

Figure 8 Different Team member immerse in 3D environment

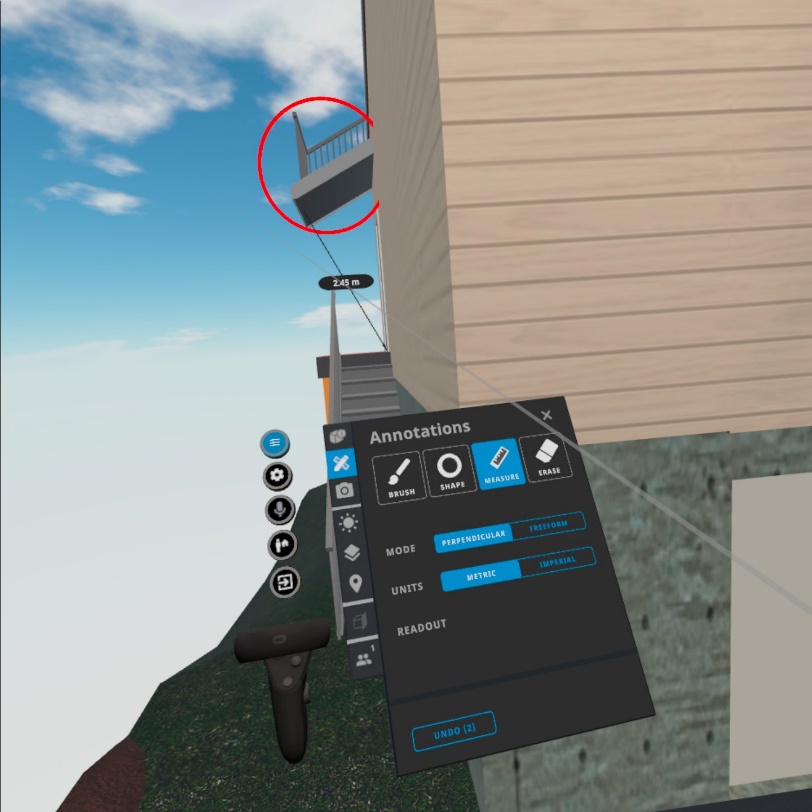
Team members can also carry out VR remote meeting to review the modification need from team members. For example, they can make use of the utility features such as measurement, mark-up tools, object details and sectional view for the user to present their idea during the remote meeting effectively. The building service engineer (blue) can use the mark-up tool to add annotations and comments on the ceiling of a specific room so that the structural team member (yellow) can adjust the setting out of the structural beam to avoid crash with this building services utilities during VR inspection.

(charts)

After they have agreed how they would modify their design and the construction sequence in the VR inspection, team members can have a clear understanding of the need of other members. They can amend their own respective data model and combine with the use of design collaboration module in BIM 360. As a result, different team members can modify the model effectively and avoid crash of elements, which greatly increases the productivity.

# Safety Hazard Identification

Besides, it is a good tool to identify locations with safety hazard. As the user can visualise the model from it very beginning to the final completion stage. All the safety hazards during the construction can be identified and find out the exact locations with the high risk of safety deficiency such as confined space, locations which easy to fall from height. For example, the balcony at the west evaluation of the residential house which is above ground for 2.45m meters and at the edge location, which is highly susceptible to the hazard of falling from height. This can help the managers to arrange special training for workers such as working on height and pay more attention to this location during the construction of the balcony.



# Limitations

VR can provide a great environment for collaboration and identify location with safety hazard for the users. However, the subscription cost is quite high and often exists as a separated plug-in or services rather than integrated with the collaborate tools. It made individual need to pay extra cost to buy this service to use, which lower the motivation for the construction professionals to adopt this technology. According to two services providers like “IrisVR” and “the Wild” which can function as a plug-in with Autodesk BIM360 and Revit. Their monthly subscription is about $225 USD and $295 USD, which is not an affordable price for some company especially some small size company to adopt this solution.

Besides, the compatibility of add-on of “Prospect” should be improved. For example, one must need to open the local desktop software Autodesk Revit to load the model data from the cloud BIM 360, and use the VR plug-in in Revit to transfer the BIM model data its external VR software “Prospect” to parse the model data so that we can visualise the immersive VR environment on the external software which shown on the below figure. It is quite not user-friendly. To make it more user-friendly, it should be integrated in the cloud platform of Control Room (such as the BIM 360), so that when all the project team members access to the cloud platform, they can open the model file and then press one button to access the immersive VR environment for walkthrough and remote meeting immediately rather than installing external software and so many steps to start with the visualisation with VR.

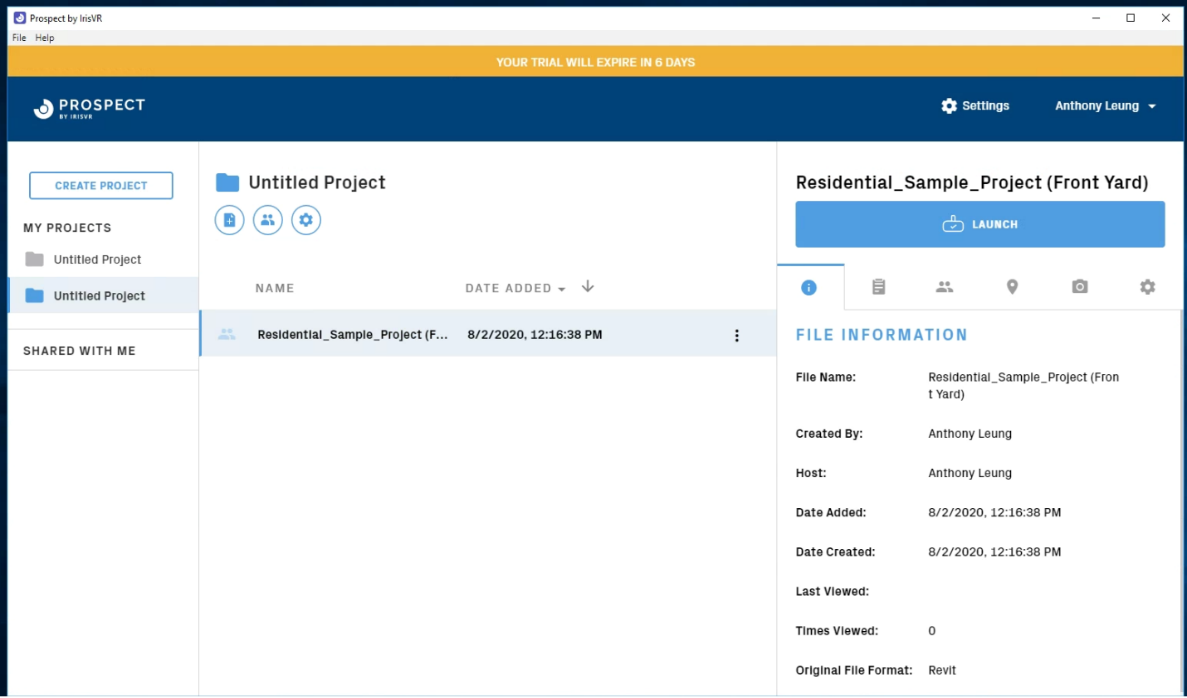


Figure 9 Overview of Prospect

# Dashboard

# Identify insight from safety record

In the first dashboard, we can identify that the trend of the number of accidents of constructing the residential house is decreasing across the years from 2017 to 2020 and the basement with the highest number of accidents. One can choose whatever categories under different indicators such as “Severity”, “body part”, “main activity”, “Risk Category” and “Injury Type” so that the total number of fatalities, incidences and the number of accidents across different years will be changed. It is easy to identify most of the accidents belongs to the activity of concreting , category of risk with slip or trip on the same level, workers suffering from body parts such as leg and the severity of most of the case is low. (The dashboard file is on…)

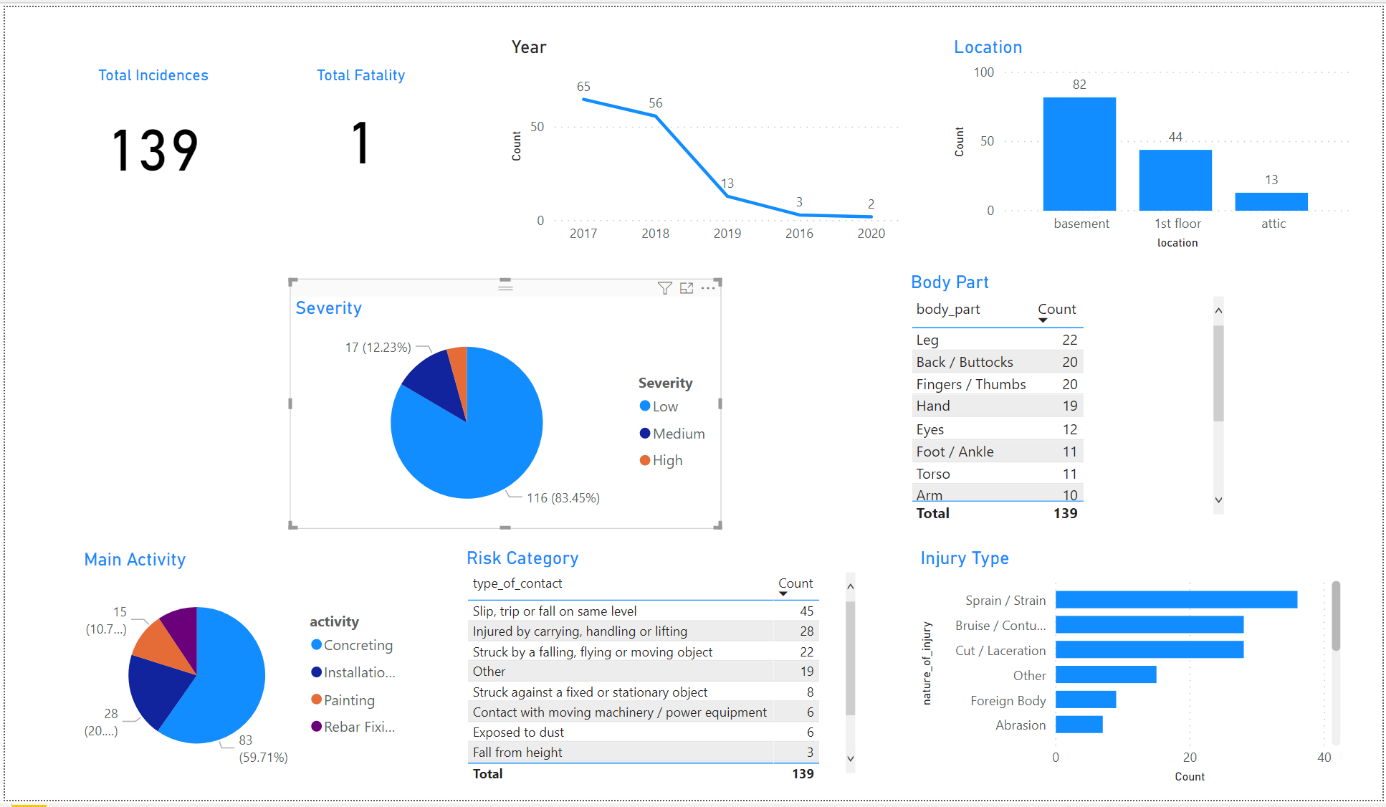


Figure 10 Dashboard Visualisation by Power BI - 1

According to these messages provided via this dashboard, the project managers should pay more attention to the activity like concreting and the location of basement. The managers can make investigation to see what lead to the workers suffering from high risk of accident in the basement when concreting. Besides, the managers can provide more personal protection equipment to protect the legs of the workers.

Besides, the second dashboard use a tree level diagram, which shows the root on how to constitute the number of accidents. The tree diagram has separated into different levels, the first one is “nature of injury”, second is “activity”, third is “location” and the last one is “no of day lost”. For example, when we selected one of category under the first level “severity”, then the number of accidents will be separated into different groups under the second level “location’”. And then it will separate into different groups under the third level “activity”, when we click one of the group, the number of accidents will be separated in different groups again under the forth level ‘body part’, so that we can identify the number of accidents based on different level of a specific root.

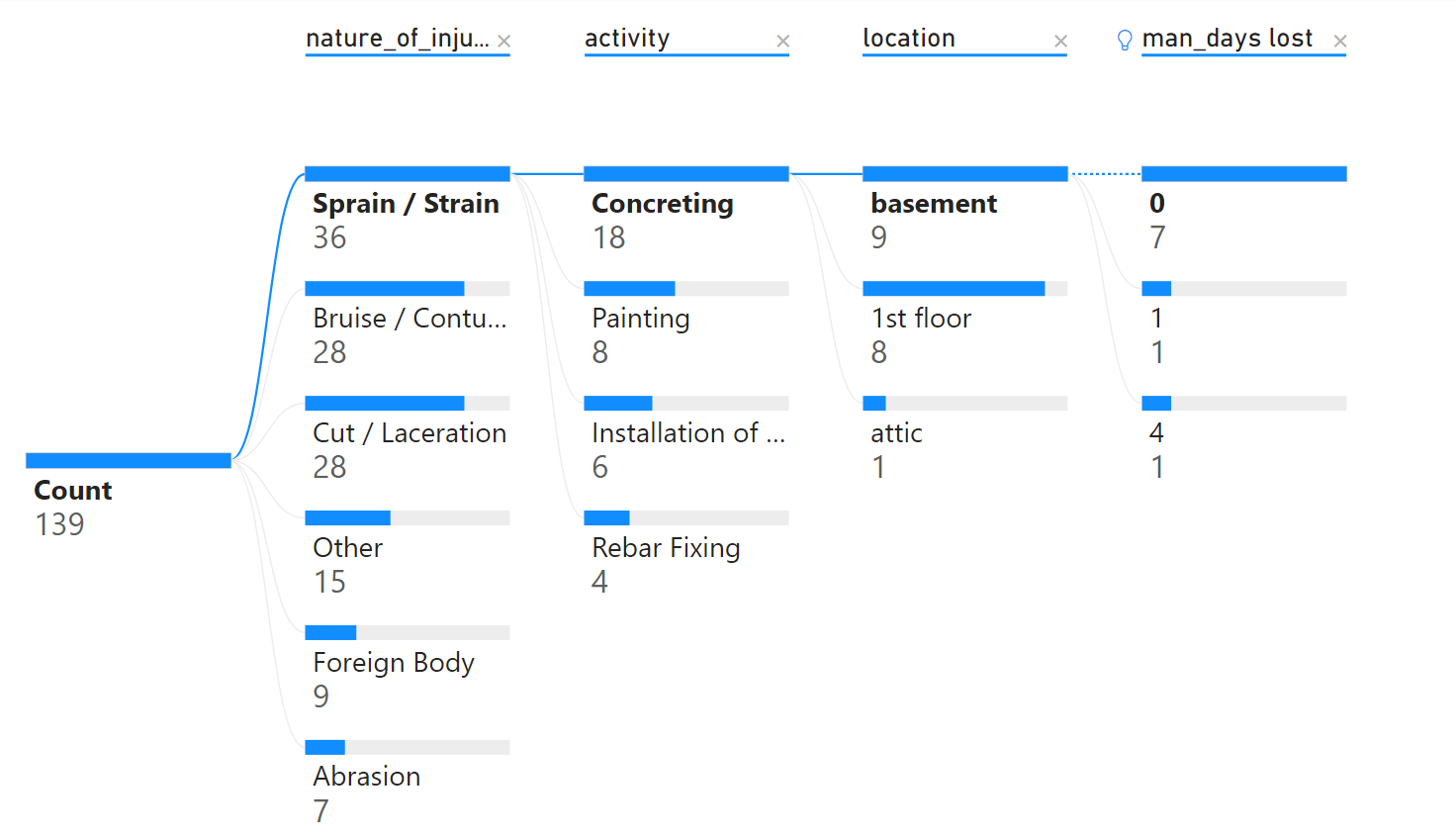


Figure 11 Dashboard Visualisation by Power BI – 2

The Project Managers can easily identify which construction activities at where to cause different types of the nature of injuries and the productivity lost. It gives a chance for the project manager to identify each nature of injury concentrated on what activities and where its location and how to affect the productivity lost, so the manager can understand where should pay more attention to mitigate the risk of injury and how it would affect the man-day lost.

# Limitations

The Power BI is a great platform to present the data to give insight, patterns or abnormality. However, as AEC Sector is a complicated and complex industry, it is quite difficult to standardize a database schema format for data visualization. Since different construction company will have their own standard and indicators to report their project safety, progress related issue and workflow for quality assurance process. As a result, the dashboard function of the control room platform should be highly customizable so that the user can manually edit the schema so that they can keep track on the indicators they want. (Use Open API to solve this problem said of literature?)

Besides, some users may still want to use the Power BI dashboard for data visualization rather than developed this function for the control room platform. However, its integration capabilities with other applications must be improved for a better experience. Originally the Power BI dashboard can be integrated with the BIM 360 cloud platform, so that the construction professional can understand the condition of the BIM model and the project data at the same time. However, Microsoft have changed their data security policy recently so that they don’t allow the user to publish the Power BI dashboard to the websites and other external software. It makes the integration between the Power BI and other platform not in a convenient way. One of the solutions is that the Control Room platform should be at least able to open and interpret the Power BI “.pbix” file so that the construction processionals can just upload the Power BI document to their Control Room platform so that the dashboard can be integrated.

Edward Tufte advice on some critical analysis on the communication of information and the challenges of information visualisation and bias

# Web Viewer

# Description of sensory data

Overall, xxx data points were collected from [date]. The range of different parameters is tabulated as below:

|  |  |
| --- | --- |
| **Parameters** | **Range** |
| Temperature |  |
| Humidity |  |

# Visualisation of sensory data

As the forge API is not very user friendly and not so many documentations available on the internet, the web viewer is not a completely ﬁnished product, but it shows the majority of the functions it could have.

The web viewer is as shown on the below figure. There is a toolbar below the 3D model for the users to navigate the model such as rotating the model or dragging for translation of model data. Besides, there is a property panel so that the user can find out the property information for each of the elements inside the model. For example, ……

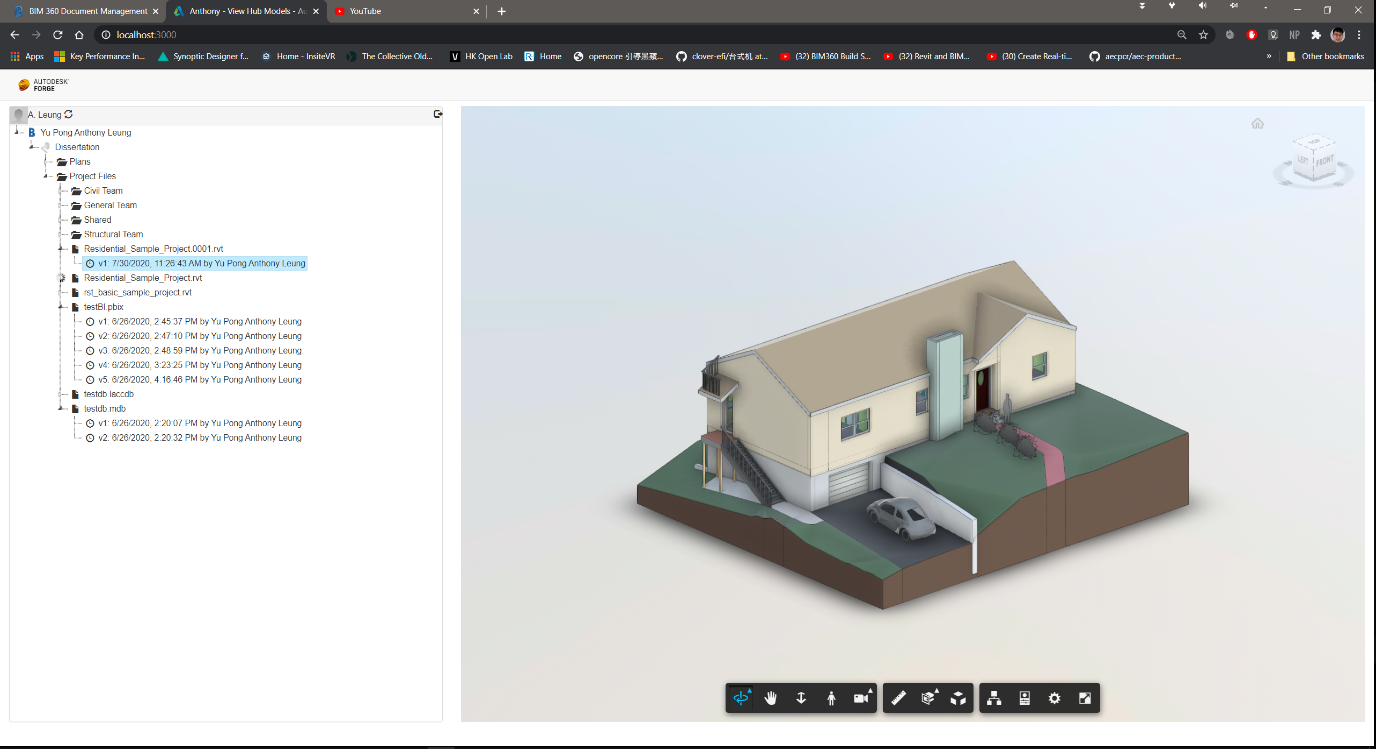


Figure 12 Data Visualisation by Viewer Application developed by Forge API

Besides, the sensor data such as humidity/temperature is visualised with the JavaScript library Chart.js/d3. It can dynamically display sensor readings with the changing frequency of 10 seconds.

(chart)

# Functionality for Construction Professionals

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

# Limitations

**maybe try and think about why Forge was difficult to use and why other approaches were easier - do a compare and contrast to try and think about what needs to improve in forge to make it a viable building block in the system**

The forge API is not easy for the beginners to use. Although Autodesk can already provide different documentation on the internet, it is highly fragmented and not easy to start with. Also, some of the coding document to modify the content of the viewer application suggested from documentation which is only for the old version of the viewer application. For example, the author wants to customise the property panel of the viewer application to add customised content such as the sensory data but it is not successful.

Regarding to this issue, a visual programming interface is suggested so that the user can make use of this API to link the data or get data from other external application easily. The Author originally want to integrate the sensory data into the digital model for visualisation, however, it is very difficult to carry out this task and very less documentation to explain how to do it. As a result, the author used external library to visualise the sensory data. As capturing data by IoT device is becoming much popular, the Control Room platform should provide an easier way to integrate both the sensory data with the model data for visualisation.

# How all the things combined together as an ensemble

illustrate how a day to day-basis would work based on your ensemble

# Limitation (500)

Although this study shows the ability of how the overall Control Room system to improve the project delivery, there was some limitation for this study.

# Recommendation (Link to Intro, LR)

-Talk more about how the integrity can be improved

=> forge is difficult to use, less documentation

=> Power BI cannot insert as card on the BIM360 platform

=> BIM360 shd with plug-in to display the sensory data /SQL data

=> weak in support external data such as sensory data

# Future works

=>Automation / Analysis

Standised process of a control room can manage to five a good building process to build a connected city.

# Conclusion (Link to Intro, LR)

While BIM benefits the delivery of buildings by providing greater efficiencies at all stages of a project lifecycle, VR offers the possibility to explore the human elements of architecture, the form, space and aesthetics of buildings, through an immersive experience (Corke, 2016). Although still in its early days, VR has shown extensive benefits to bring to the architecture and construction industry, from functional and aesthetic evaluation of projects to daylight and lighting studies as well as client collaboration and communication (Corke, 2017).

Through a literature review, it was found that only a handful of available VR applications for architecture and construction uses have been reviewed.

To provide more comprehensive and detailed review on the functionality of a Control Room, this study evaluated multiple functionality that were available on the market recently. Application such as BIM 360, Prospects, Autodesk Forge API, Microsoft were identified and evaluated.

Their capabilities were evaluated including collaboration, information management, ease to use, forms of visualisation, insight as well as license cost.

Recommendations were given on how architecture and construction firms at different levels of interest in VR can apply these applications more effectively.

This study provides a first-hand review to AEC industry who are planning to build a control room platform.

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# Research Log

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# Appendix

Coding, github

1. Reference Link: <https://projectdataanalytics.uk/past-events/projecthack5-output> [↑](#footnote-ref-1)