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# BUILDING A NEXT GENERATION AI PLATFORM FOR AEC: A REVIEW AND RESEARCH CHALLENGES


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# Overview

## 01 Introduction

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- *Advanced technologies*
- *Research methods*
- *Knowledge map*

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- *AI-based data acquisition*
- *AI-based BIM model generation*
- *Blockchain-based collaboration*
- *AR-based visualization*

## 03 AI-based CM

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- *Safety management*
- *Quality management*
- *Contract management*
- *Cost management*
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- *Potentials of developing AI platform for AEC*
- *Existing challenges*
- *Future work*
- *Links between industry and academia*

# 01 Introduction

- *Motivations in AEC*
- *Advanced technologies*
- *Research methods*
- *Knowledge map*

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# Motivations in AEC

## Great Potentials of Cost Saving:

The Architecture, Engineering and Construction (AEC) industry is one of the largest industries in the world; yet it is also known to have the lowest productivity gains of any industry in the past decades.

According to World Economic Forum (2016),

*1%* rise in AEC industry productivity could save

*$100 billion* a year.

(Source: World Economic Forum 2016)

## Current Problems:

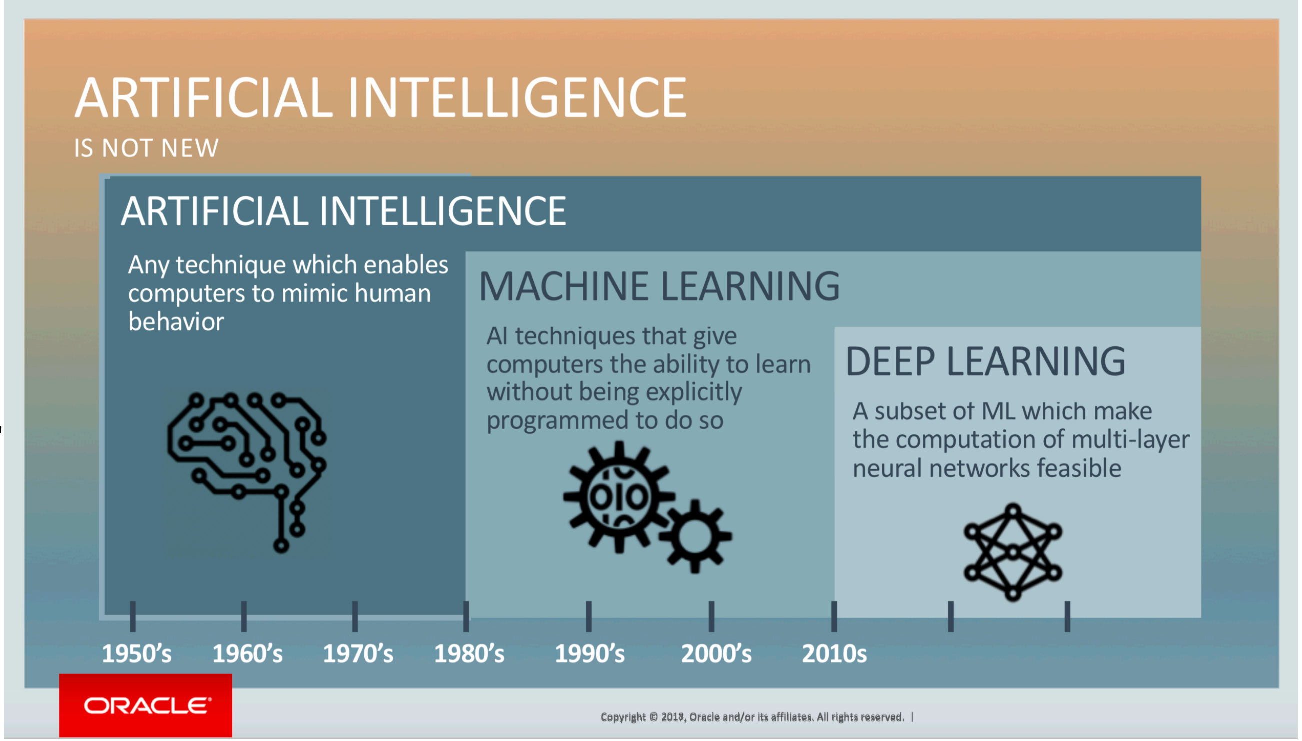
- High monitoring costs
- Difficulty in real-time monitoring
- Lack of trust and transparency
- Ineffective transmission of site information

# Advanced technologies

## What is Artificial Intelligence?

To address these challenges, researchers have tried to explore some advanced techniques into AEC industry.

**Example:**
Artificial Intelligence (AI),
Building Information Modeling (BIM),
3D Reconstruction,
Augmented Reality (AR),
Blockchain, etc.

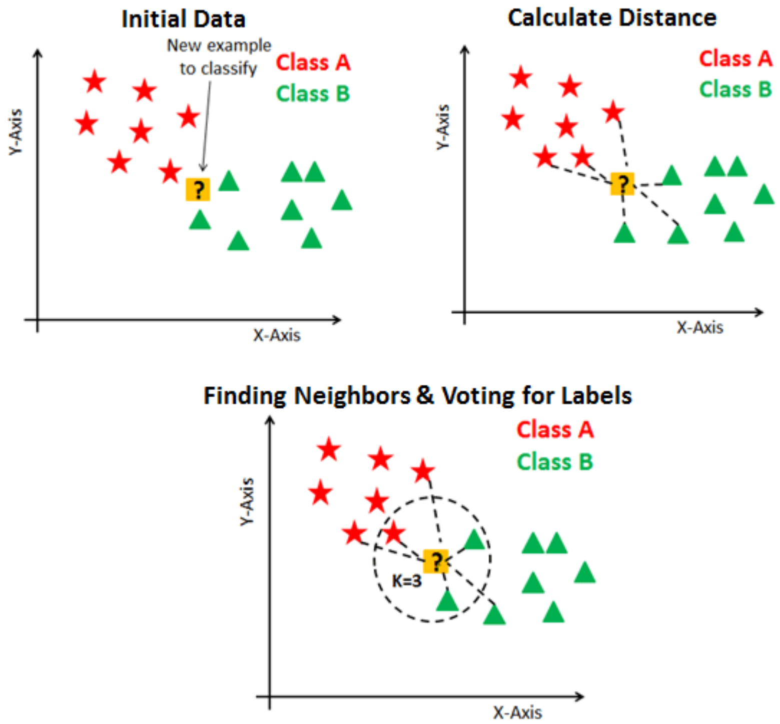



(Source: Oracle 2019)

# Advanced technologies

## K-Nearest Neighbors Algorithm (KNN)

- Used for classification and regression
- Classify based on distance
- Assign the same class to K nearest examples

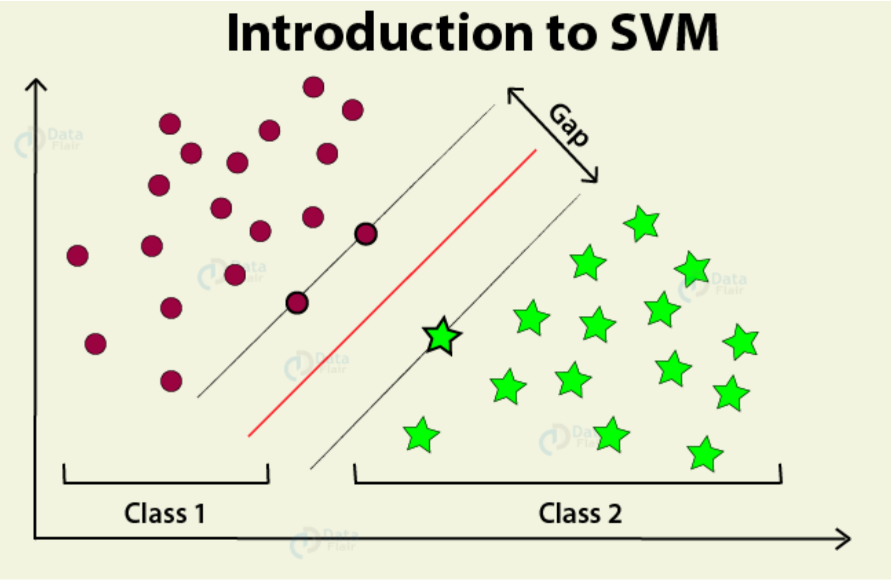



(Source: Navlani 2018)

# Advanced technologies

## Support Vector Machine (SVM)

- Used for two-group classification
- Classify based on decision boundary found by using kernel trick to transform data
- Perform well with a limited amount of data

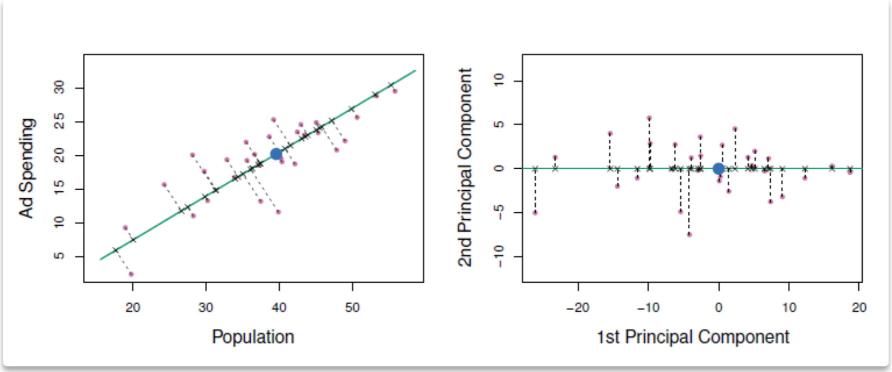


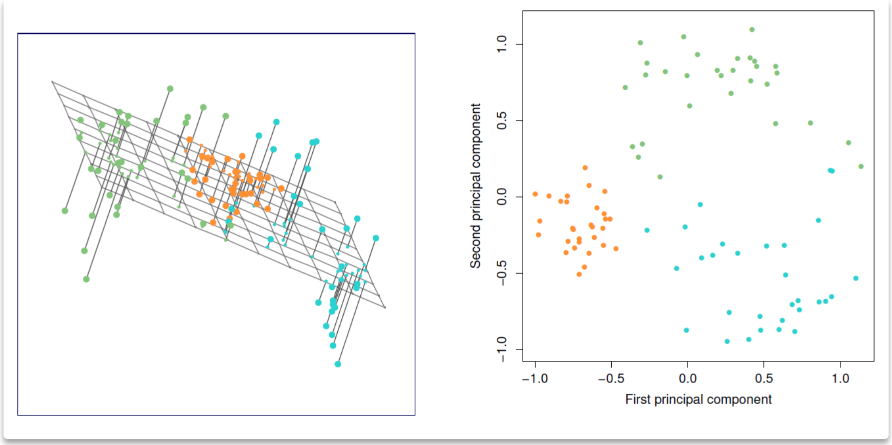

(Source: Dataflair Team 2019)

# Advanced technologies

## Principal Component Analysis (PCA)

- Used for reducing the dimensionality of datasets
- Used for extracting the main feature components of the data
- Increase interpretability
- Minimize information loss



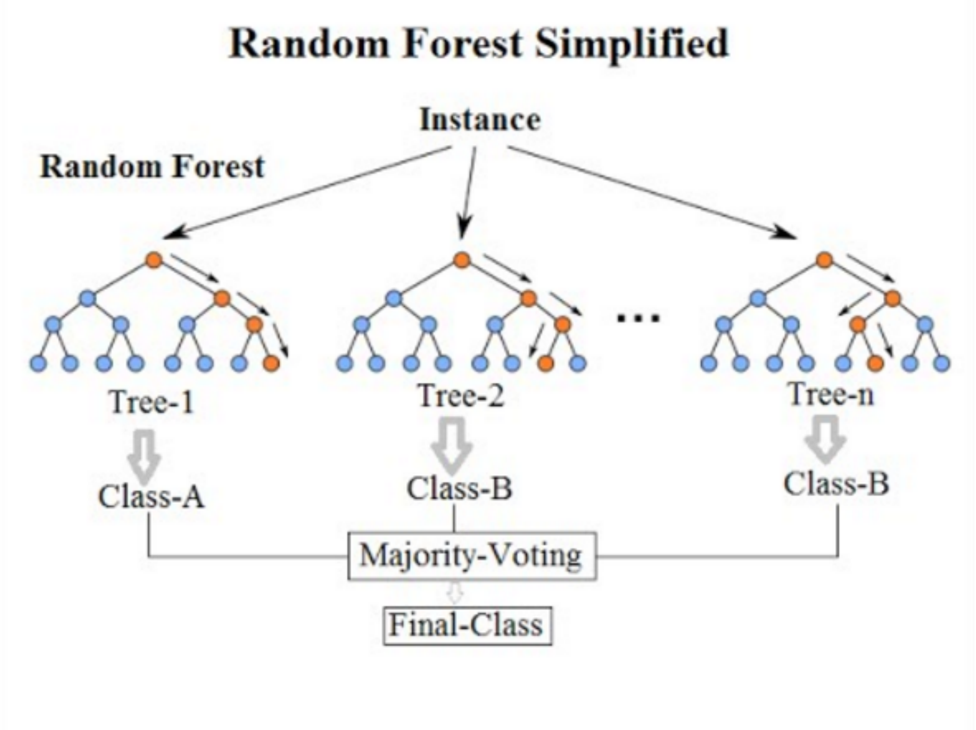




(Source: Young 2020)

# Advanced technologies

## Random Forest (RF)

- Used for classification and regression
- Consist of many decision trees
- Get final class based on the majority vote of all the trees of the forest

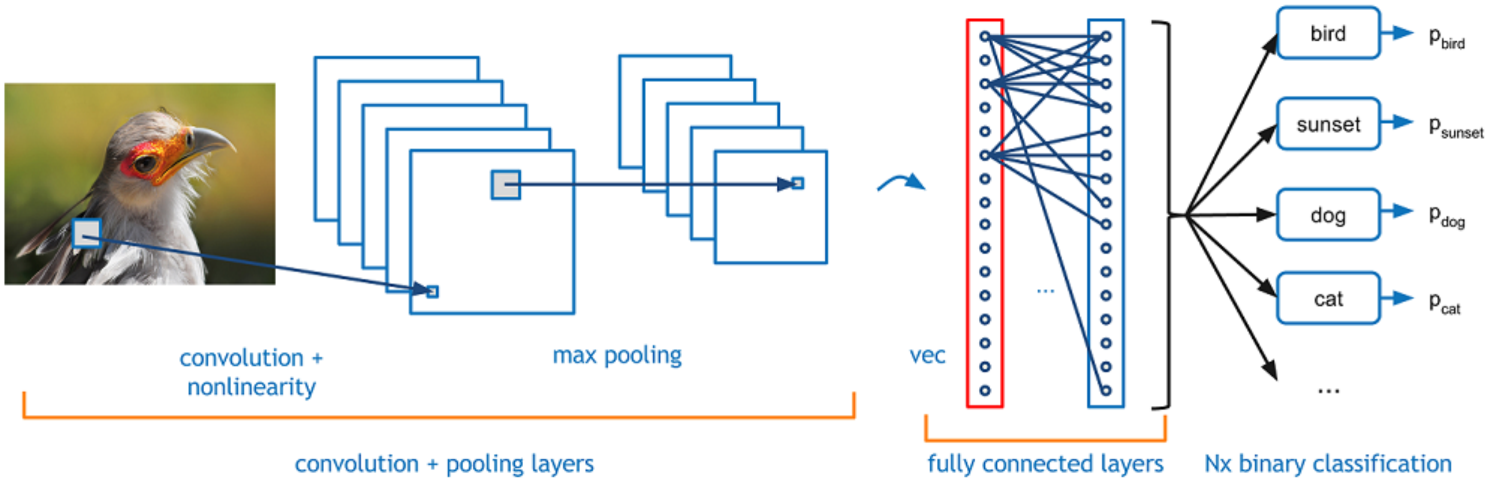



(Source: Koehrsen 2017)

# Advanced technologies

## Convolutional Neural Network (CNN)

- Commonly used for classifying images
- Extract local features by learning the filters that recognize batches
- Share parameters among neurons to reduce the complexity
- Learn high-level features by combining multiple low-level features




(Source: dshahid380 2019)

# Research methods

## First Step: Searching

**Database:** Web of Science, ScienceDirect, ASCE, IEEE, Google Scholar.

**Period Range:** 2014 - 2020

**Type of Literature:** journal articles, conference papers.

**Involved Topics:** artificial intelligence, computer vision, civil engineering, and construction management

## Second Step: Filtering

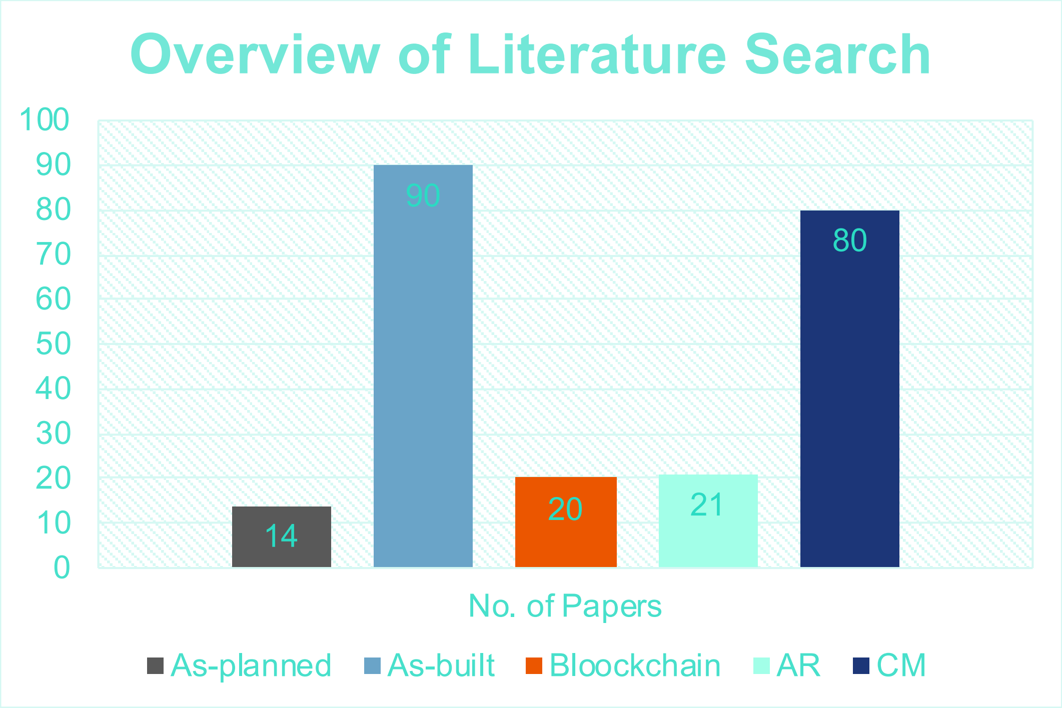
| Topic | Keyword |
|---|---|
| As-planned BIM Model Generation | 2D drawings, BIM, floor plan, AI |
| As-built BIM Model Generation | Point clouds, construction, BIM, machine learning, deep learning, registration, segmentation, classification, 3D reconstruction |
| Blockchain-based Collaboration | Blockchain, AI, IoT, smart contract, BIM, construction |
| AR-based Visualization | Augmented reality, AI, construction management |
| AI-based Construction Management | Machine learning, deep learning, progress monitoring, construction safety, quality inspection |

# Research methods

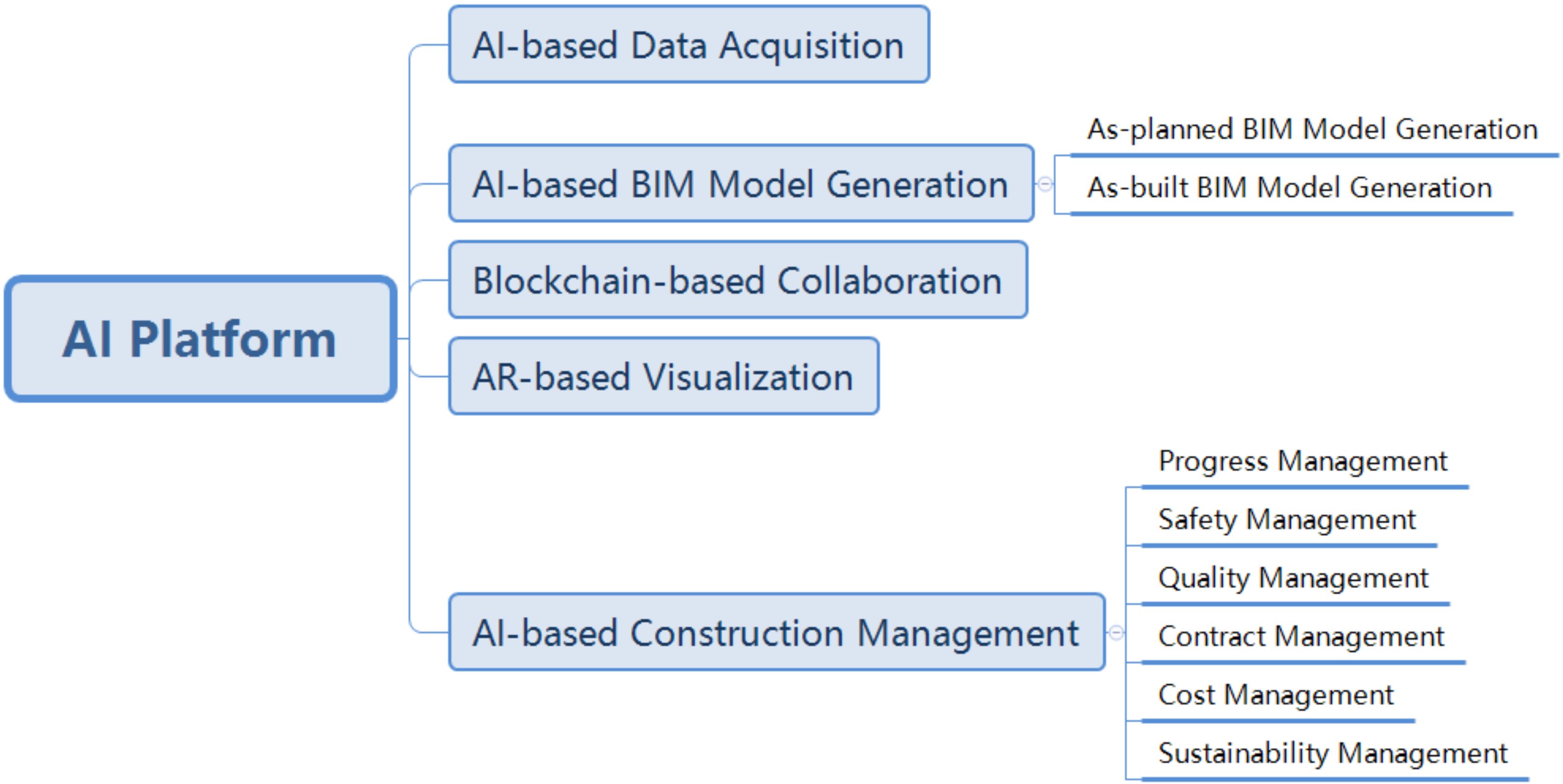
## First Step: Searching

## Second Step: Filtering

After the two-step searching and filtering, **225** academic papers are selected.



# Knowledge map



# 02 AI Platform

- *Framework for AI platform*
- *AI-based data acquisition*
- *AI-based BIM model generation*
- *Blockchain-based collaboration*
- *AR-based visualization*

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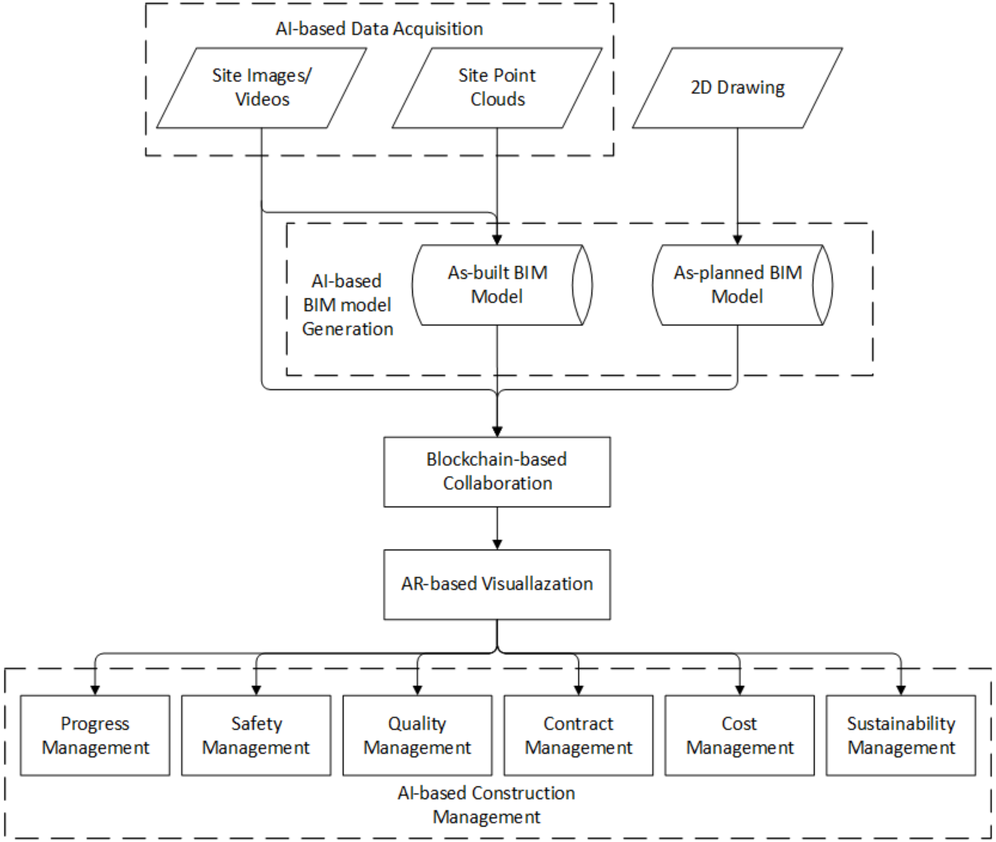
# Framework for AI platform

**Input:** Images/videos,
Point clouds,
2D drawings.

**Technology:** AI, BIM, Blockchain, AR

**Output:** Progress management,
Safety management,
Quality management,
Contract management,
Cost management,
Sustainability management.



# AI-based data acquisition

## Traditional method:
## Manual drawing

Time-consuming and costly

## New method:
## UAVs + AI

Efficient and cost-effective



(Source: Civil + Structural Engineer Media 2020;
Commercial UAV news 2018)

# AI-based data acquisition

## What is UAVs?

Unmanned aerial vehicles (UAVs) can collect image data in the inaccessible areas or undertake tasks that are dangerous to human beings (Shang and Shen 2017).

## Benefits:

- Lower labor costs
- Higher efficiency
- Visual coverage of site

## Challenges:

- Incompleteness of coverage
- Autonomous path planning and navigation

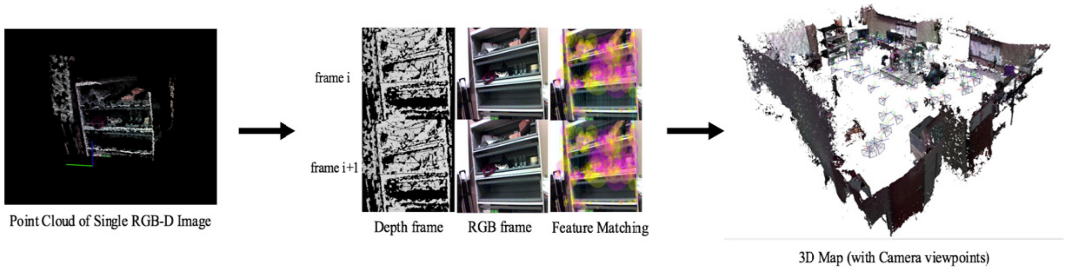



**Figure 1. Workflow of generating the 3D map of an indoor office using RGB-D camera and the graph-based SLAM approach**

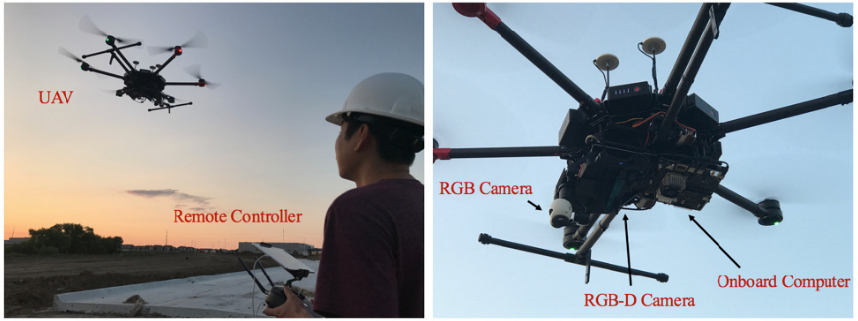



**Figure 3. Experimental Setup: (a) UAV and on-site operator; (b) the attached positions of RGB camera, RGB-D camera and onboard computer on the craft**

(Source: Shang and Shen 2017)

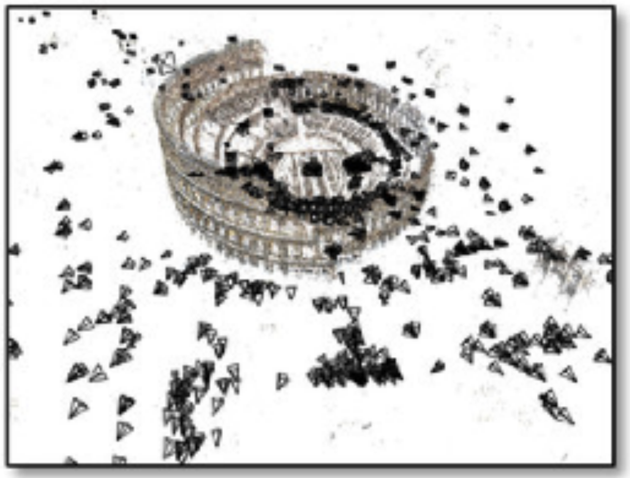
# AI-based BIM model generation

**3D Reconstruction**
3D reconstruction is the process of capturing the shape and appearance of real objects. It is the creation of three-dimensional models from a set of images.

**Structure From Motion (SfM):** structure images.

**Multi View Stereo (MVS):** make 3D dense point clouds.

To make a 3D model from set of images, we need firstly do SfM and then MVS.



(Source: McCann 2014)

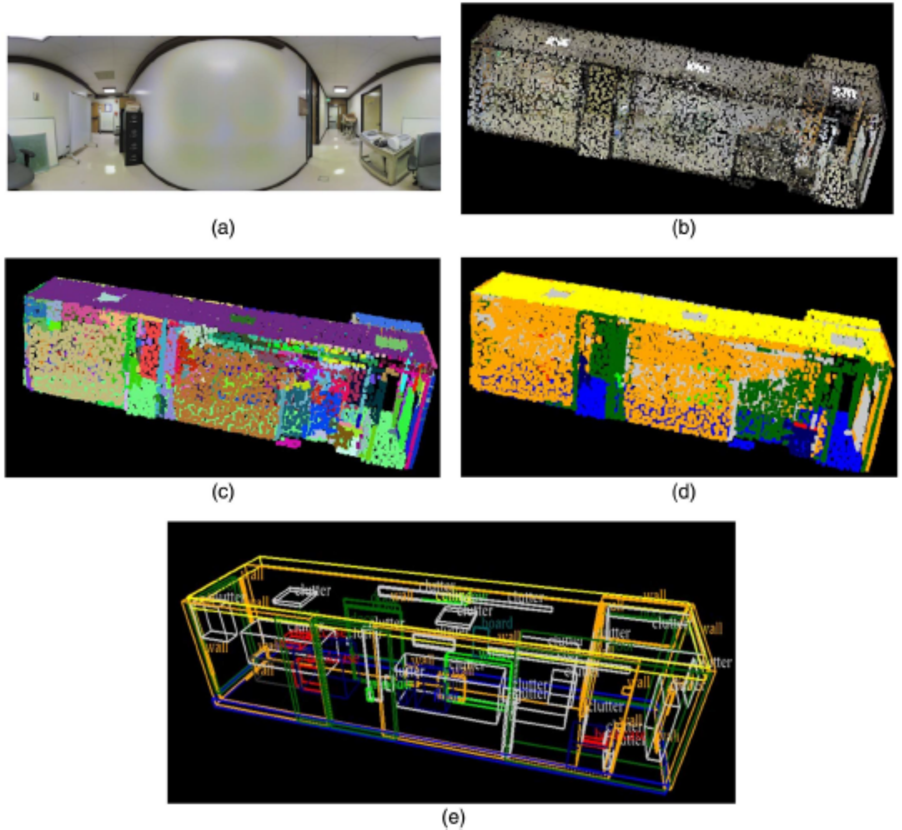
# AI-based BIM model generation

## General Procedure:

(a) Data collection
(b) Geometric model generation
(c) Segmentation for building elements
(d) Building elements classification
(e) 3D model reconstruction

## Methods:

(b): SfM + MVS + CNN (DL)
(c): KNN, PCA (ML)
(d): SVM, RF (ML) or 2D/3D CNN (DL)




(Source: Chen et al. 2019)

# AI-based BIM model generation

## Example: Chen et al. (2019)

Table 3 shows that the detection accuracy varies widely between classes due to the different geometries and amounts of training data available for each class.

**Table 3.** Objectwise accuracy (percentages) comparison between different recognition methods

| Class | Armeni et al. (2016) | Qi et al. (2017a) | Liu et al. (2017) | Proposed |
|---|---|---|---|---|
| Beam | 66.7 | — | **78.6** | 42.1 |
| Board | 3.9 | 11.7 | 37.2 | **54.6** |
| Bookcase | 54.7 | — | **85.0** | 36.9 |
| Ceiling | 71.6 | — | **89.6** | 84.8 |
| Chair | 16.2 | 33.8 | 58.1 | **61.9** |
| Column | **91.8** | — | 89.4 | 43.8 |
| Door | 54.1 | — | 33.4 | **55.0** |
| Floor | 88.7 | — | 95.0 | **97.2** |
| Sofa | 6.8 | 4.8 | **77.0** | 15.7 |
| Table | 46.0 | 46.7 | **70.5** | 30.7 |
| Wall | **72.9** | — | 60.1 | 52.4 |
| Window | 25.9 | — | **75.3** | 54.3 |
| Average | 49.9 | 24.2 | 70.8 | 52.4 |

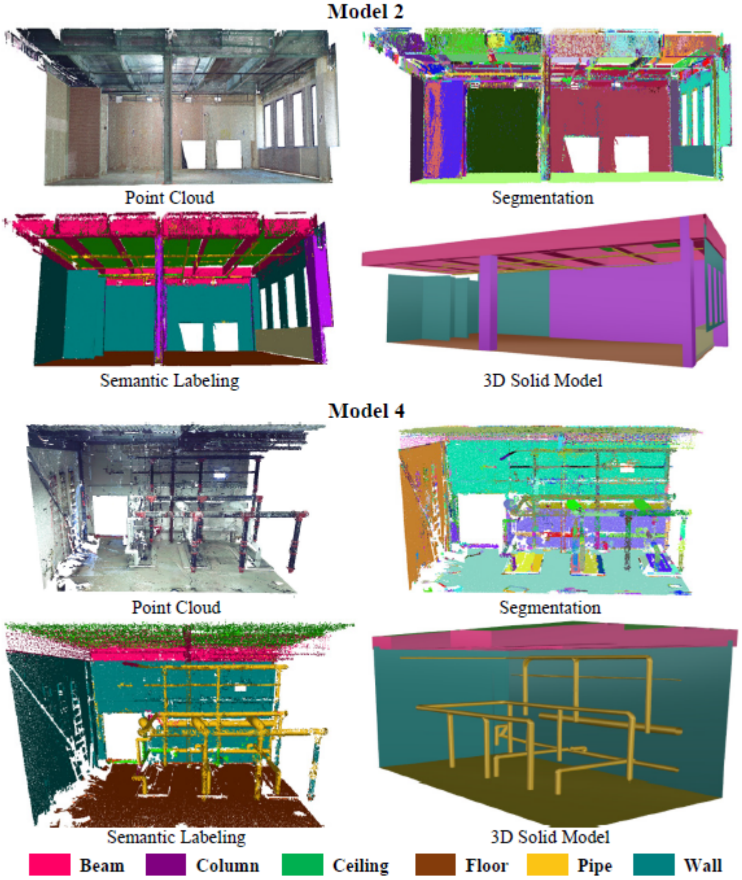
Note: Bold numbers indicate best-performing method.

(Source: Chen et al. 2019)

# AI-based BIM model generation

## Benefits:

- Time-saving generation process
- Less labor costs
- Real-time reflection of progress

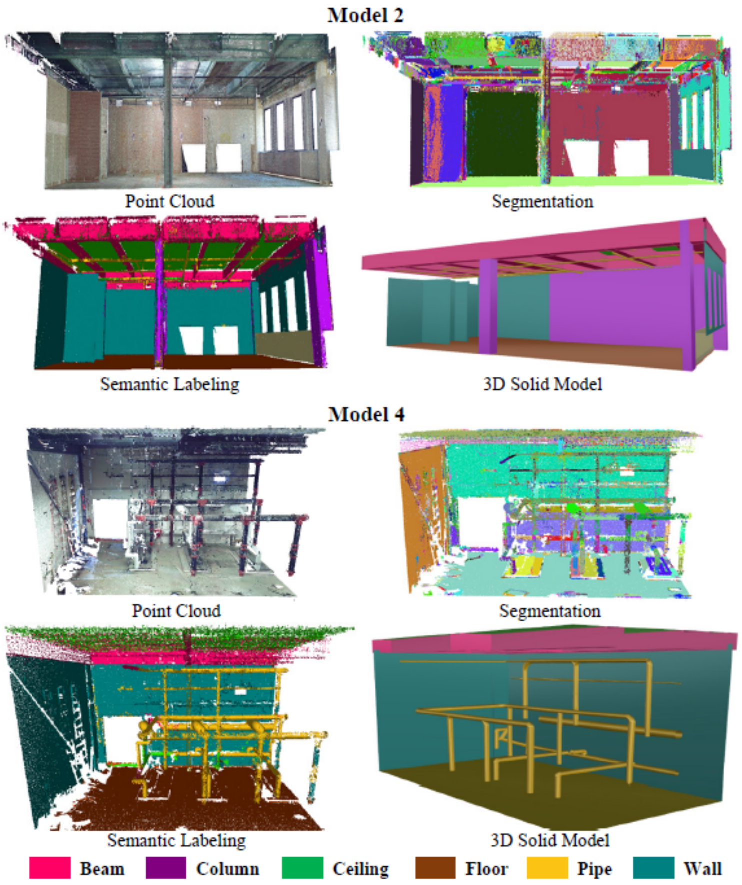



(Source: Perez-Perez et al. 2018)

# AI-based BIM model generation

## Challenges:

- Lack of “end-to-end” algorithm
- Impact of noise and occlusions
- Limited size of memory of algorithms
- Lack of training dataset with diverse data




(Source: Perez-Perez et al. 2018)

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# Blockchain-based collaboration

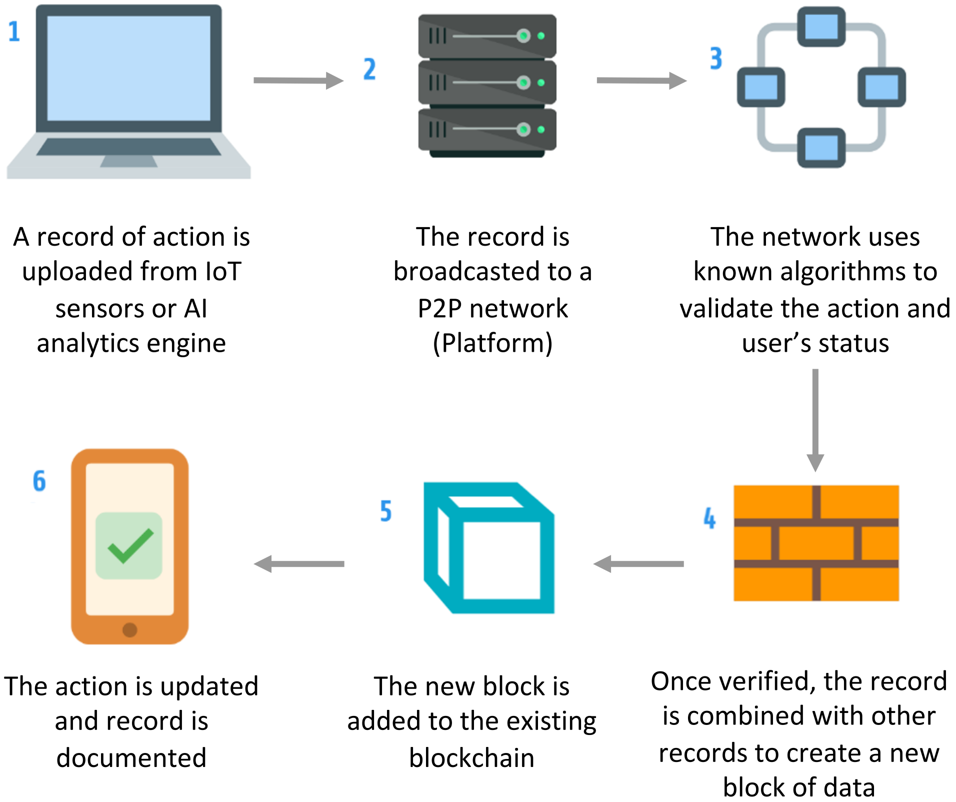
## What is Blockchain?

Originating from Bitcoin, blockchain is a distributed public ledger that the data, assets and transaction records can be shared among participants in the network to achieve mutual-trust network.

(Hargaden et al. 2019)

## Characteristics:

- ***Immutability***
- ***Decentralization***
- ***Transparency***
- ***Trustless Mechanism***



# Blockchain-based collaboration

## How to use Blockchain?

Develop a framework with the integration of blockchain, AI, smart contract, BIM, IoT.

**Blockchain:** Progress updating & information tracking

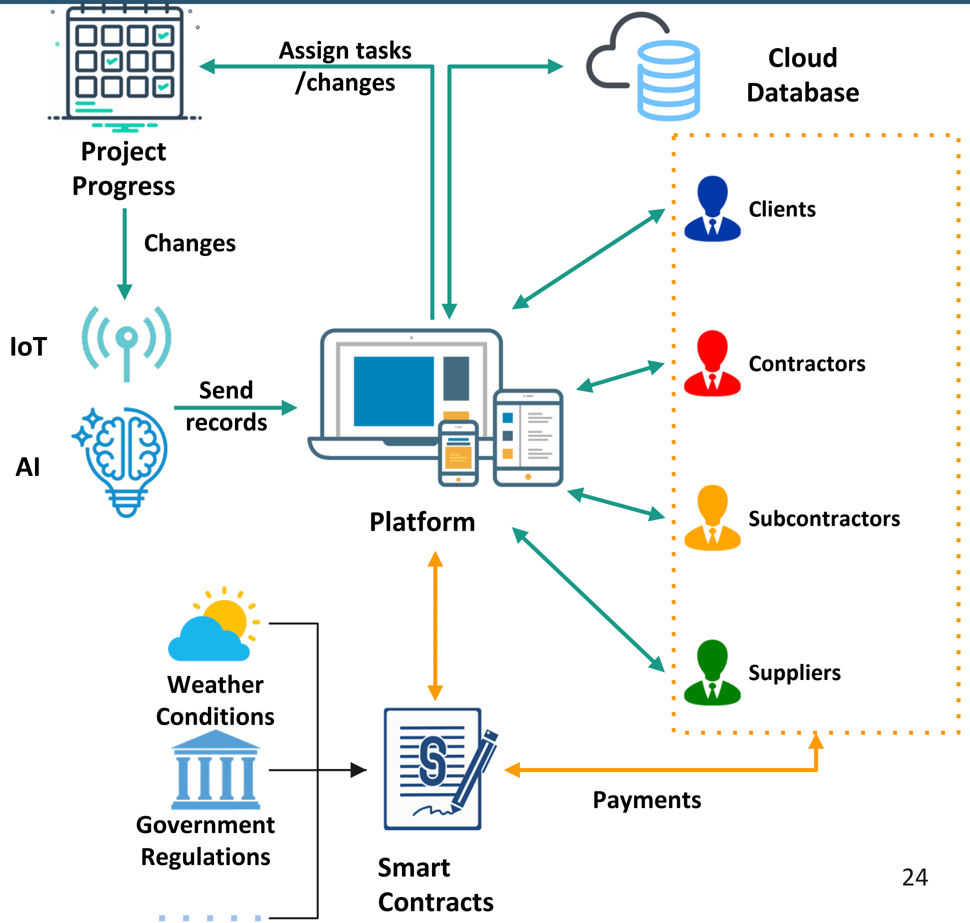
**AI:** Automated progress monitoring & decision making

**Smart contract:** Automated code compliance checking

**BIM:** Data storage for building information

**IoT:** Data collection and updating

## Possible framework (right)

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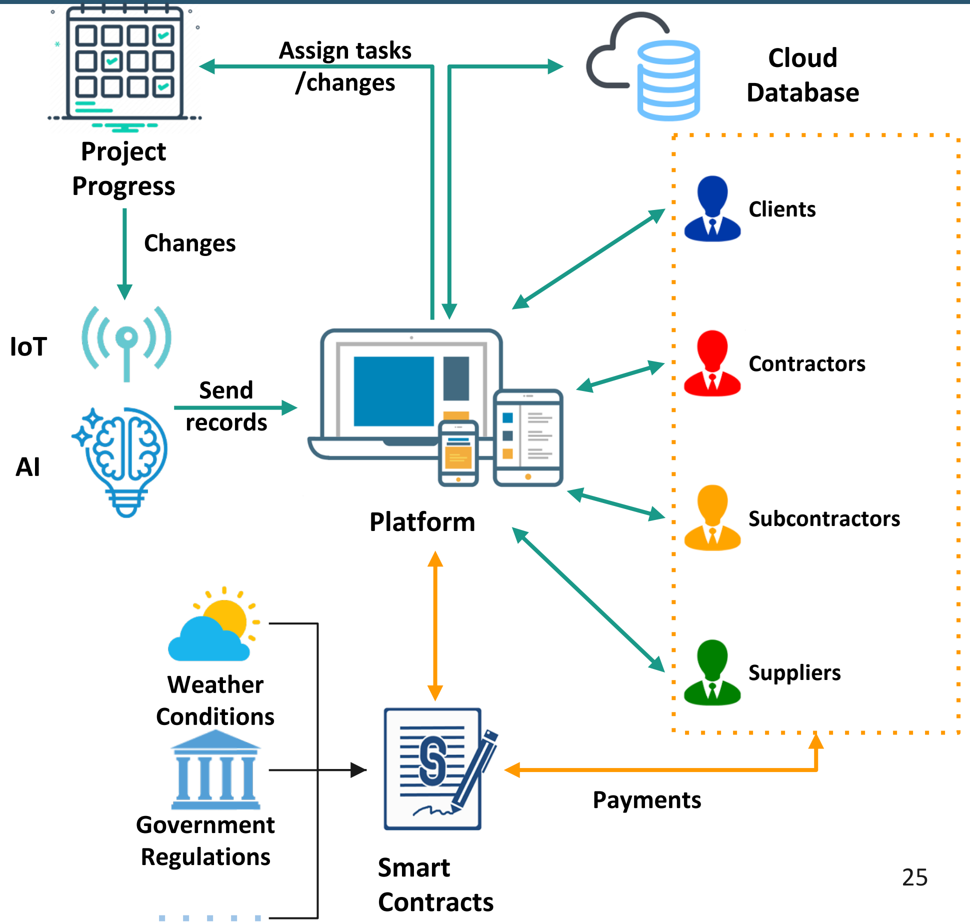
# Blockchain-based collaboration

## Challenges:

- Still in the infancy stage
- Difficult to be adopted by traditional industry
- No actual design or use case of integration
- Unpredictable costs of transferring

## Possible framework (right)

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# AR-based visualization

## What is AR?

- A combination of real and virtual worlds
- Real-time interaction
- Accurate 3D registration of virtual and real objects

## How to use AR?

**Progress management:**
Using color code to show the difference between the schedule and real work

**Defect detection:**
Mapping the BIM model to the site for tasks confirmation


(Source: Ratajczak et al. 2019, Lamsal and Kunichika 2019)

# AR-based visualization

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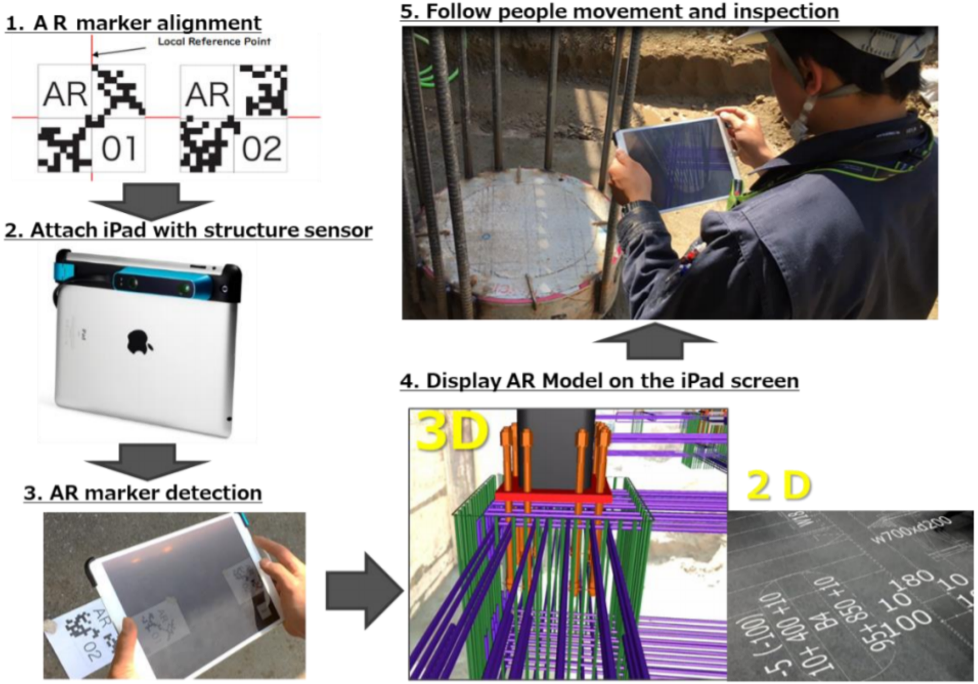



(Source: Ratajczak et al. 2019, Lamsal and Kunichika 2019)

# AR-based visualization

## Benefits:

**Visualization:** Display the progress deviation quickly and visually. Reduce decision-making errors

**Efficiency:** Integrate multiple information to improve productivity

## Challenges:

**Localization:** Lack of rapid and accurate unmarked localization method

**Fragmentation:** Lack of a platform to aggregate all functions

## AI role:

**Localization:** Simultaneous Localization and Mapping (SLAM)

# 03 AI-based CM

- *Progress management*
- *Safety management*
- *Quality management*
- *Contract management*
- *Cost management*
- *Sustainability management*
- *Summary*

# Progress management

## Type:

**Geometry-based progress monitoring:**

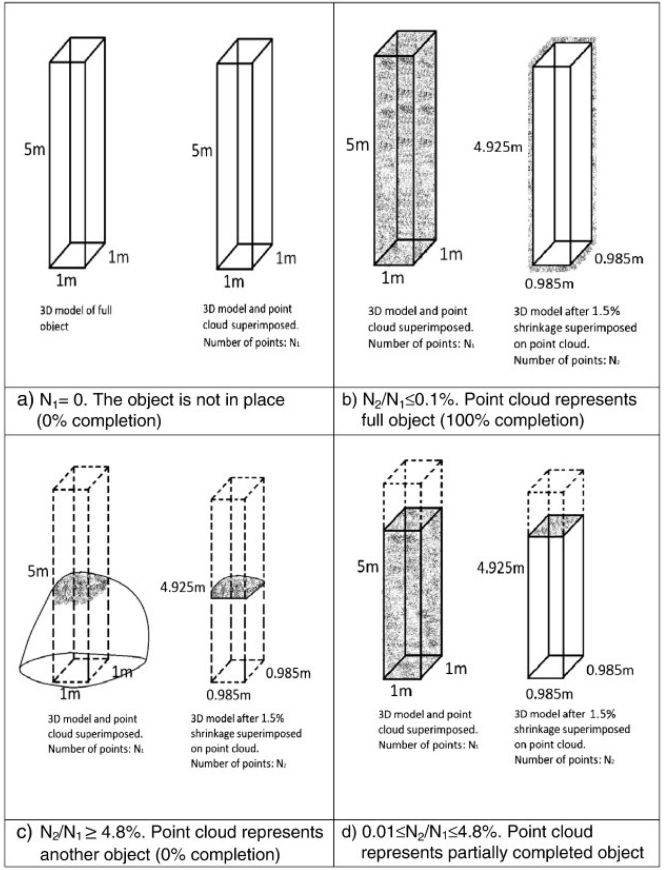
- Align the As-built model and As-planned model
- Use different operations to conclude the occupancy rate

**Appearance-based progress monitoring:**

- Check whether corresponding materials in the as-planned model are identified in the as-built model

**Mixed progress monitoring:**

- Geometry-based method for most scenario
- Appearance-based method for occlusion




(Source: Zhang and Arditi 2013)

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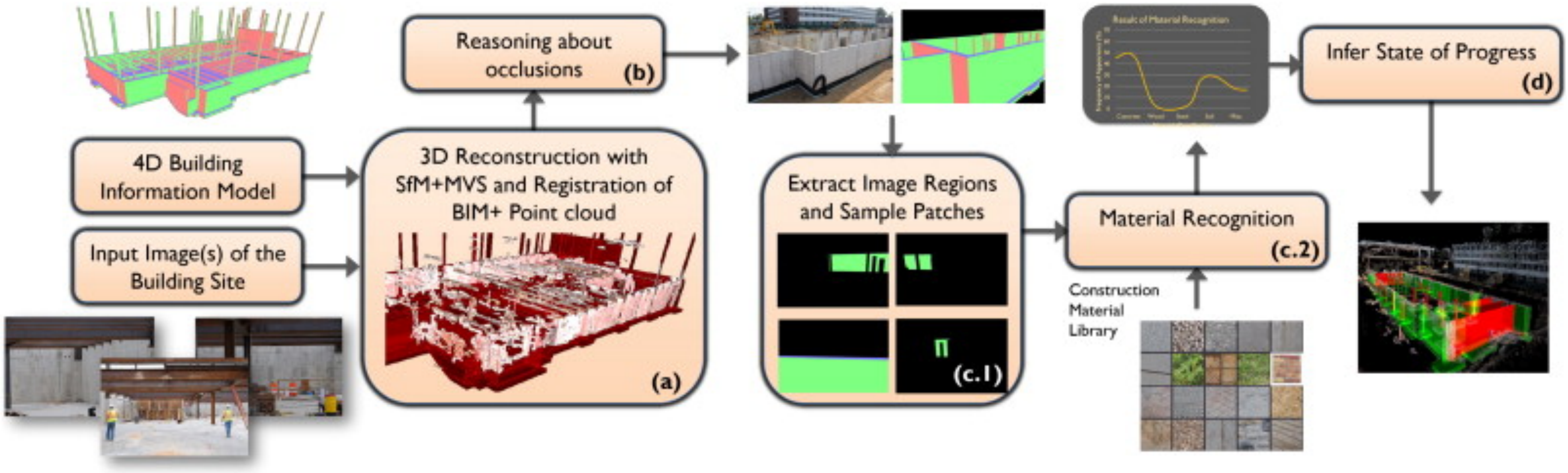
# Progress management




(Source: Han and Golparvar-Fard 2015)

# Progress management

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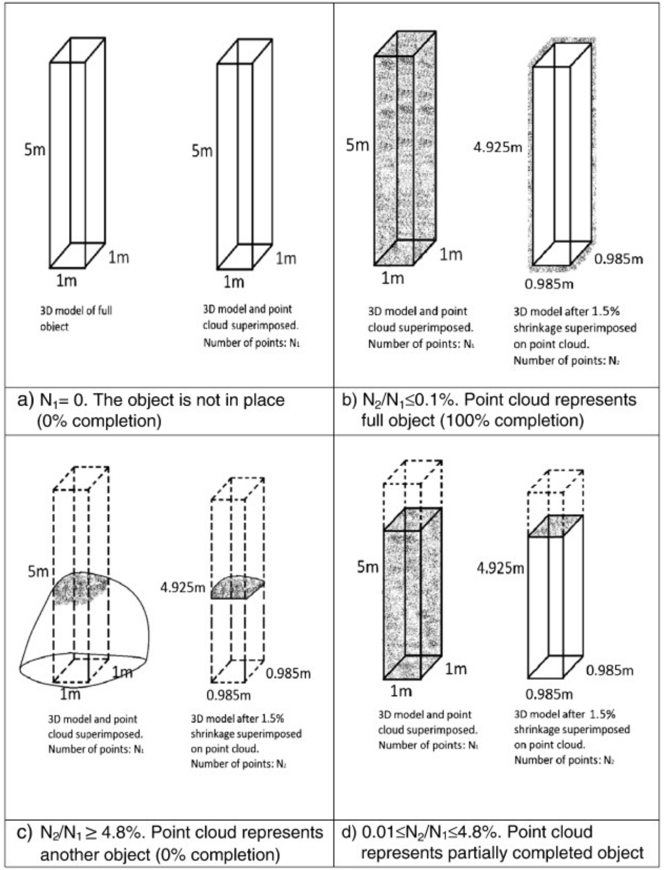



(Source: Zhang and Arditi 2013)

# Progress management

## Where is AI

**Models Alignment:**
Similar to point clouds registration

**Material identification:**

- Gaussian Mixture Model
- Artificial Neural Network
- Support Vector Machine (most accurate)

## Benefits:

**Reduced workload:**
Automated progress monitoring

**Reduced cost:**
Reduce the number of employees

## Challenges:

- Facing occlusion and noise
- Not accurate when as-planned models lack details
- Lack of using high-level reasoning (e.g. construction sequencing)

# Progress management

| Scan day | ID | Activity name | Start date | End date | Recognized visible progress | Scheduled progress | Actual visible progress |
|---|---|---|---|---|---|---|---|
| 2008-08-12 | 7 | Slab on Grade – Ground Floor | 2008-07-20 | 2008-08-19 | 67% | 67% | 65% |
| | 8 | Walls & Columns – Ground Floor | 2008-08-04 | 2008-09-01 | 21% | 32% | 20% |
| | 9 | Concrete Slab – 2nd Floor | 2008-08-18 | 2008-09-16 | 0% | 0% | 0% |
| 2008-08-19 | 7 | Slab on Grade – Ground Floor | 2008-07-20 | 2008-08-19 | 100% | 100% | 100% |
| | 8 | Walls & Columns – Ground Floor | 2008-08-04 | 2008-09-01 | 48% | 48% | 48% |
| | 9 | Concrete Slab – 2nd Floor | 2008-08-22 | 2008-09-22 | 0% | 0% | 0% |
| 2008-08-21 | 7 | Slab on Grade – Ground Floor | 2008-07-20 | 2008-08-19 | 100% | 100% | 100% |
| | 8 | Walls & Columns – Ground Floor | 2008-08-04 | 2008-09-01 | 50% | 58% | 50% |
| | 9 | Concrete Slab – 2nd Floor | 2008-08-22 | 2008-09-22 | 0% | 0% | 0% |
| 2008-08-26 | 7 | Slab on Grade – Ground Floor | 2008-07-20 | 2008-08-19 | 100% | 100% | 100% |
| | 8 | Walls & Columns – Ground Floor | 2008-08-04 | 2008-09-02 | 67% | 67% | 65% |
| | 9 | Concrete Slab – 2nd Floor | 2008-08-22 | 2008-09-22 | 0% | 14% | 0% |
| 2008-08-29 | 7 | Slab on Grade – Ground Floor | 2008-07-20 | 2008-08-19 | 100% | 100% | 100% |
| | 8 | Walls & Columns – Ground Floor | 2008-08-04 | 2008-09-03 | 71% | 81% | 72% |
| | 9 | Concrete Slab – 2nd Floor | 2008-08-22 | 2008-09-26 | 0% | 17% | 0% |

(Source: Turkan et al. 2012 )

# Safety management

## What is Computer Vision?

Computer vision is a field of artificial intelligence that trains computers to interpret and understand the visual world (SAS 2020).

## Its Benefits/Limitations?

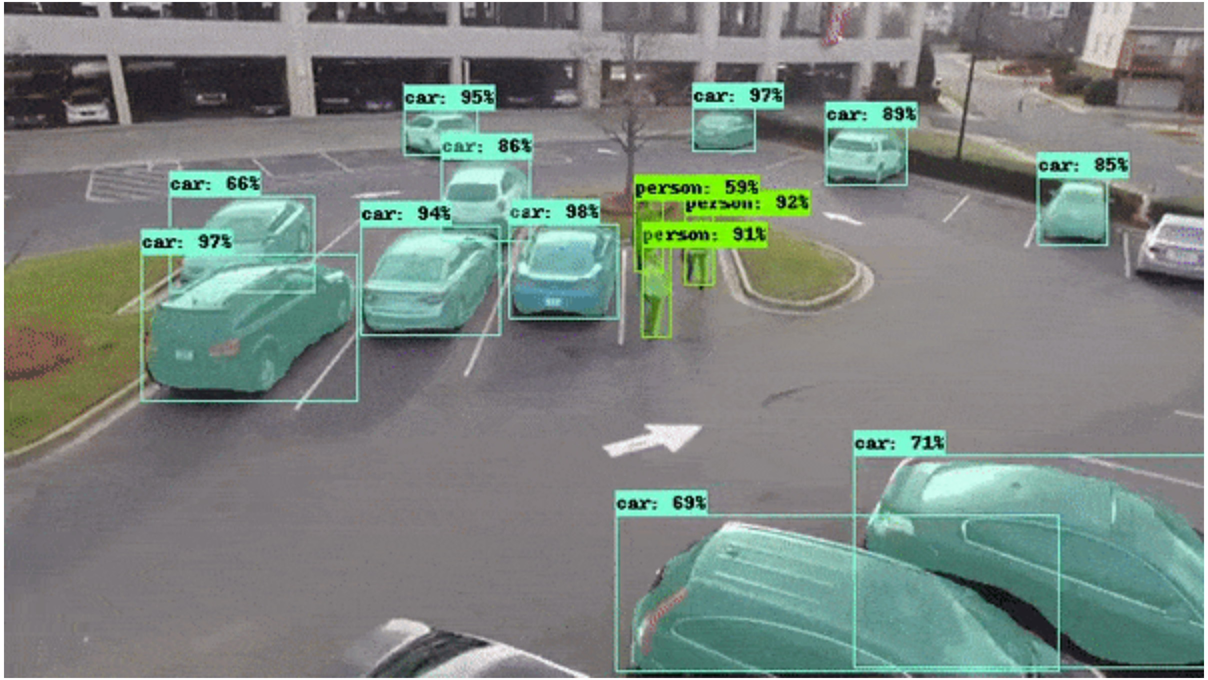
**Benefits:**

- Faster and simpler process
- Accurate outcome
- Cost reduction

**Limitations:**

- Lack of specialists
- Need for regular monitoring

(Source: Allerin 2019)




(Source: Towards Data Science 2018)

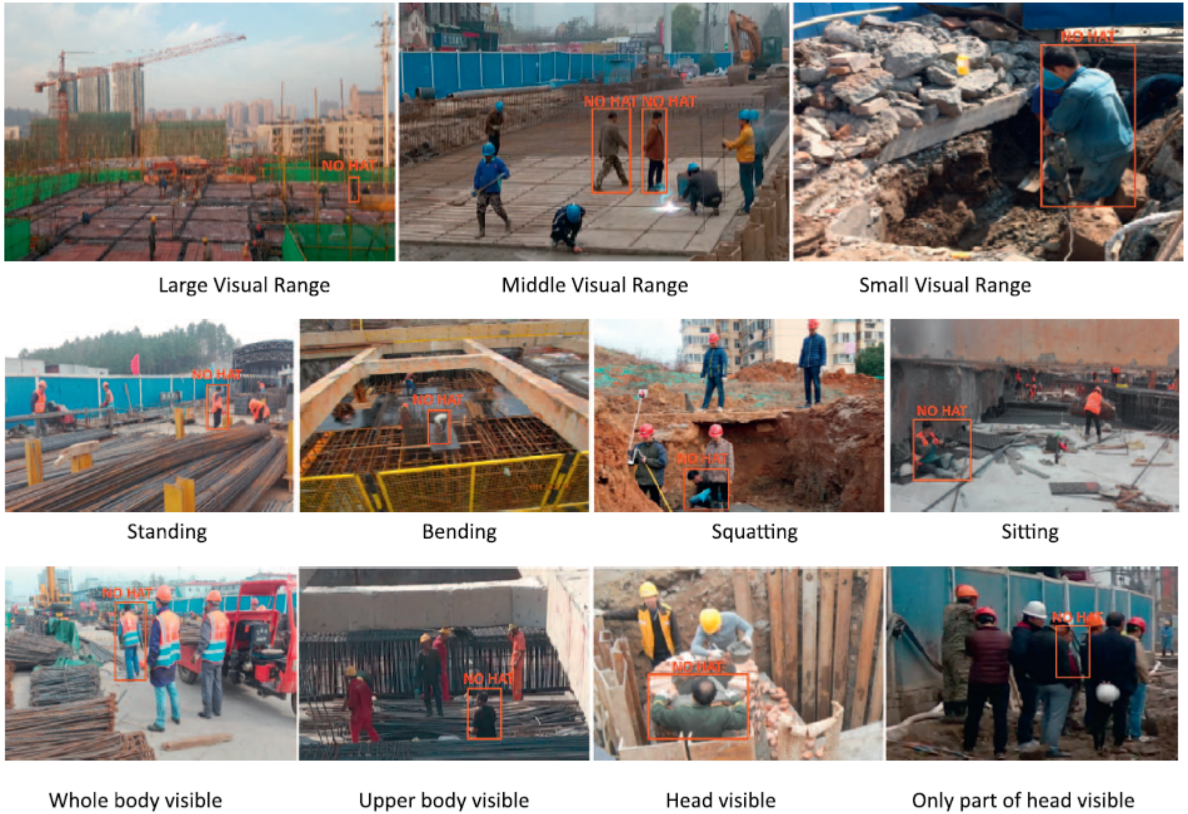
# Safety management

## Methods:

Faster R-CNN (object detection)

## Applications

**1. PPE Detection**
Identify whether workers on site wear Personal Protection Equipment (PPE) properly, e.g. hardhat.




(Source: Fang et al. 2018)

# Safety management

## Methods:

Faster R-CNN (object detection)

## Applications

**2. Unsafe Behavior Detection**
Detect the unsafe behaviors that workers are doing on sites, e.g. traversing structural supports during the construction.


Fig. 4. Examples of detection of individuals walking on supports.

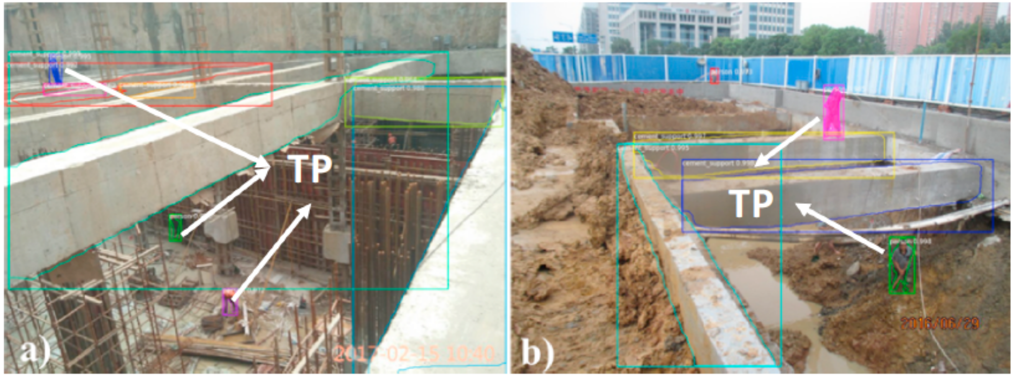



Fig. 5. Examples of detection of an individual walking on supports.

(Source: Fang et al. 2019)

# Safety management

## Methods:

Faster R-CNN (object detection)

## Applications

**3. Hazardous Area Detection**
Detect the areas that have risks of accidents on sites, e.g. the edges of slab.

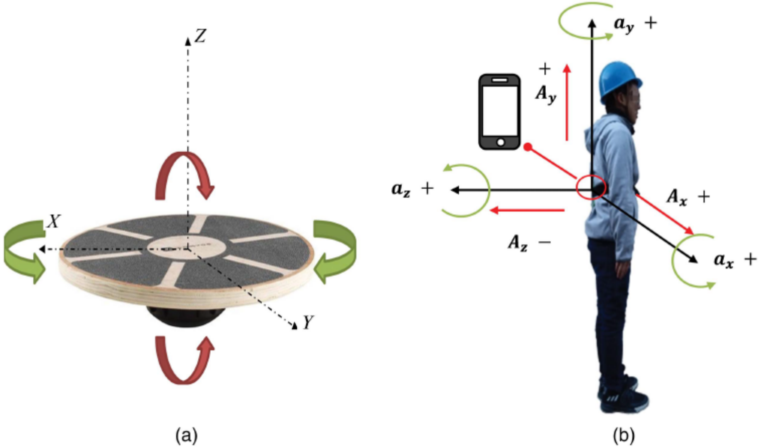



**Fig. 2.** Use of a balance board to simulate LOB scenes: (a) simulation in multiple directions; and (b) three-axis acceleration and angle collection.

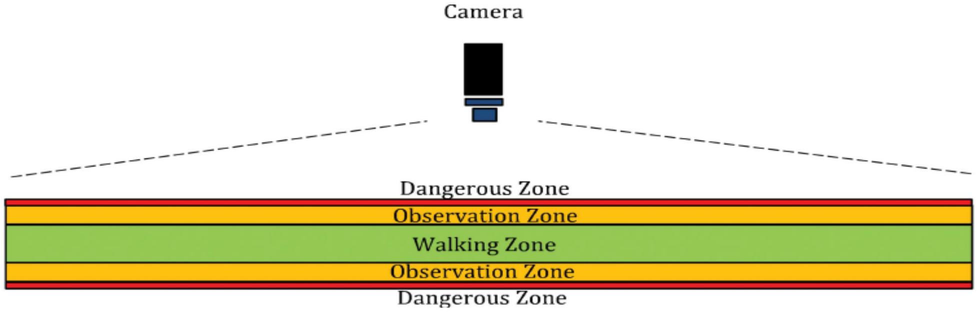



**Fig. 3.** Layout of the test platform.

(Source: Zhang et al. 2019)

# Safety management

## Benefits:

**Reduced occurrence of accidents:**

- Alarming mechanism
- Prediction model

**Reduced labor costs:**

- Automated detection

## Challenges:

- Lack of lager datasets with diverse images for training
- Negative effect of occlusions
- No common standard to evaluate the performance of detection

Sunny Cloudy Misty Rain Hazy

**Fig. 5.** Image frame examples under different weather conditions.

**Table 4**
Precision, recall and miss rate ratios in different weather conditions.

| Categories | No. | Value | TP | FP | FN | Precision (%) | Recall (%) | Miss rate (%) | Speed (s) |
|---|---|---|---|---|---|---|---|---|---|
| Weather | 1 | Sunny | 2459 | 83 | 123 | 96.7 | 95.2 | 4.8 | 0.204 |
| | 2 | Cloudy | 2155 | 98 | 94 | 95.7 | 95.8 | 4.2 | 0.202 |
| | 3 | Misty rain | 1586 | 107 | 98 | 93.7 | 94.2 | 5.8 | 0.209 |
| | 4 | Hazy | 2186 | 123 | 164 | 94.7 | 93.0 | 7.0 | 0.210 |

(Source: Fang et al. 2019)

# Quality management

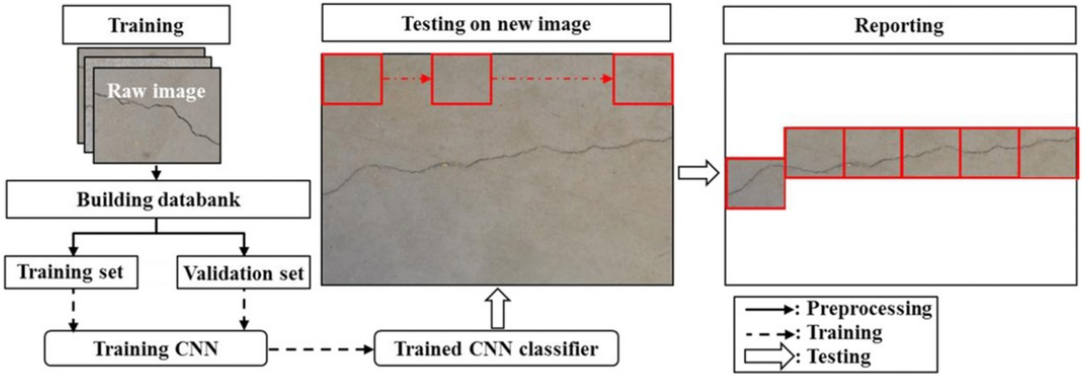
## Methods:

**AI-based objects recognition**

- Convolutional Neural Network
- Support Vector Machine
- Faster R-CNN
- Fully Convolutional Networks

## What it can do?

- Rail detection
- Sewer detection
- Tunnel detection
- Road detection
- Building detection




(Source: Cha et al. 2017, Cha et al. 2018)

# Quality management

## Methods:

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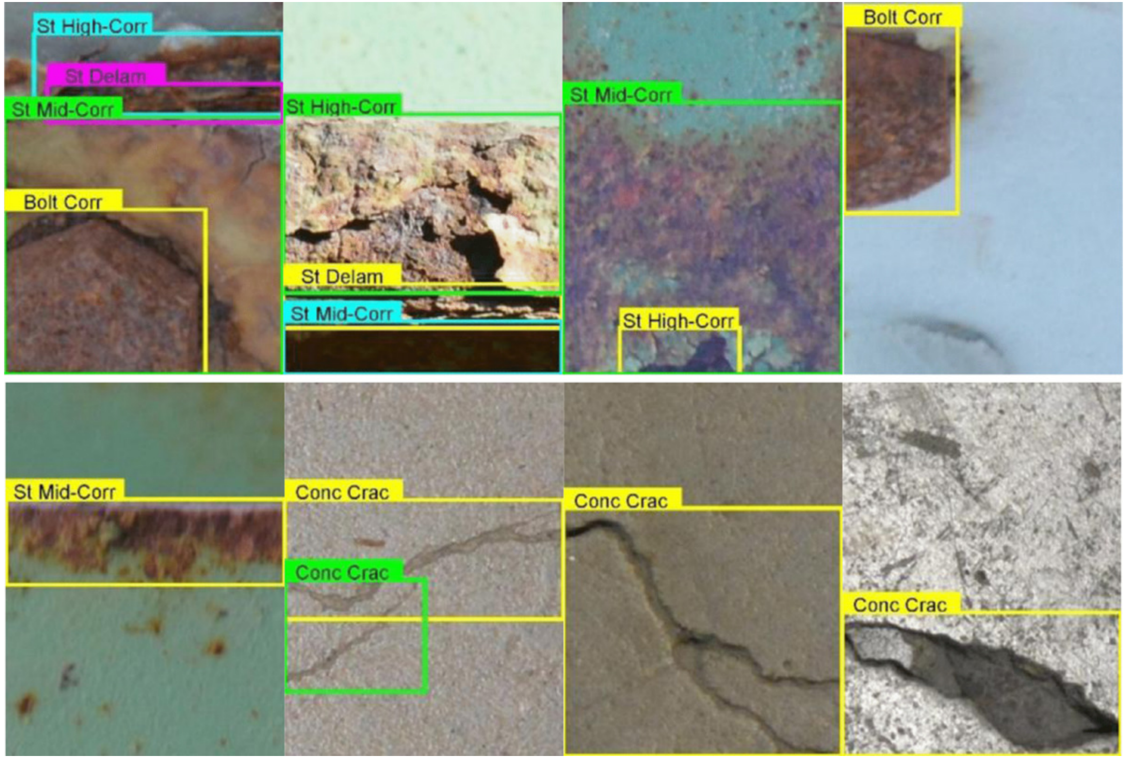



(Source: Cha et al. 2017, Cha et al. 2018)

# Quality management

## Methods:

**AI-based objects recognition**

- Convolutional Neural Network
- Support Vector Machine
- Faster R-CNN
- Fully Convolutional Networks

## What it can do?

- Rail detection
- Sewer detection
- Tunnel detection
- Road detection
- Building detection

## Benefits:

**Reduced workload:**

- Automated progress monitoring

**Reduced cost:**

- Reduce the number of employees

## Challenges:

- Lacking large database for training
- One algorithm can only detect a limited type of quality defects
- Cannot be applied to recognize defects which are not visible



(Source: Cha et al. 2017, Cha et al. 2018)

# Quality management

**Table A1**
Continued

| No. | # of Pos.[(i)] | # of Neg.[(ii)] | # of TP[(iii)] | # of TN[(iv)] | # of FP[(v)] | # of FN[(vi)] | Accuracy | Precision | Recall | F1 | Remark |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 3 | 55 | 553 | 54 | 538 | 15 | 1 | 0.97 | 0.78 | 0.98 | 0.87 | Figure 14(c) |
| 4 | 37 | 571 | 35 | 566 | 5 | 2 | 0.99 | 0.88 | 0.95 | 0.91 | Figure 14(d) |
| 5 | 58 | 550 | 41 | 550 | 0 | 17 | 0.97 | 1.00 | 0.71 | 0.83 | Figure 14(e) |
| 6 | 45 | 269 | 42 | 266 | 3 | 3 | 0.98 | 0.93 | 0.93 | 0.93 | – |
| 7 | 23 | 291 | 23 | 289 | 2 | 0 | 0.99 | 0.92 | 1.00 | 0.96 | – |
| 8 | 35 | 279 | 35 | 275 | 4 | 0 | 0.99 | 0.90 | 1.00 | 0.95 | – |
| 9 | 31 | 283 | 25 | 283 | 0 | 6 | 0.98 | 1.00 | 0.81 | 0.89 | – |
| 10 | 31 | 283 | 29 | 281 | 2 | 2 | 0.99 | 0.94 | 0.94 | 0.94 | – |
| 11 | 32 | 282 | 32 | 279 | 3 | 0 | 0.99 | 0.91 | 1.00 | 0.96 | – |
| 12 | 30 | 284 | 30 | 277 | 7 | 0 | 0.98 | 0.81 | 1.00 | 0.90 | – |
| 13 | 30 | 284 | 30 | 283 | 1 | 0 | 1.00 | 0.97 | 1.00 | 0.98 | – |
| 14 | 31 | 283 | 31 | 281 | 2 | 0 | 0.99 | 0.94 | 1.00 | 0.97 | – |
| 15 | 31 | 283 | 30 | 253 | 30 | 1 | 0.90 | 0.50 | 0.97 | 0.66 | – |
| 16 | 38 | 276 | 32 | 271 | 5 | 6 | 0.96 | 0.86 | 0.84 | 0.85 | – |
| 17 | 28 | 286 | 28 | 285 | 1 | 0 | 1.00 | 0.97 | 1.00 | 0.98 | – |
| 18 | 34 | 392 | 34 | 389 | 3 | 0 | 0.99 | 0.92 | 1.00 | 0.96 | – |
| 19 | 30 | 396 | 30 | 391 | 5 | 0 | 0.99 | 0.86 | 1.00 | 0.92 | – |
| 20 | 23 | 403 | 23 | 400 | 3 | 0 | 0.99 | 0.88 | 1.00 | 0.94 | – |

(Source: Cha et al. 2017)

# Quality management

The performance of the network for the testing set

| Case | mAP (%) | Average precision (%) Concrete cracks | Medium steel corrosion | High steel corrosion | Bolt corrosion | Steel delamination |
|---|---|---|---|---|---|---|
| 1 | 87.1 | 90.3 | 84.6 | 83.3 | 90.2 | 87.0 |
| 2 | 85.0 | 89.8 | 85.4 | 80.6 | 89.8 | 79.5 |
| 3 | 86.1 | 90.5 | 85.9 | 83.5 | 90.1 | 80.5 |
| 4 | 86.6 | 89.5 | 85.0 | 82.5 | 89.7 | 86.4 |
| 5 | 85.6 | 89.1 | 83.8 | 82.7 | 90.2 | 82.1 |
| 6 | 86.5 | 90.3 | 84.2 | 82.7 | 90.6 | 84.5 |
| 7 | 87.6 | 89.8 | 85.9 | 85.1 | 90.5 | 86.5 |
| 8 | 87.6 | 90.4 | 85.5 | 84.3 | 90.6 | 87.4 |
| 9 | 85.3 | 89.5 | 84.3 | 83.3 | 89.7 | 79.7 |
| 10 | 85.8 | 90.8 | 85.9 | 82.9 | 89.7 | 79.5 |
| 11 | 87.6 | 90.2 | 83.0 | 82.5 | 98.0 | 84.2 |
| 12 | 85.4 | 89.9 | 84.8 | 82.4 | 90.0 | 79.7 |
| 13 | 85.5 | 90.3 | 85.4 | 79.5 | 89.8 | 82.6 |
| 14 | 85.2 | 89.2 | 84.3 | 82.2 | 89.4 | 80.8 |
| 15 | 85.2 | 89.8 | 83.5 | 81.7 | 90.3 | 80.8 |
| 16 | 87.6 | 90.5 | 85.7 | 84.4 | 90.4 | 87.3 |
| 17 | 87.2 | 90.8 | 84.3 | 84.9 | 90.7 | 85.5 |
| 18 | 85.7 | 89.3 | 85.0 | 85.2 | 90.1 | 79.0 |
| 19 | 85.4 | 90.9 | 85.6 | 82.3 | 89.5 | 78.7 |
| 20 | 85.0 | 90.4 | 83.9 | 82.4 | 89.4 | 78.9 |

(Source: Cha et al. 2018)

# Contract management

## Definition:

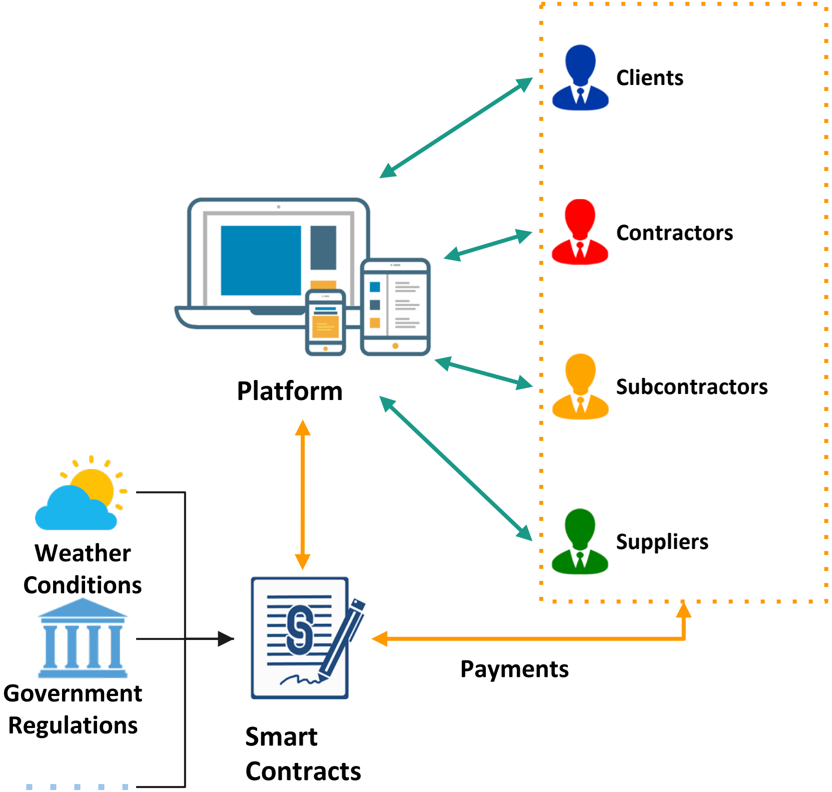
Contract management: The process that manages the creation and execution of contracts efficiently (Chen et al. 2019), involving various stakeholders (e.g. contractor, client, engineers, government, etc.).

## Applications:

- Automated contract execution
- Automated code compliance
- Automated payment

## Benefits:

- Reduced labor costs
- Reduced processing time
- Increased reliability



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## Applications:

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- Automated payment

## Challenges:

- Reference data model that explicitly defines terms, conditions relationships, etc.
- Machine-readable script of contract that can be reviewed and verified by experts

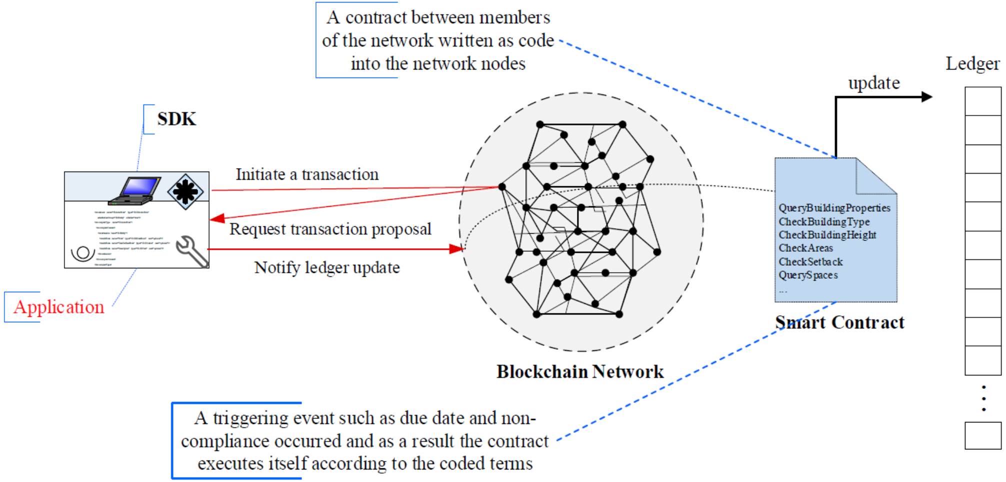


**Figure 3.** The concept of smart contract in a blockchain network.

(Source: Nawari and Ravindran 2019)

# Cost management

## Methods:

- Neural network (NN)
- Support Vector Machine (SVM)
- Case-Based Reasoning (CBR)

## What it can do?

- Estimating costs with limited information

## Benefits

- Support decision making

## Limitation

- Model construction is time consuming and tedious

| | Description | Min | Max | Average | Remark |
|---|---|---|---|---|---|
| | Year | From 2004 to 2007 | | | None |
| | Budget | 1. BTL 2. National Finance | | | Nom. |
| | School Levels | 1. Elementary 2. Middle 3. High | | | Nom. |
| | Land Acquisition | 1. Existing 2. Building lots 3. Green Belts | | | Nom. |
| Input | Class Number | 12 | 48 | 31 | Num. |
| | Building Area | 1204 | 3863 | 2694 | Num. |
| | Gross Floor Area | 4925 | 12,710 | 9656 | Num. |
| | Storey | 3 | 7 | 4.7 | Num. |
| | Basement Floor | 0 | 2 | 0.5 | Num. |
| | Floor Height | 3.3 | 3.6 | 3.5 | Num. |
| Output | Total Construction Cost | | | | |

(Source: Kim et al. 2013)

| Notation | Algorithm/model | Algorithm type | MAPE (%) | MAPE (%) categorization | $R^2$ | $R^{*2}$ |
|---|---|---|---|---|---|---|
| M1 | XGBoost | Ensemble methods | 9.091 | Below 10 | 0.931 | 0.929 |
| M2 | Quadratic regression[a] | MRA | 9.120 | Below 10 | 0.857 | 0.851 |
| M3 | Plain regression[a] | MRA | 9.130 | Below 10 | 0.803 | 0.796 |
| M4 | Quadratic MLP[a] | ANNs | 9.200 | Below 10 | 0.904 | 0.902 |
| M5 | Plain MLP[a] | ANNs | 9.270 | Below 10 | 0.913 | 0.912 |
| M6 | Semilog regression[a] | MRA | 9.300 | Below 10 | 0.915 | 0.910 |
| M7 | Extra trees | Ensemble methods | 9.714 | Below 10 | 0.948 | 0.947 |
| M8 | Natural log MLP[a] | ANNs | 10.230 | Below 20 | 0.905 | 0.910 |
| M9 | Bagging | Ensemble methods | 10.246 | Below 20 | 0.914 | 0.911 |
| M10 | RF | Ensemble methods | 10.503 | Below 20 | 0.916 | 0.913 |
| M11 | AdaBoost | Ensemble methods | 10.679 | Below 20 | 0.875 | 0.871 |
| M12 | SGB | Ensemble methods | 11.008 | Below 20 | 0.926 | 0.924 |
| M13 | Reciprocal regression[a] | MRA | 11.200 | Below 20 | 0.814 | 0.801 |
| M14 | Power (2) regression[a] | MRA | 11.790 | Below 20 | 0.937 | 0.931 |
| M15 | DNNs | ANNs | 12.059 | Below 20 | 0.785 | 0.779 |
| M16 | DT | Tree model | 12.488 | Below 20 | 0.886 | 0.883 |
| M17 | Genetic fuzzy | Hybrid model | 14.700 | Below 20 | 0.863 | 0.857 |
| M18 | CBR | Case-based | 17.300 | Below 20 | 0.859 | 0.852 |
| M19 | SVM | Kernel-based | 21.217 | Unacceptable | 0.136 | 0.133 |
| M20 | Fuzzy | Fuzzy theory | 26.300 | Unacceptable | 0.857 | 0.851 |

(Source: ElMousalami et al. 2018)

# Sustainability management

## Definition:

The practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout the full life cycle of a building (EPA 2016).

## Applications:

- Automated material management
- Automated facility management
- Building performance simulation

## Benefits:

- Reduced material waste
- Labor cost and time saving
- Energy efficiency improvement


(Source: Mixbrow Construction 2020)

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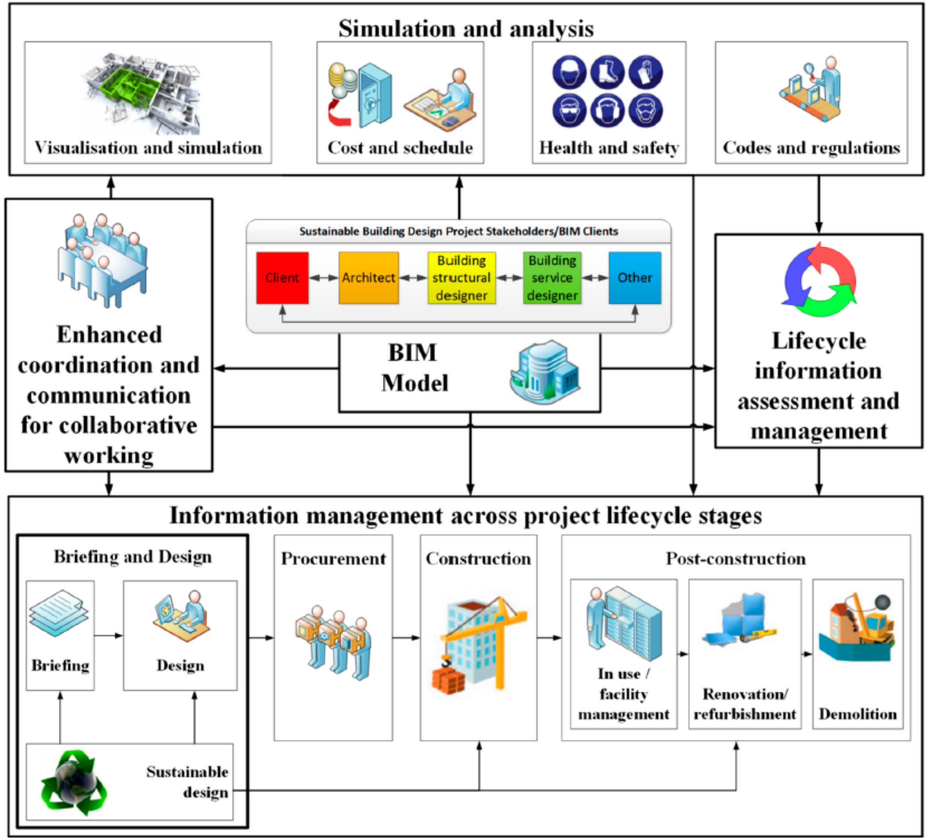
## Applications:

- Automated material management
- Automated facility management
- Building performance simulation

## Challenges:

- Uncertainty based on incomplete building documentation
- Management of information transfer between real-time operations system and BIM model




(Source: Liu et al. 2019)

# Sustainability management

## Definition:

The practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout the full life cycle of a building (EPA 2016).

## Applications:

- Automated material management
- Automated facility management
- Building performance simulation

## Challenges:

- Uncertainty based on incomplete building documentation
- Management of information transfer between real-time operations system and BIM model

## Future Direction:

- Apply AI technology in resource allocation
- Apply AI technology in real-time facility monitoring

# Summary

| CM | Progress | Safety | Quality | Contract | Cost | Sustainability |
|---|---|---|---|---|---|---|
| Involved Techs | AI, BIM, UAV | | | Blockchain, AI, IoT | AI | AI, BIM |
| Applications | Progress monitoring | PPE detection;<br>Unsafe behavior detection;<br>Hazardous area detection | Defect detection | Automated contract execution, code compliance, payment | Estimating costs with limited information | Automated material management; Automated facility management; Building performance simulation |
| Benefits | Reduced workload, costs, time | | | Reduced disputes | Decision making support | Reduced material waste; Labor cost and time saving; Energy efficiency improvement |
| Challenges | Occlusion and noise; Datasets; Generalized models | | | Readability | Time-consuming and tedious in model generation | Uncertainty; Information transfer |

# 04 Conclusions

- ***Potentials of developing AI platform for AEC***
- ***Existing challenges***
- ***Future work***
- ***Links between industry and academia***

# Potentials of developing AI platform for AEC

## With the integration of advanced technologies, a new revolution is occurring.

1. **Automated BIM model generation**
Decrease the risks of delay and cost overruns.

2. **Blockchain-based collaboration**
Resolve the problems of lack of trust.

3. **AR-based visualization**
Develop immersive interaction between real-life projects and stakeholders.

4. **AI-based construction management**
Make remote management possible and effective.

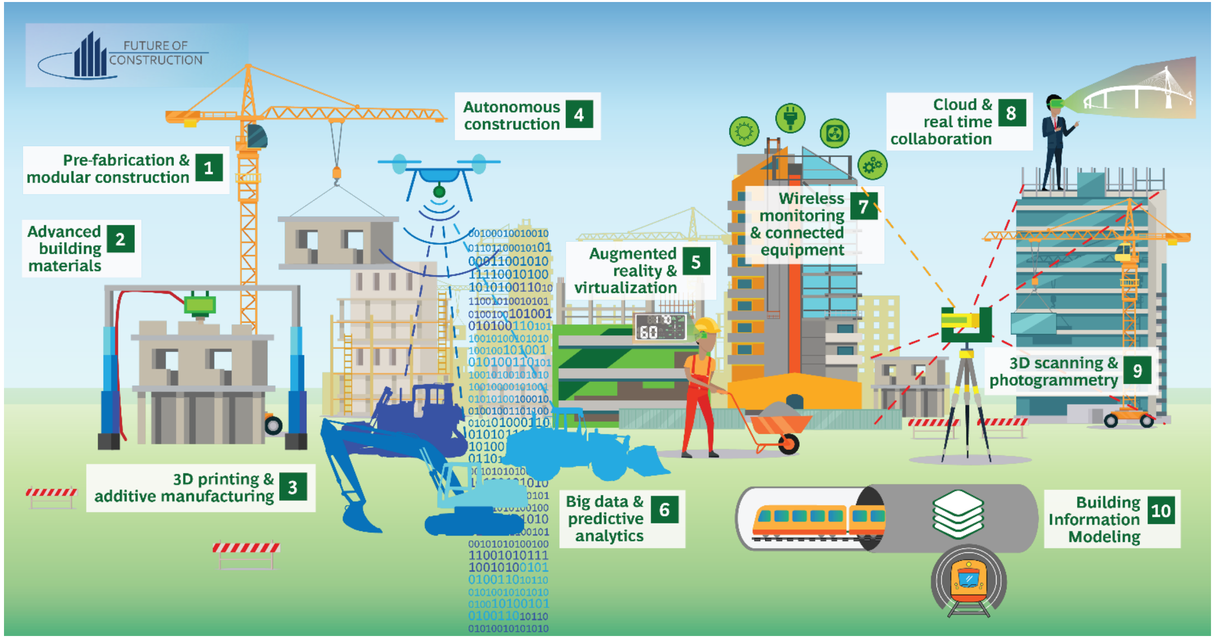
# Existing challenges

**Technology:**
- Inability of AR mobile devices to run AI algorithms for localization
- Inability of integrating generated model with schedule
- Reduced quality of generated model due to occlusions and noise
- Expensive computing costs of AI-based models
- Low ability of generalization of AI-based models

**Framework:**
- Lack of large uniform dataset for training deep learning algorithms
- Lack of standard to evaluate performance of AI-based models
- Lack of actual framework and implementation of blockchain in AEC
- Difficulty of being adopted rapidly by traditional industry

# Future work

- Technical problem solving
- Actual framework
- Uniform standard
- Widespread adoption




(World Economic Forum 2018)

# Links between academia and industry

## Academia

**AI Platform**

- AI-based Data Acquisition
- AI-based BIM Model Generation
  - As-planned BIM Model Generation
  - As-built BIM Model Generation
- Blockchain-based Collaboration
- AR-based Visualization
- AI-based Construction Management
  - Progress Management
  - Safety Management
  - Quality Management
  - Contract Management
  - Cost Management
  - Sustainability Management

## Industry

- AI-based Data Acquisition → **Automated data collection; Automated site inspection**
- AI-based BIM Model Generation → **Progress monitoring**
- Blockchain-based Collaboration → **Collaboration platform**
- AR-based Visualization → **Progress visualization; Project delivery**
- AI-based Construction Management → **Progress monitoring; Unsafe conditions detection; Defect detection; Automated contract execution; Automated cost estimate; Smart facility management**

# Thank you

Q & A

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