



Improving Decision-Making Process of AEC Projects by Connecting the Virtual and Physical World

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Outline

- Background
- Objectives
- Two Examples:
 - Visualization of Indoor Thermal Environment on mobile devices based on AR and CFD
 - Integrating BrIM and Sensing Data for Safety Management during Bridge Construction
- Ongoing Work



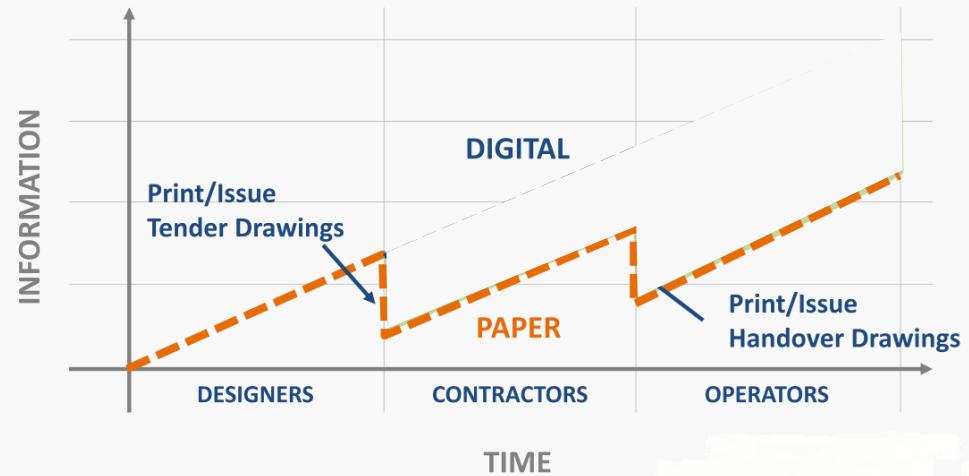
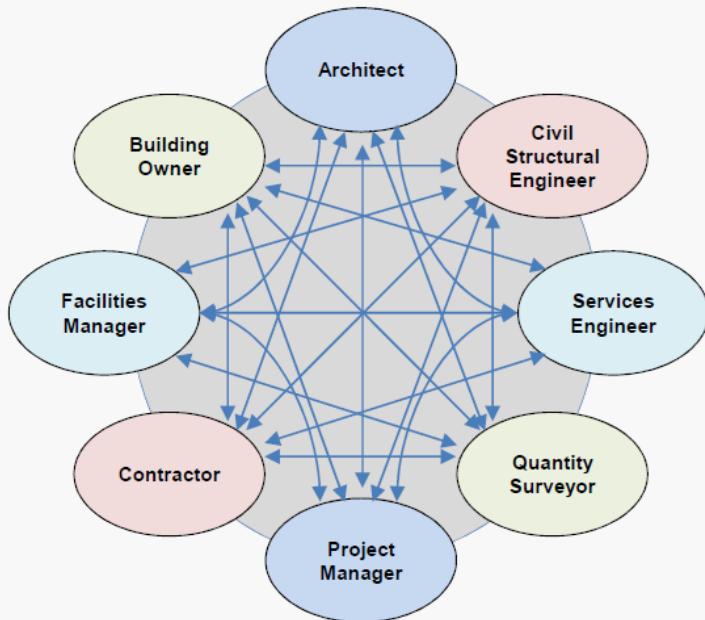
Background

□ Building Information Modeling



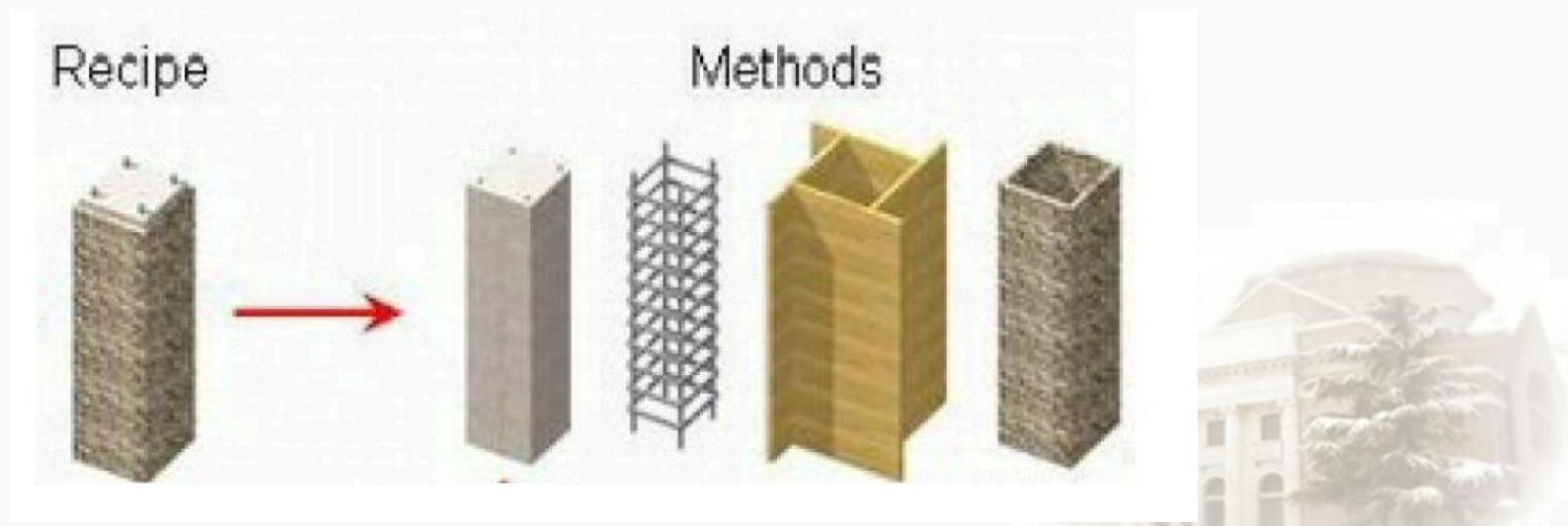
Background

□ Building Information Modeling



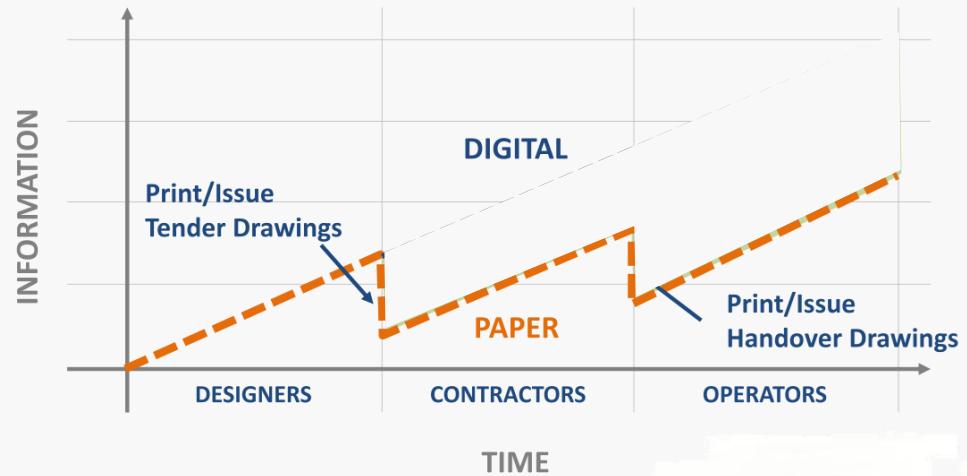
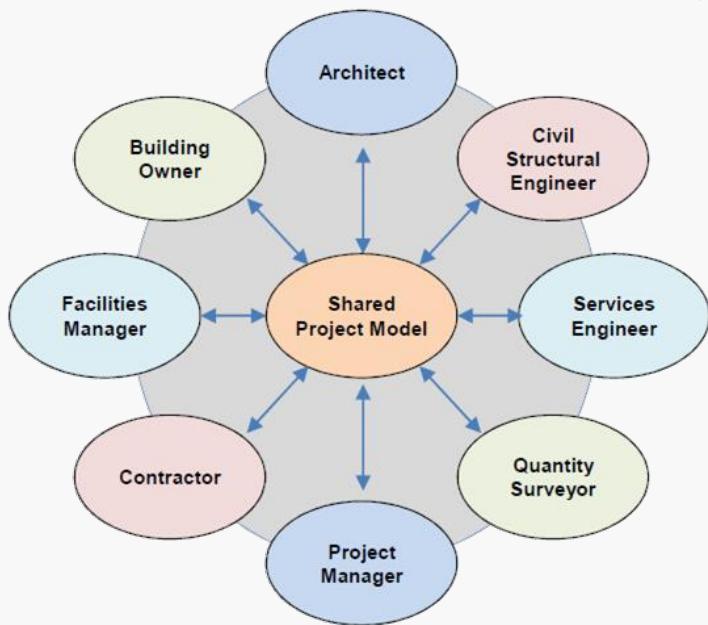
□ Building Information Modeling

- a digital representation of the physical and functional characteristics of a facility
- a shared knowledge resource for information about a facility, forming a reliable basis for decisions during its life cycle, from earliest conception to demolition

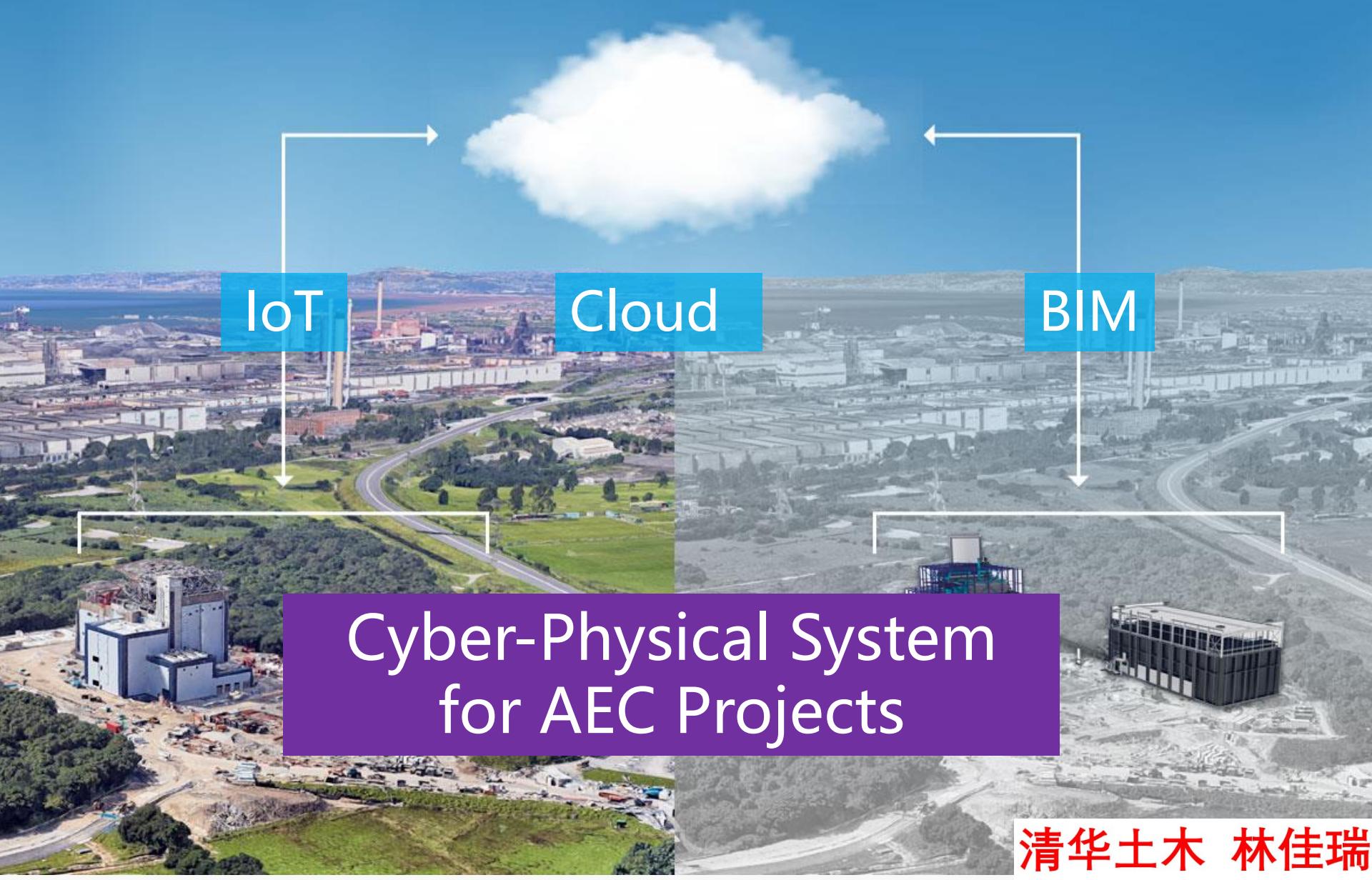


Background

□ Building Information Modeling



Objectives



Visualization of Indoor Thermal Environment based on CFD and AR



□ Background

- Computational Fluid Dynamics (CFD) is widely used for understanding indoor thermal environment
- CFD is hard to understand and interpret for non-experts
- Augmented Reality (AR) is introduced

□ Problems

- Limited mobility, computational capacity
- Large scale CFD data
- Lack intuitive interaction methods



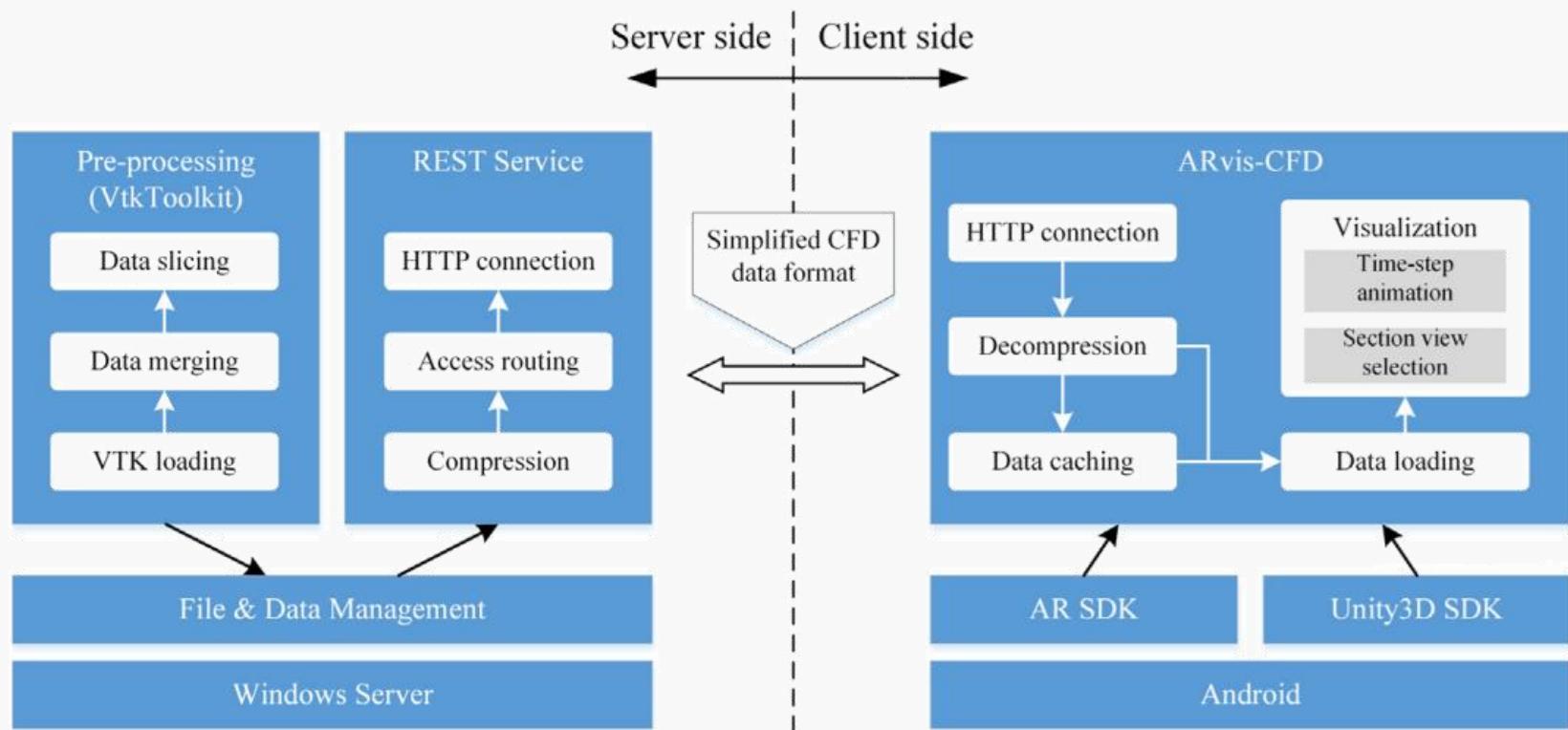
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Visualization of Indoor Thermal Environment based on CFD and AR



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□ Framework



Visualization of Indoor Thermal Environment based on CFD and AR



- Mobile friendly data format
- Problems of existing formats

```
# vtk DataFile Version 2.0  
Really cool data ](1)  
ASCII | BINARY ](2)  
DATASET type ](3)  
...  
POINT_DATA n ](4)  
...  
CELL_DATA n ](5)  
...
```

Part 1: Header

Part 2: Title (256 characters maximum, terminated with newline \n character)

Part 3: Data type, either ASCII or BINARY

Part 4: Geometry/topology. *Type* is one of:

STRUCTURED_POINTS
STRUCTURED_GRID
UNSTRUCTURED_GRID
POLYDATA
RECTILINEAR_GRID
FIELD

```
DATASET UNSTRUCTURED_GRID  
POINTS n dataType
```

$P_{0x} P_{0y} P_{0z}$

$P_{1x} P_{1y} P_{1z}$

...

$P_{(n-1)x} P_{(n-1)y} P_{(n-1)z}$

CELLS n size

$numPoints_0, i, j, k, l, \dots$

$numPoints_1, i, j, k, l, \dots$

$numPoints_2, i, j, k, l, \dots$

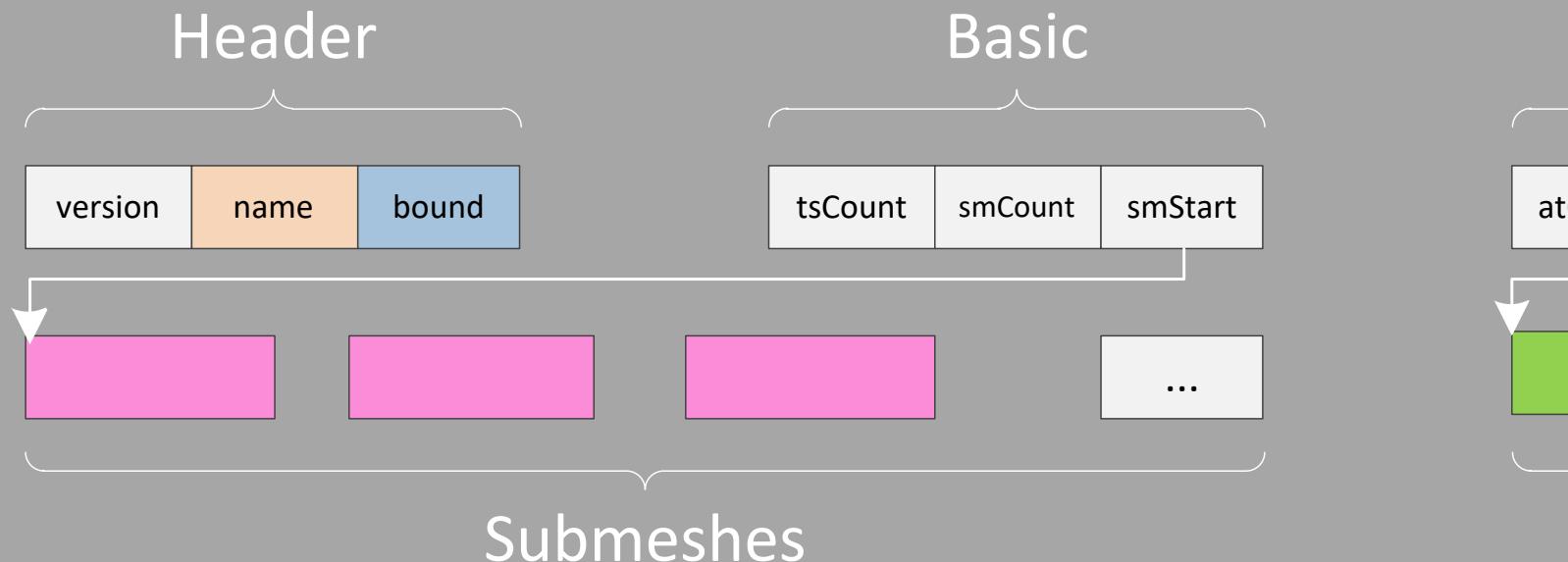
...

$numPoints_{n-1}, i, j, k, l, \dots$

Visualization of Indoor Thermal Environment based on CFD and AR

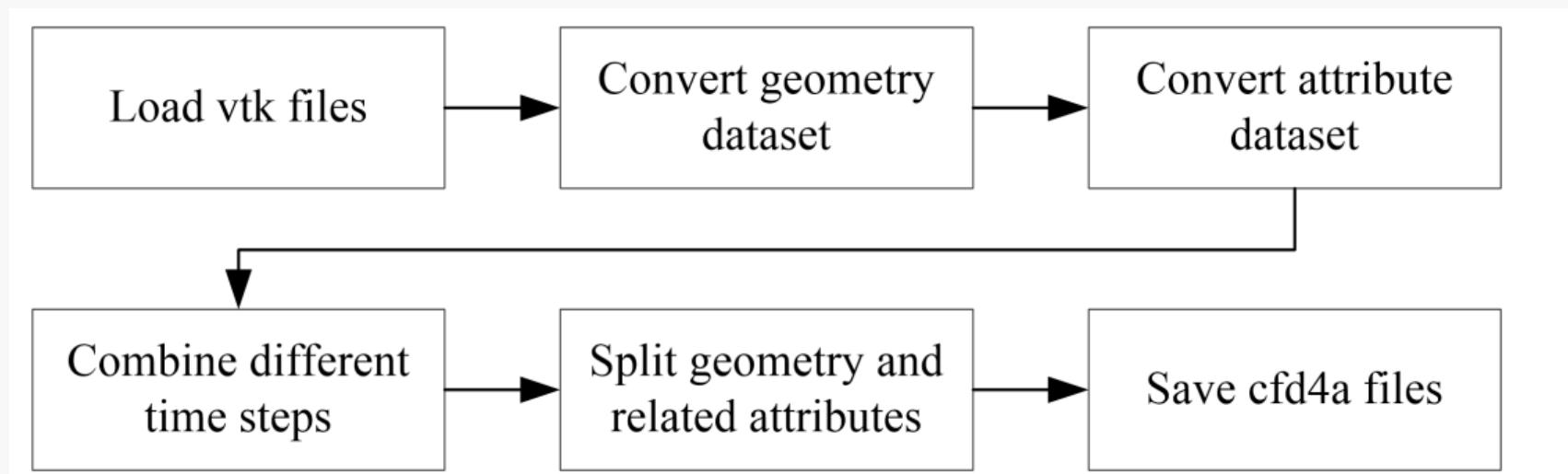


- Mobile friendly data format
 - Problems of existing formats
 - Requirements of mobile devices



Visualization of Indoor Thermal Environment based on CFD and AR

- Mobile friendly data format
 - Problems of existing formats
 - Requirements of mobile devices
- Data pre-processing



Visualization of Indoor Thermal Environment based on CFD and AR



- Mobile friendly data format
 - Problems of existing formats
 - Requirements of mobile devices
- Data pre-processing
- Server side data hosting

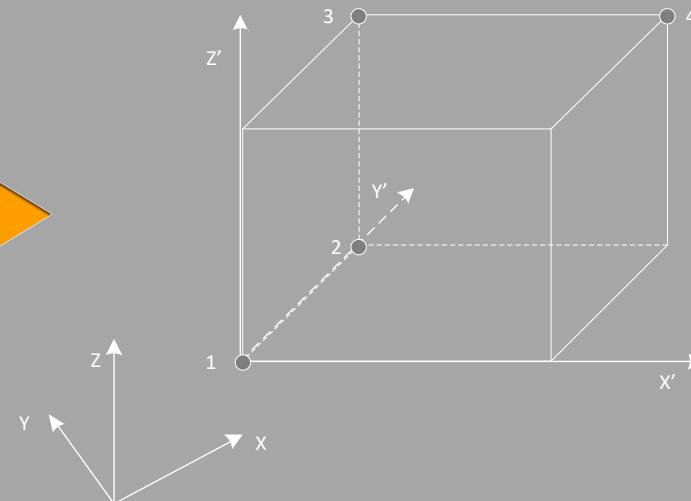
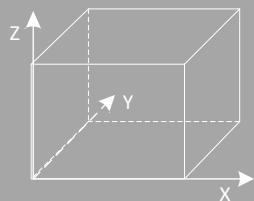


Available RESTful API operations.

Route	Functions	Supported operations
/bim/	list available BIM models	GET
/bim/{id}	manage BIM models	GET, POST, DELETE
/scan	list available point cloud models	GET
/scan/{id}	manage point cloud models	GET, POST, DELETE
/slice	list available slice views	GET
/slice/{id}	manage slice views	GET, POST, DELETE
/tube	list available streamline views	GET
/tube/{id}	manage streamline views	GET, POST, DELETE

Visualization of Indoor Thermal Environment based on CFD and AR

- Augmented Visualization
- Transformation between different coordination systems



$$P_c = (P_1 + P_4)/2$$

$$S = Distance(P_4, P_1)/L_{diag}$$

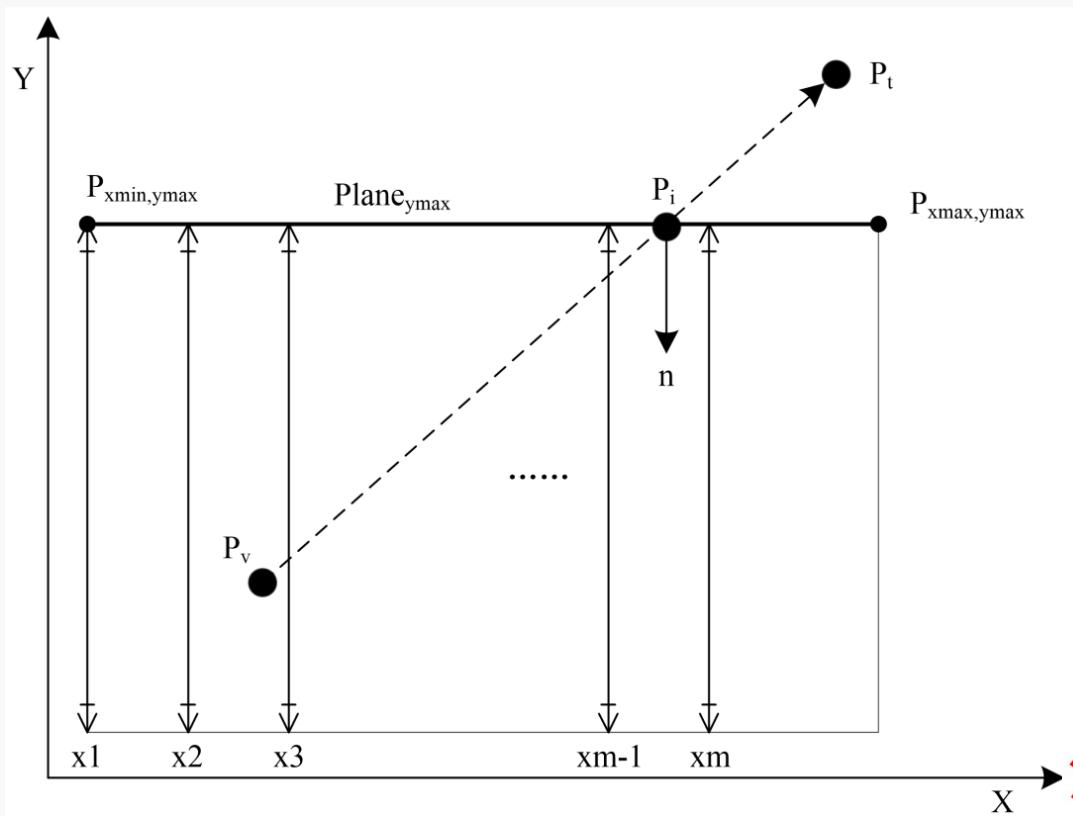
$$V_{forward} = Normalize(P_2 - P_1)$$

$$V_{up} = Normalize(P_3 - P_2)$$

$$V_{right} = Normalize(P_4 - P_1)$$

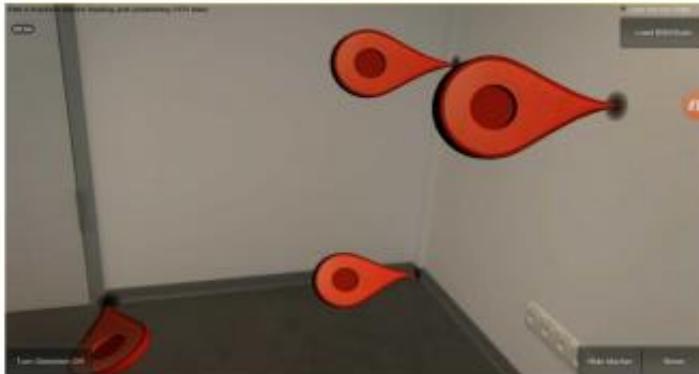
Visualization of Indoor Thermal Environment based on CFD and AR

- Augmented Visualization
 - Transformation between different coordination systems
 - Generate section views

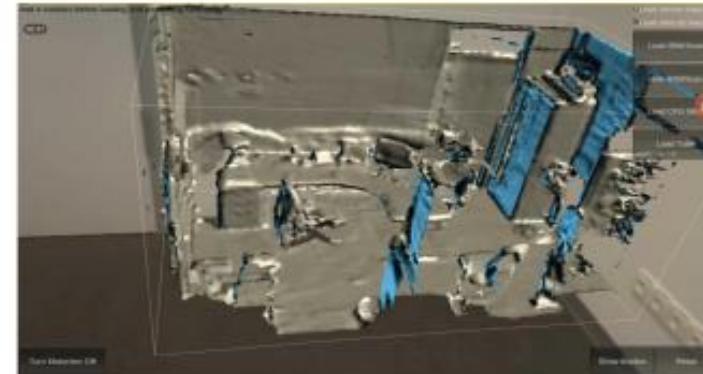


Visualization of Indoor Thermal Environment based on CFD and AR

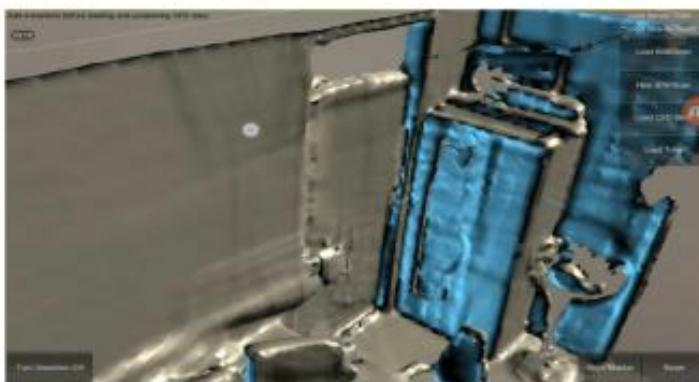
□ Demonstration



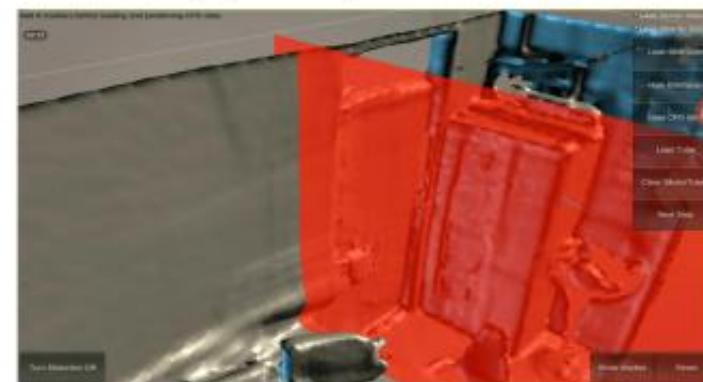
(a) Put marker



(b) Load point cloud



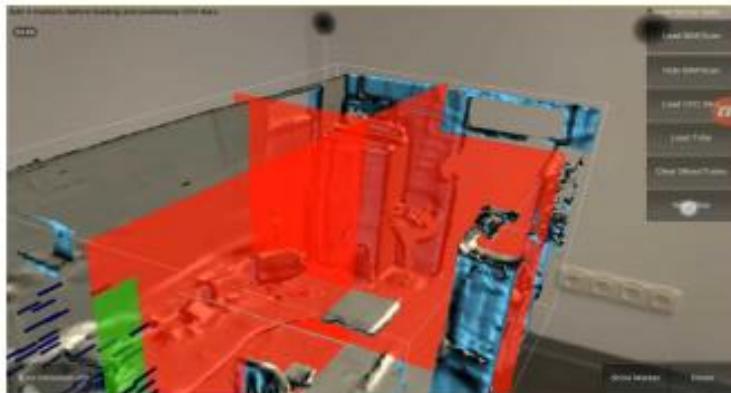
(c) Touch on screen: the white dot



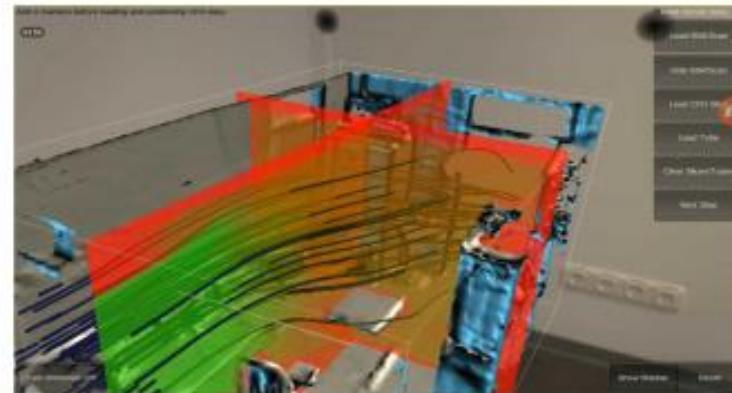
(d) Load slice based on touch position

Visualization of Indoor Thermal Environment based on CFD and AR

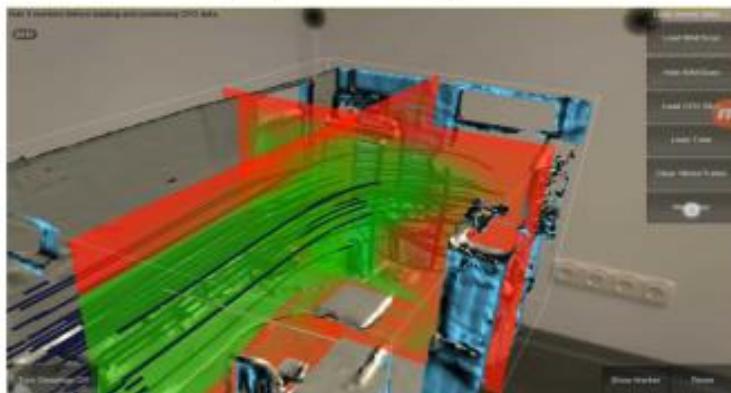
□ Demonstration



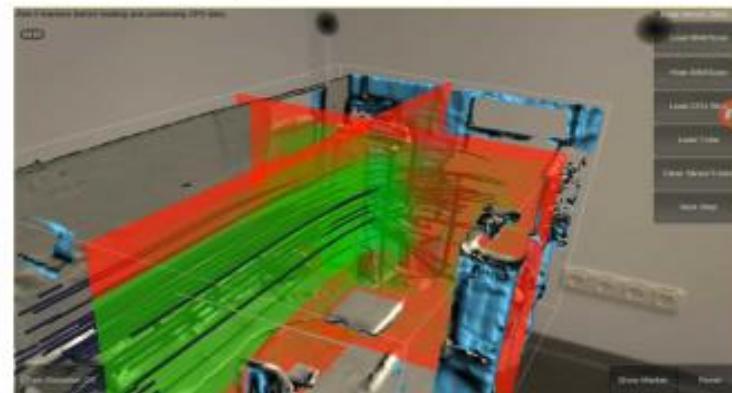
(a) Time step 1



(b) Time step 2



(c) Time step 3



(d) Time step 4

Visualization of Indoor Thermal Environment based on CFD and AR

□ Demonstration



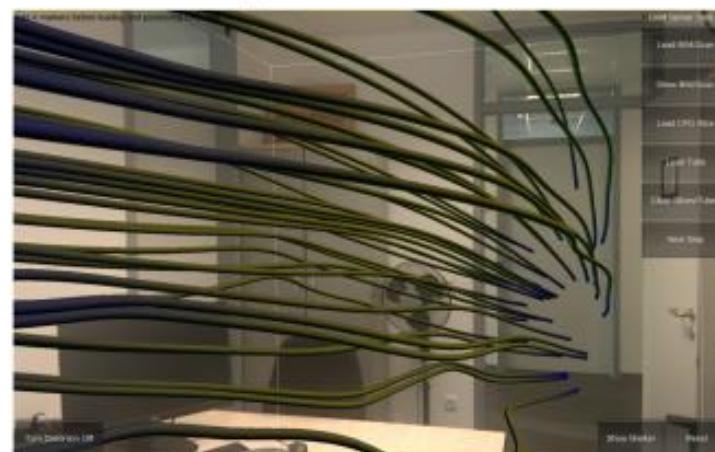
(a) Airflow begin



(b) Time step 1



(c) Time step 2



(d) Airflow go through 清华土木 林佳瑞

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□ Demonstration



(a) Time step 1



(b) Time step 2



(c) Time step 3



(d) Time step 4

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Visualization of Indoor Thermal Environment based on CFD and AR



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□ Performance analysis

Loading time (ms) comparison between vtk and cfd4a.

Data	Content type	vtk	cfd4a	Ratio
BIM model	Geometric data	77	16	79.2%
Point cloud	Geometric data	355	237	33.2%
y slice	Same geometric data and different attribute data of multiple time steps	1689	180	89.3%
x slice	Same geometric data and different attribute data of multiple time steps	1301	141	89.2%
Streamline	Different geometric and attribute data of multiple time steps	4716	1847	60.8%

File size (kB) comparison between vtk and cfd4a.

Data	vtk	cfd4a	cfd4a (zipped)	Ratio	Ratio (zipped)
BIM model	382	245	77	35.9%	79.9%
Point cloud	4296	3576	1572	16.8%	63.4%
y slice	15,612	5165	1643	66.9%	89.5%
x slice	11,700	3856	1259	67.0%	89.2%
Streamline	74,439	60,021	14,354	19.4%	80.7%

Visualization of Indoor Thermal Environment based on CFD and AR



□ Highlights

- an integrated approach to AR-based CFD visualization of indoor thermal environment on mobile devices
- mobile-friendly data format, data conversion algorithms, and services, new interaction methods
- With high data compression and loading time saving ratio
- Easy to integrate other AR devices

Lin, J.* , Cao, J., Zhang, J., van Treeck, C. and Frisch, J. (2019). "Visualization of Indoor Thermal Environment on Mobile Devices based on Augmented Reality and Computational Fluid Dynamics; *Automation in Construction*. 103: 26-40.

Integrating BrIM and Sensing Data for Bridge Safety Management



□ Problems

4D BIM 黄河桥

开始 施工BIM创建 4D进度管理 4D监控管理 4D安全分析

指定当前WBS 4D/3D切换 方式 计... 步长 1 周 正... 2014/9/21 4D模拟

前置任务分析 里程碑分析 周进度计划 Excel周报表
计算节点优先级 进度分析 周进度报表 Excel日报表
设置节点优先级 导出4D状态 Excel月报表 日报(细化WBS)

WBS管理器

查询条件 显示方式 (●) 完整 (○) 精简

名称	计划开始	计划完成	实际开始	实
济南黄河桥	2014-09-09	2015-12-30		2014-09-10
桥墩	2014-09-10	2014-09-15	2014-09-10	2014-09-10
临时设施	2014-09-12	2014-09-15	2014-09-12	2014-09-12
导梁安装架设	2014-09-15	2015-12-30	2014-09-15	2014-09-15
钢导梁上17#墩	2014-09-15	2015-12-30	2014-09-15	2014-09-15
首件钢桁梁安装	2014-10-16	2014-11-05	2014-10-16	2014-10-16
第一跨加劲弦安装	2014-11-06	2015-03-05	2014-11-06	2014-11-06
61桥节	2014-11-06	2014-11-15	2014-11-06	2014-11-06
60桥节	2014-11-16	2014-11-25	2014-11-16	2014-11-16
59桥节	2014-11-26	2014-12-05	2014-11-26	2014-11-26
下弦杆	2014-11-26	2014-11-27	2014-11-26	2014-11-26
铁路桥面	2014-11-28	2014-11-29	2014-11-28	2014-11-28
腹杆	2014-11-30	2014-12-01	2014-11-30	2014-11-30
上弦杆	2014-12-02	2014-12-03	2014-12-03	2014-12-03
公路桥面	2014-12-04	2014-12-04	2014-12-05	2014-12-05
推进	2014-12-05	2014-12-05	2014-12-05	2014-12-05
58桥节	2014-12-06	2014-12-15	2014-12-06	2014-12-06
下弦杆	2014-12-06	2014-12-07	2014-12-06	2014-12-06
铁路桥面	2014-12-08	2014-12-09	2014-12-08	2014-12-08
腹杆	2014-12-10	2014-12-11	2014-12-10	2014-12-10
上弦杆	2014-12-12	2014-12-13	2014-12-12	2014-12-12
公路桥面	2014-12-14	2014-12-14	2014-12-14	2014-12-14
推进	2014-12-15	2014-12-15	2014-12-15	2014-12-15
57桥节	2014-12-16	2014-12-25	2014-12-16	2014-12-16
下弦杆	2014-12-16	2014-12-17	2014-12-16	2014-12-16
铁路桥面	2014-12-18	2014-12-19	2014-12-18	2014-12-18
腹杆	2014-12-20	2014-12-21	2014-12-20	2014-12-20
上弦杆	2014-12-22	2014-12-23	2014-12-22	2014-12-22

关键路径计算 进度分析

附件管理器 4D状态显示

Ready

图形平台

安全监测

工程构件管理器

Integrating BrIM and Sensing Data for Bridge Safety Management

□ Framework

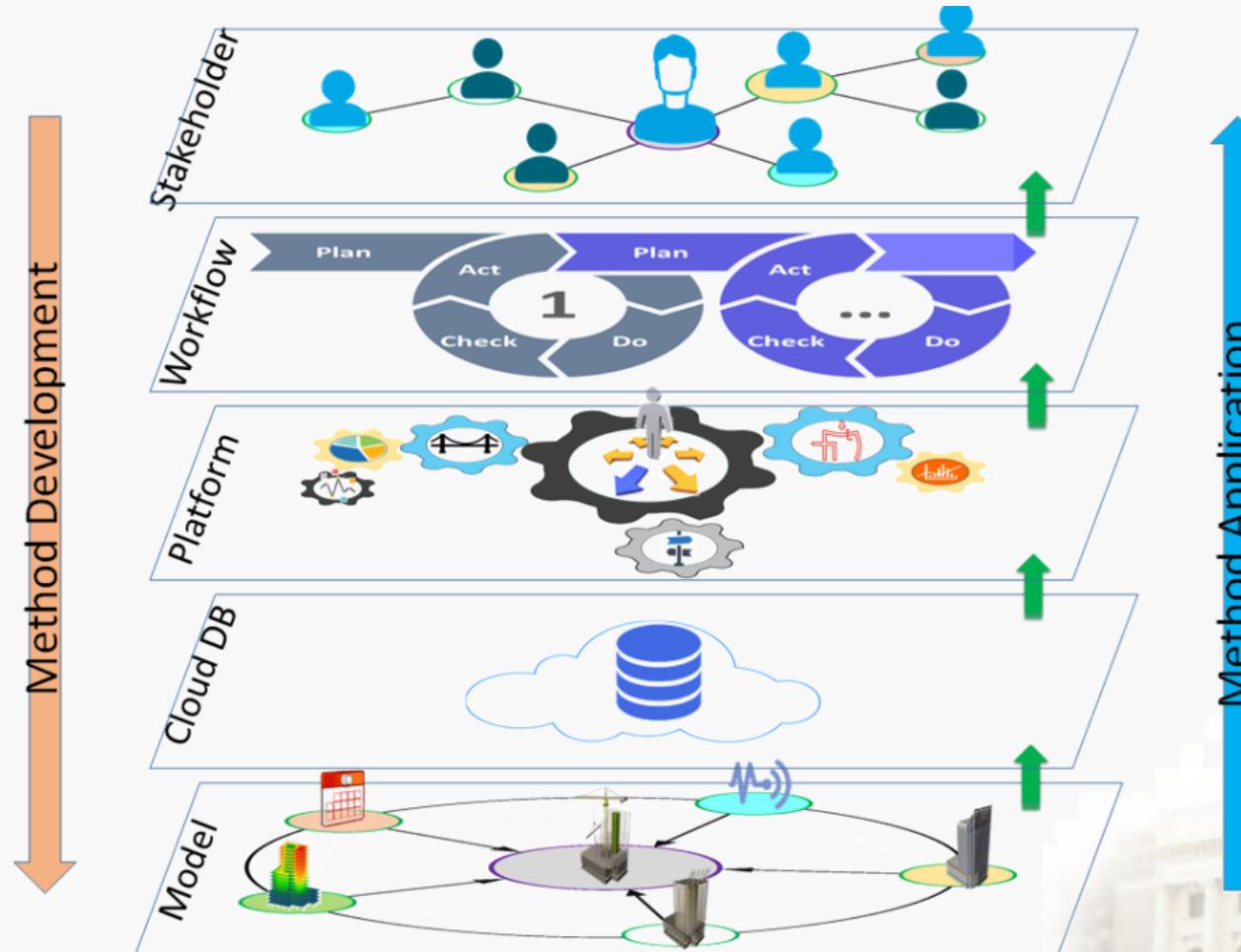


Figure 1 Framework for Closed-Loop Management of Structural Safety

Integrating BrIM and Sensing Data for Bridge Safety Management



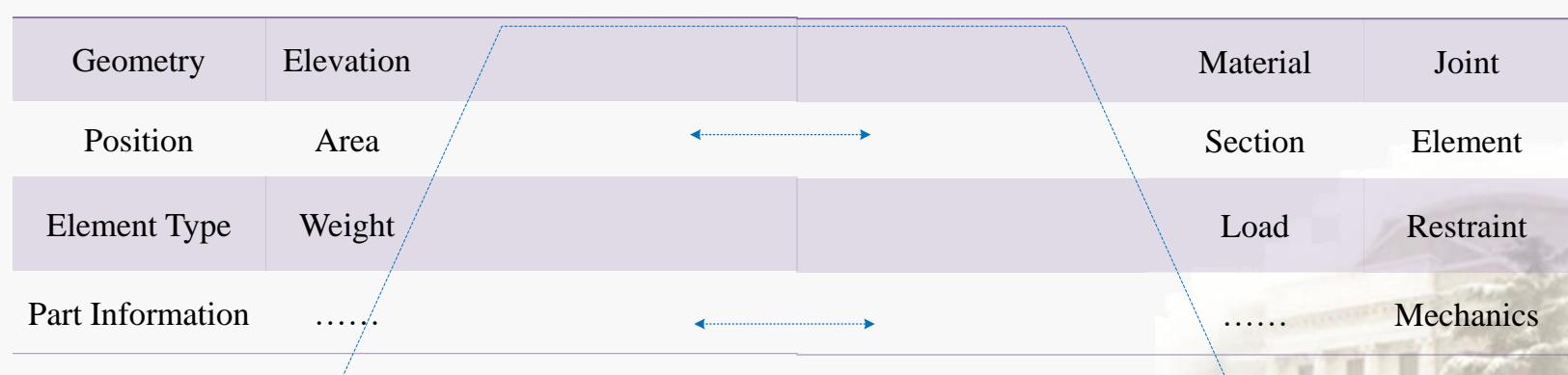
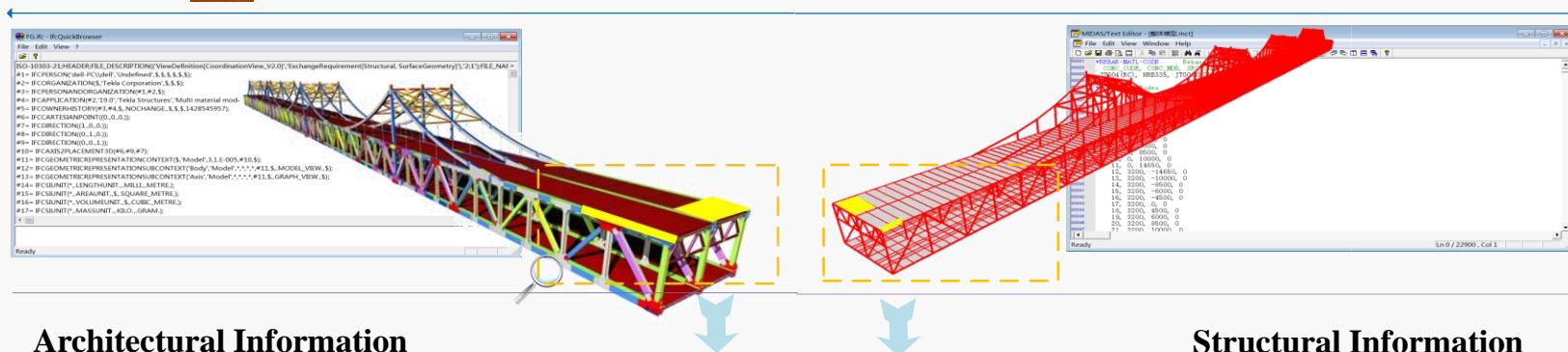
□ Integrating 3D Model and Structural Model



Architectural Model

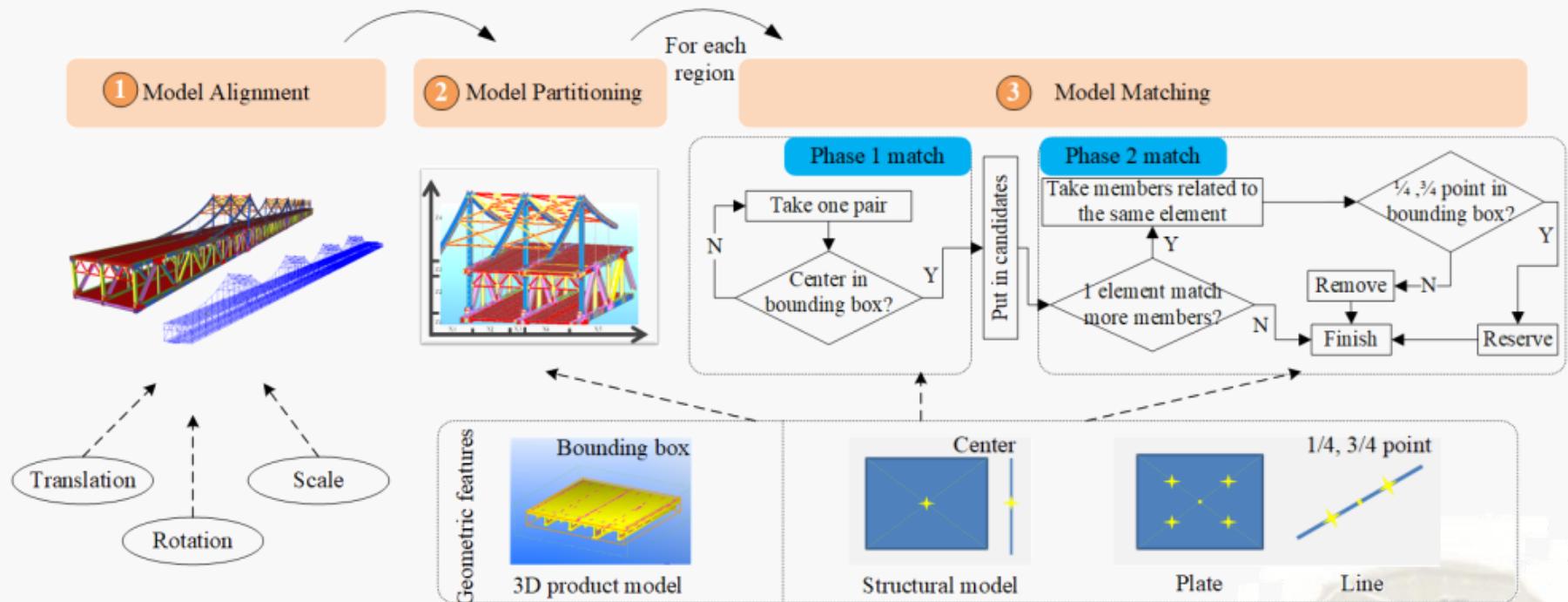


Structural Analysis Model



Integrating BrIM and Sensing Data for Bridge Safety Management

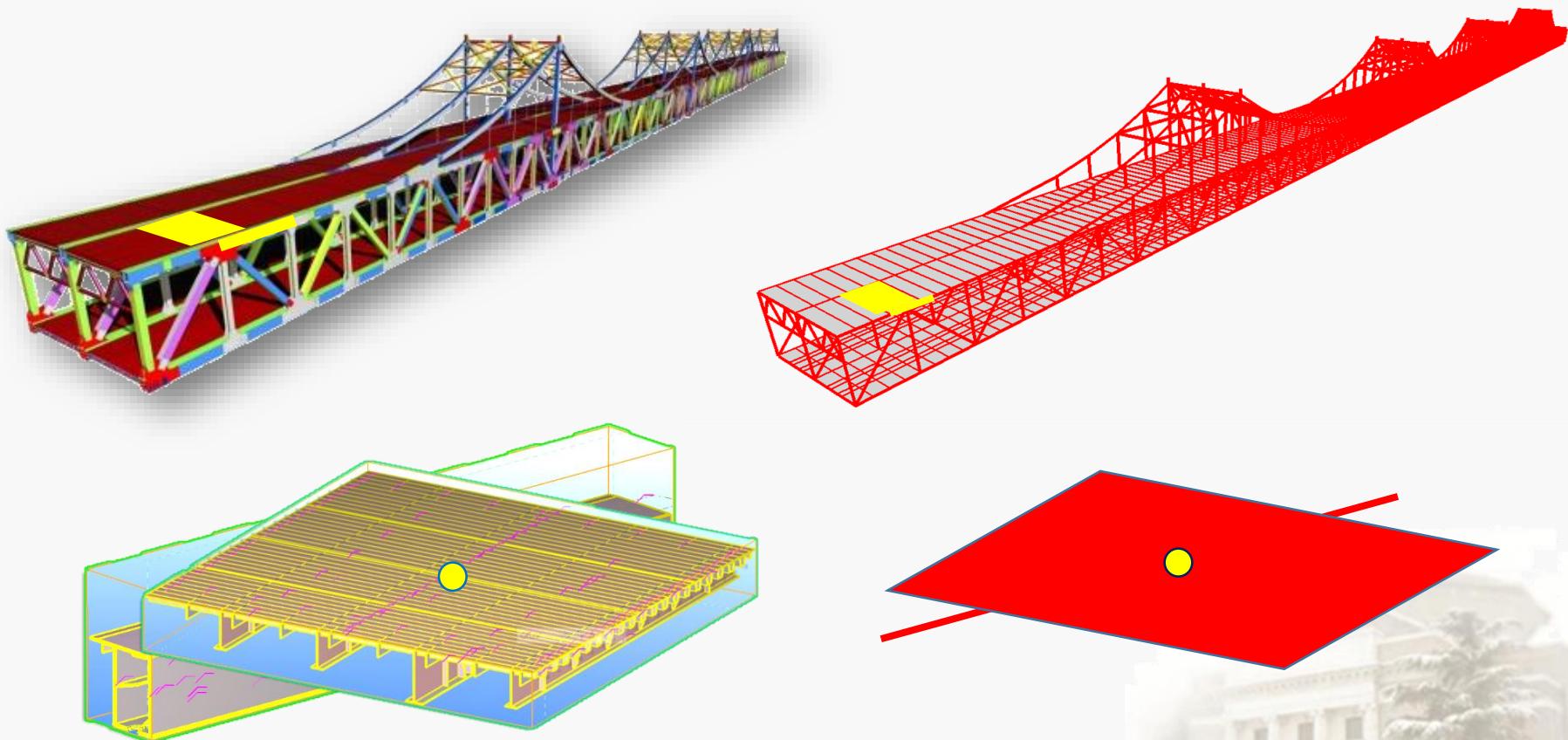
□ Integrating 3D Model and Structural Model



Integrating BrIM and Sensing Data for Bridge Safety Management



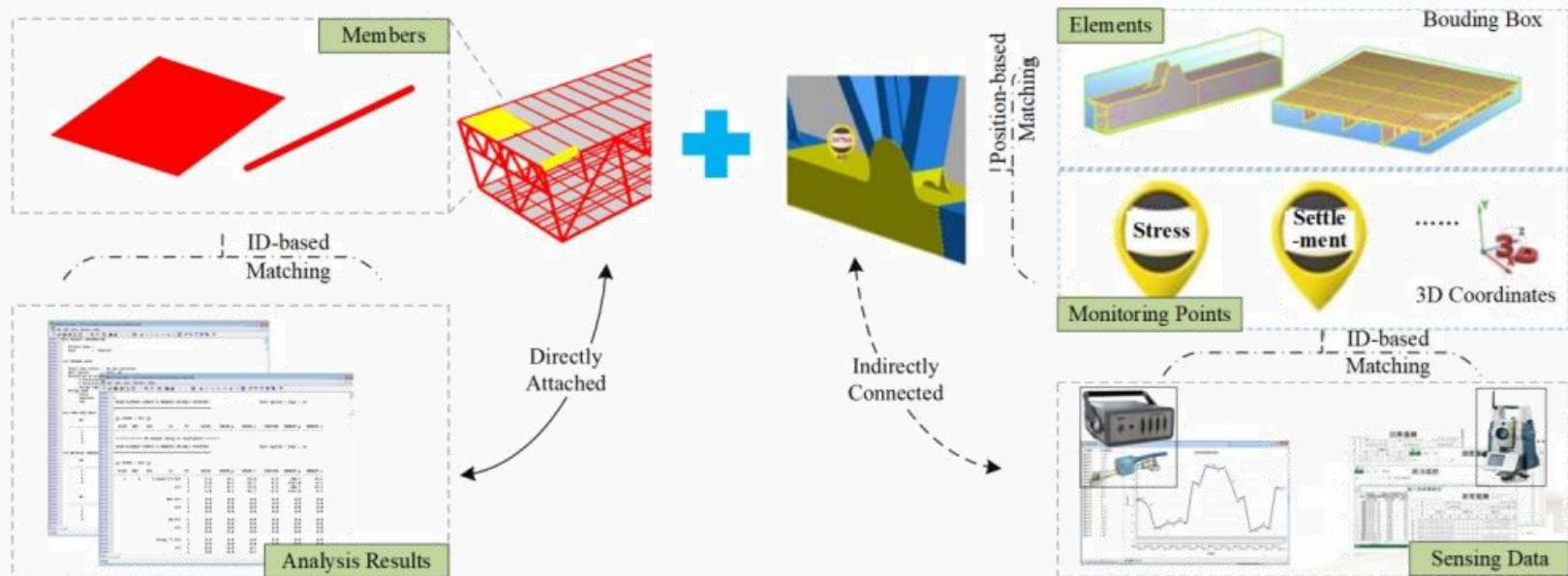
□ Integrating 3D Model and Structural Model



Feature point of beam

Integrating BrIM and Sensing Data for Bridge Safety Management

- Integrating 3D Model and Structural Model
- Integrating Sensing and Simulation Data



Integrating BrIM and Sensing Data for Bridge Safety Management



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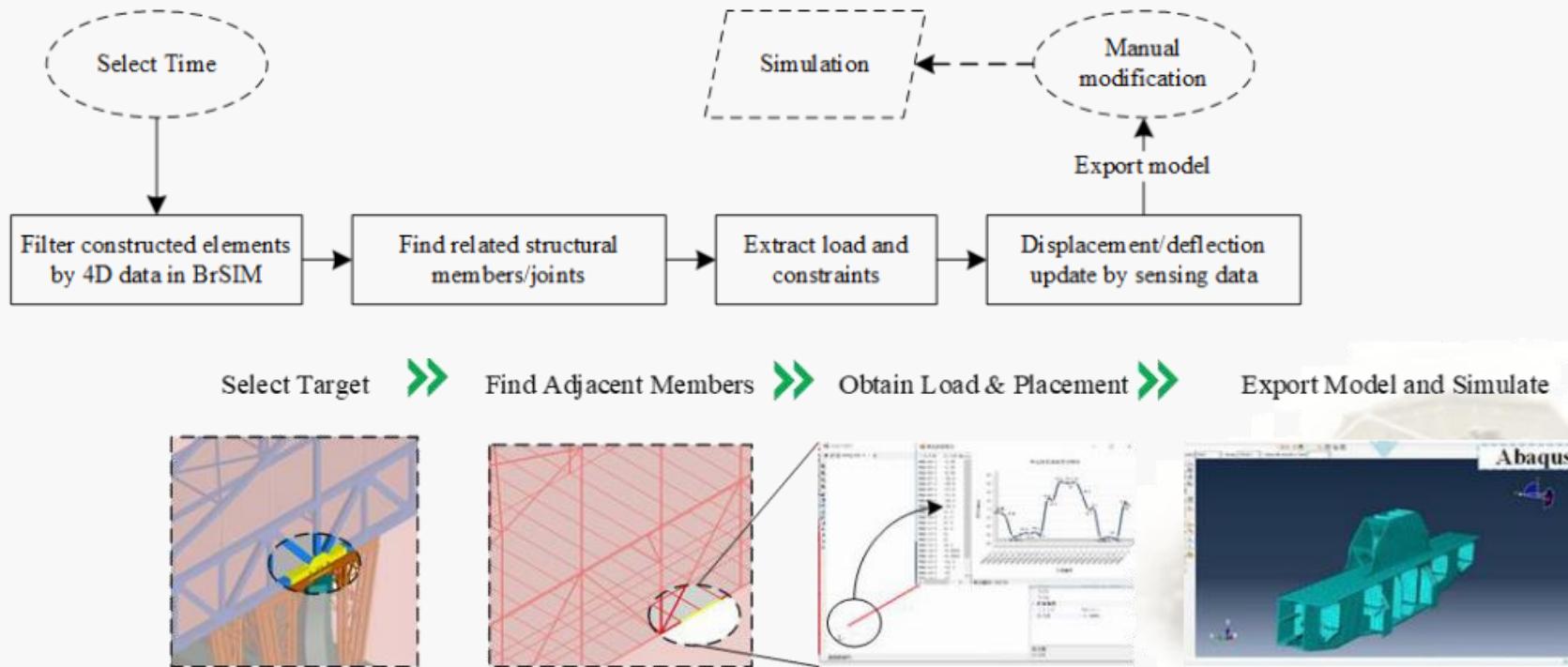
- Integrating 3D Model and Structural Model
- Integrating Sensing and Simulation Data

Data	Amount	Integration Method	Auto-Integration Rate
3D Product Elements	14,055	/	/
Structural Members	13,842	Based on proposed in section 4.1.4	98.6%
Scheduled Tasks	554	Based on name of tasks and elements	84.5%
Sensing Data	367	Based on ID of sensors	100%

Integrating BrIM and Sensing Data for Bridge Safety Management



- Integrating 3D Model and Structural Model
- Integrating Sensing and Simulation Data
- Generating Finite Element Models

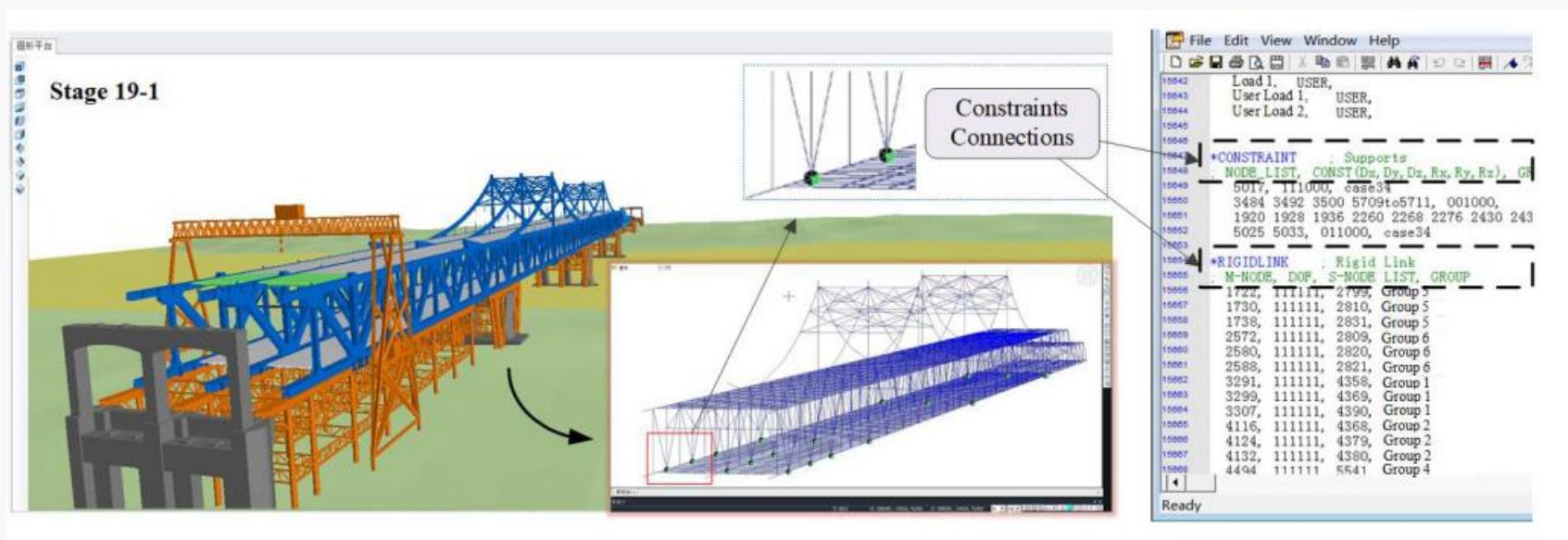


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Integrating BRIM and Sensing Data for Bridge Safety Management



- Integrating 3D Model and Structural Model
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Integrating BrIM and Sensing Data for Bridge Safety Management

- Integrating 3D Model and Structural Model
- Integrating Sensing and Simulation Data
- Generating Finite Element Models

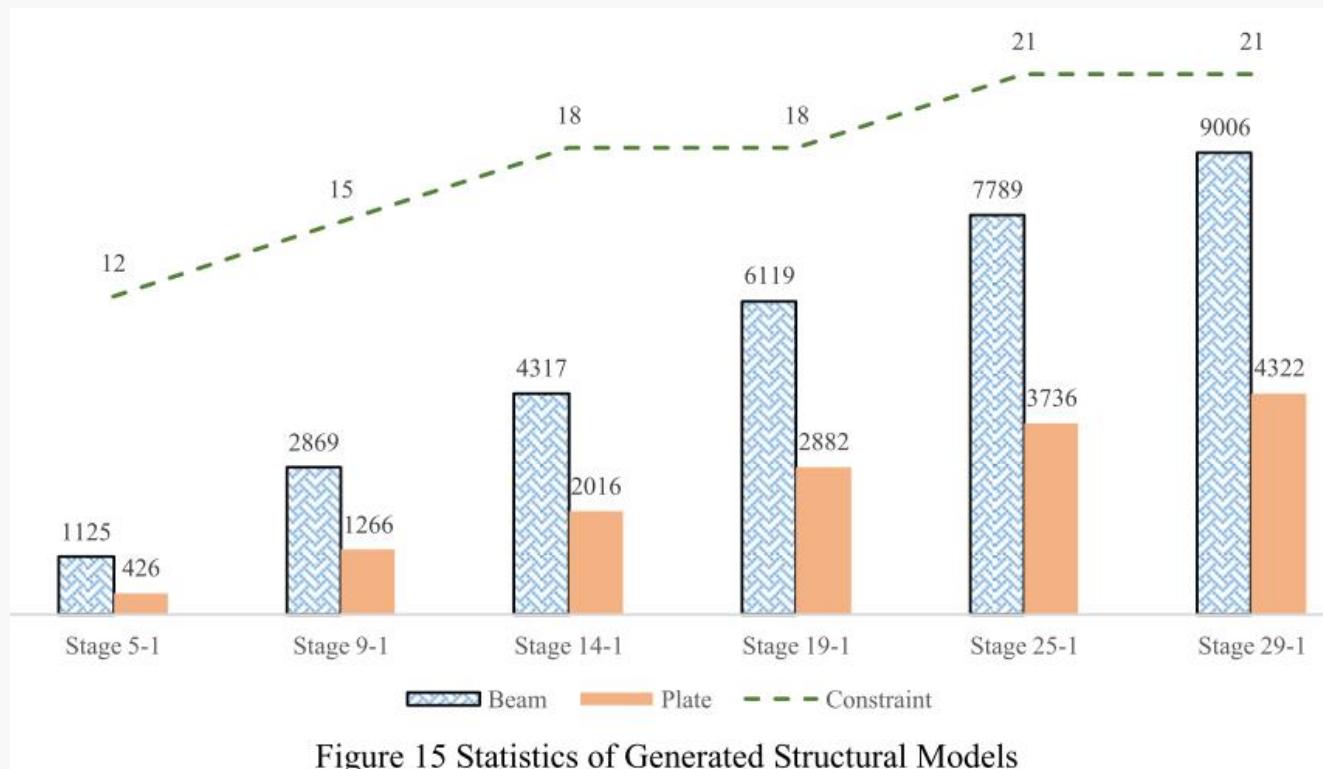
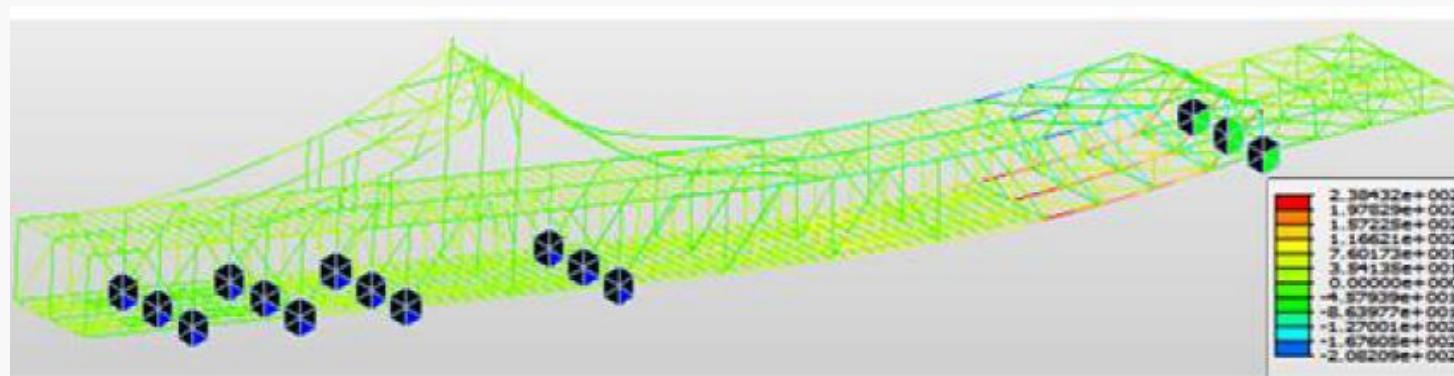
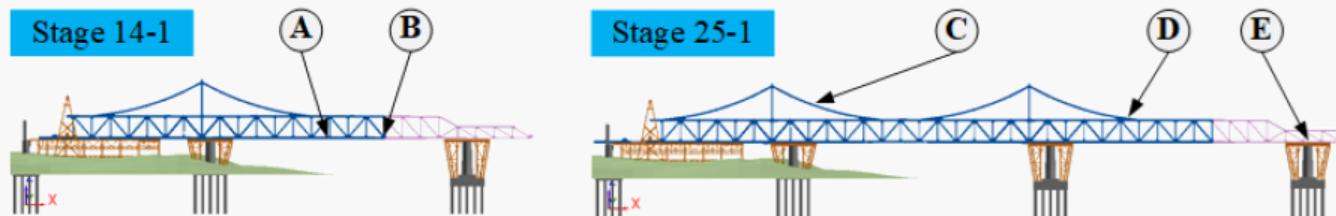


Figure 15 Statistics of Generated Structural Models

Integrating BrIM and Sensing Data for Bridge Safety Management

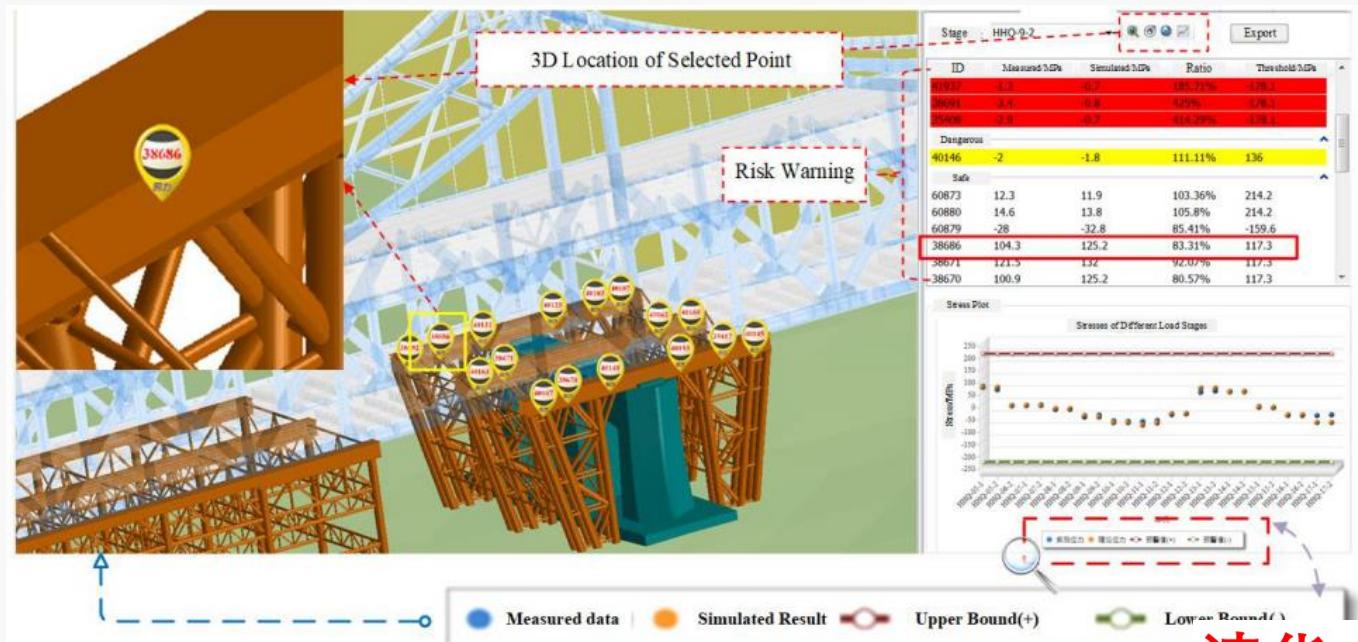


- Integrating 3D Model and Structural Model
- Integrating Sensing and Simulation Data
- Generating Finite Element Models



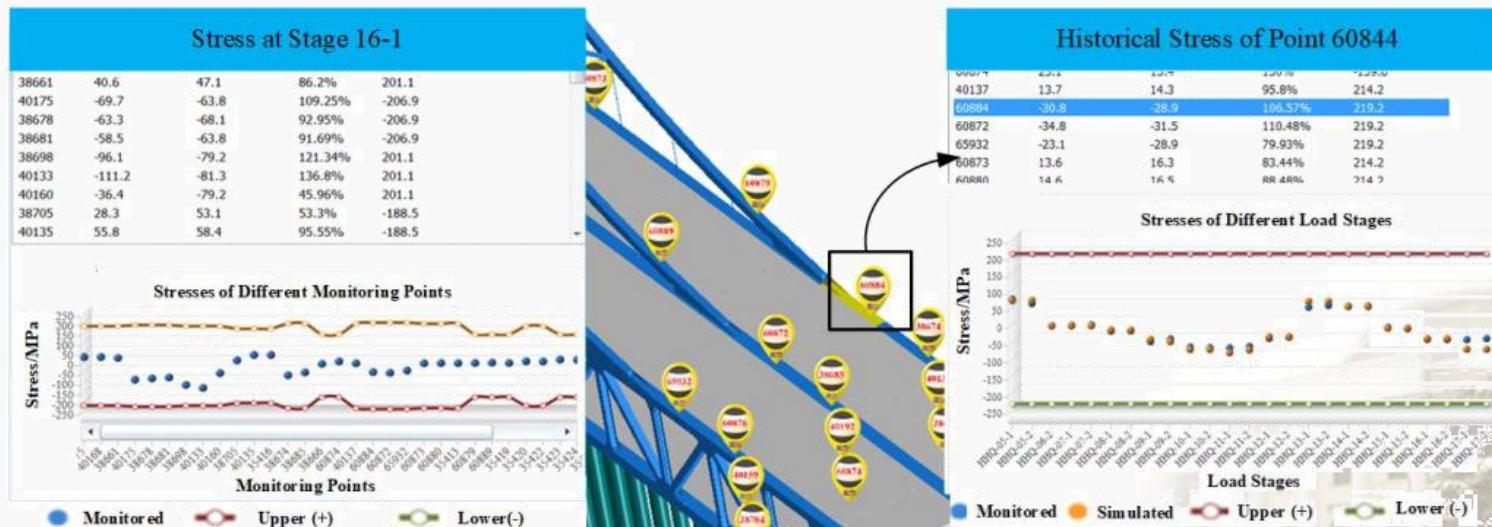
Integrating BrIM and Sensing Data for Bridge Safety Management

- Integrating 3D Model and Structural Model
- Integrating Sensing and Simulation Data
- Generating Finite Element Models
- Safety Visualization and Evaluation



Integrating BrIM and Sensing Data for Bridge Safety Management

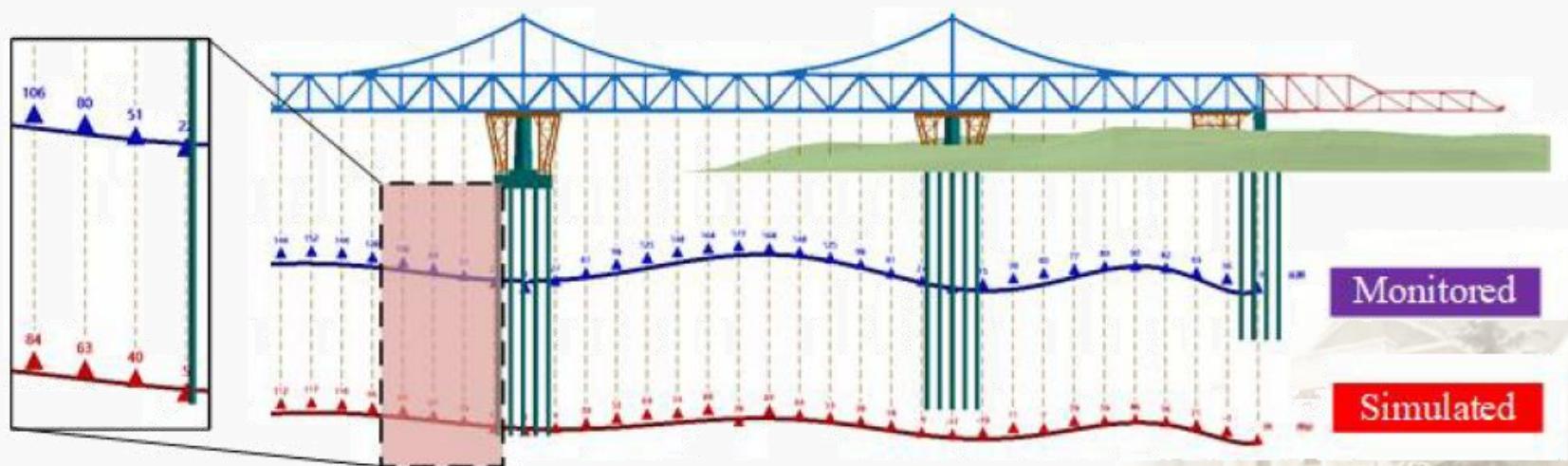
- Integrating 3D Model and Structural Model
- Integrating Sensing and Simulation Data
- Generating Finite Element Models
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Integrating BrIM and Sensing Data for Bridge Safety Management



- Integrating 3D Model and Structural Model
- Integrating Sensing and Simulation Data
- Generating Finite Element Models
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Integrating BrIM and Sensing Data for Bridge Safety Management



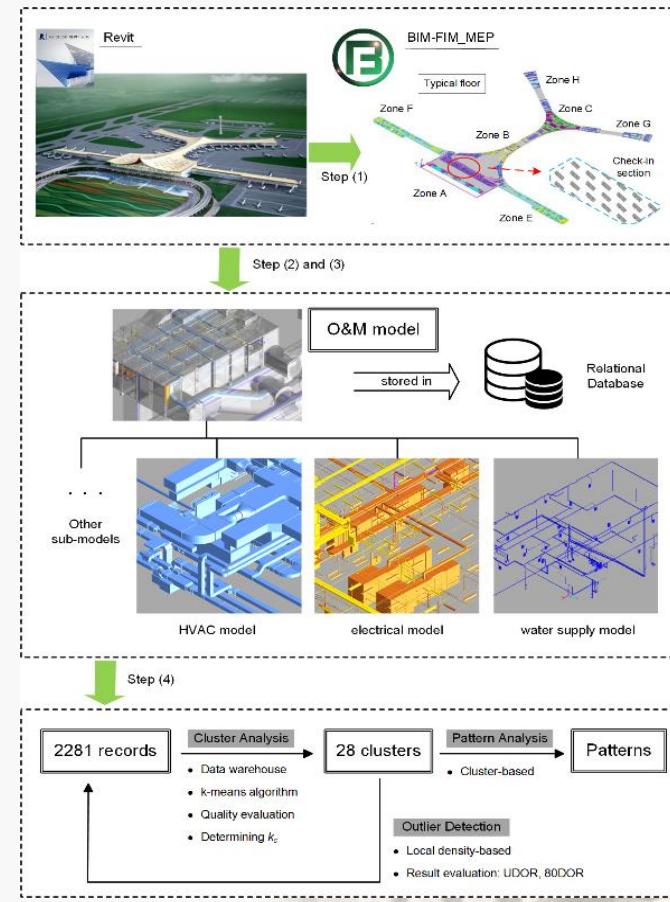
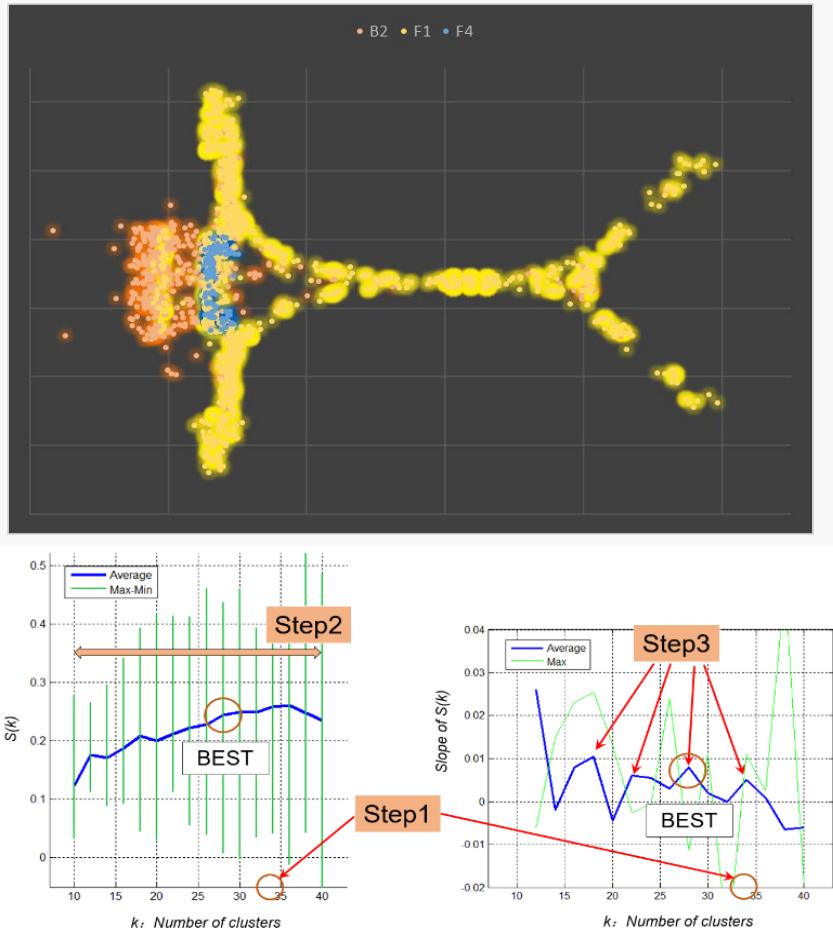
□ Highlights

- A framework automates closed-loop management of structural safety for bridge construction
- Goes beyond mere structural member generation of previous time-dependent structural model generation method
- Enables dynamic comparison and tracking of simulation results and monitoring data for risk assessment

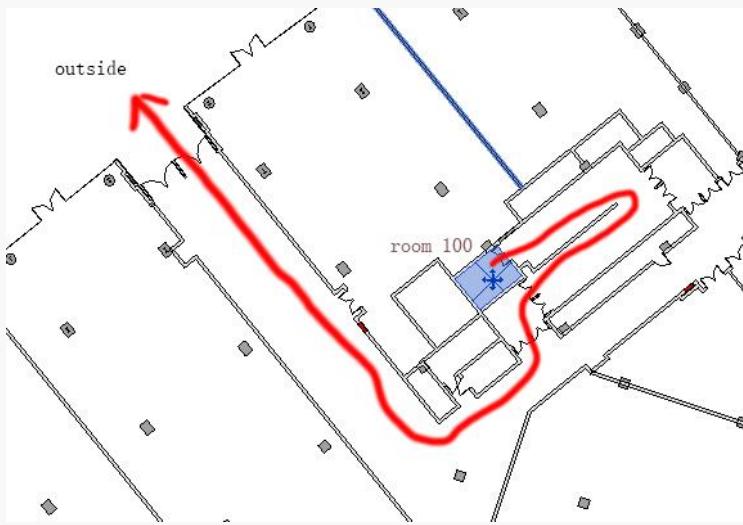
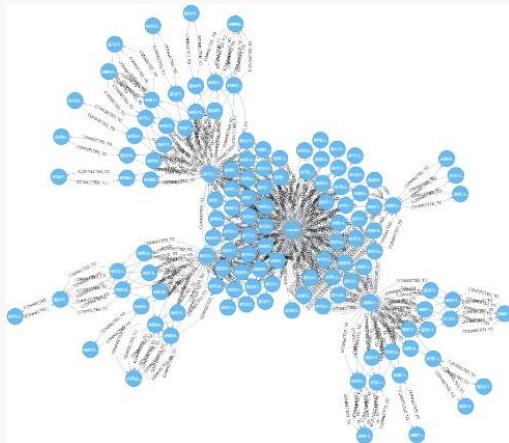
Lin, J., Zhang, J., Zhang, X. and Hu, Z.* (2019). "Automating closed-loop structural safety management for bridge construction through multisource data integration" *Advances in Engineering Software*. 128: 152-168.

Facility Maintenance/Operation

A Hybrid Information Mining Approach on BIM-based Building Operation and Maintenance
clustering, outlier detection, and pattern mining



Topological Analysis of Buildings



下游设备/管线/管件

ID	名称	标高	所属房间
1845154	斜接弯头/T	-2.0_F-1通风系统	2916356:空调机
1847561	1.0 W	-2.0_F-1通风系统	2916356:空调机
1845162	斜接弯头/T	-2.0_F-1通风系统	2916219:走廊 5'
1853406	160*120	-2.0_F-1通风系统	2916219:走廊 5'
1853432	斜接弯头/T	-2.0_F-1通风系统	2916219:走廊 5'
1845211	标准	-2.0_F-1通风系统	2916219:走廊 5'
1845209	标准	-2.0_F-1通风系统	2916219:走廊 5'
1845090	斜接弯头/T	-2.0_F-1通风系统	2916220:走廊 5'

查询构件信息

属性

属性	值
族与类型	矩形风管: 斜接弯头/T形三通 700*200送风
系统分类	送风
长度	1220
类别	风管
可用大小	450 mmx120 mm
系统类型	风机盘管
族	矩形风管
当量直径	241
类型 ID	1793653
宽度	450
水力直径	189
系统名称	FP 28
参照标高	-2.0_F-1通风系统(+4.0)_TXB

查询构件所属房间

当前设备/管线/管件信息

检修路径规划间

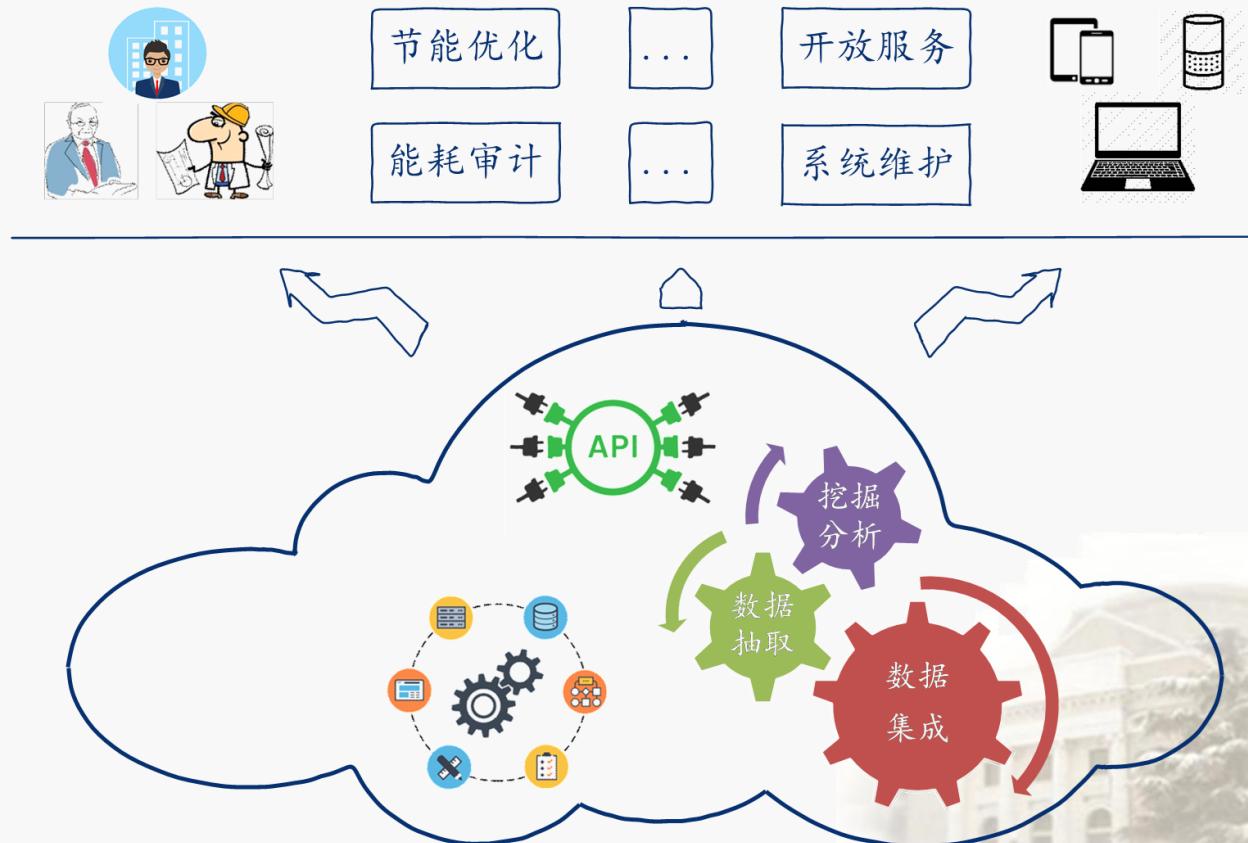
辅助检修

- 出发节点
- 目的节点
- 检修路径

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Region/City Energy Saving

Supported by the Chinese government “Cloud platform for building performance monitoring”, **focus on massive data management, service and mining**





Thank you for your attention!

Jiarui Lin, Assistant Professor

lin611@tsinghua.edu.cn

Department of Civil Engineering, Tsinghua University

April 4, 2019

