State-of-the-art and tendencies of intelligent construction in China

Zhiliang Ma

Department of Civil Engineering, Tsinghua University

清華大學
Tsinghua University

Tsinghua University

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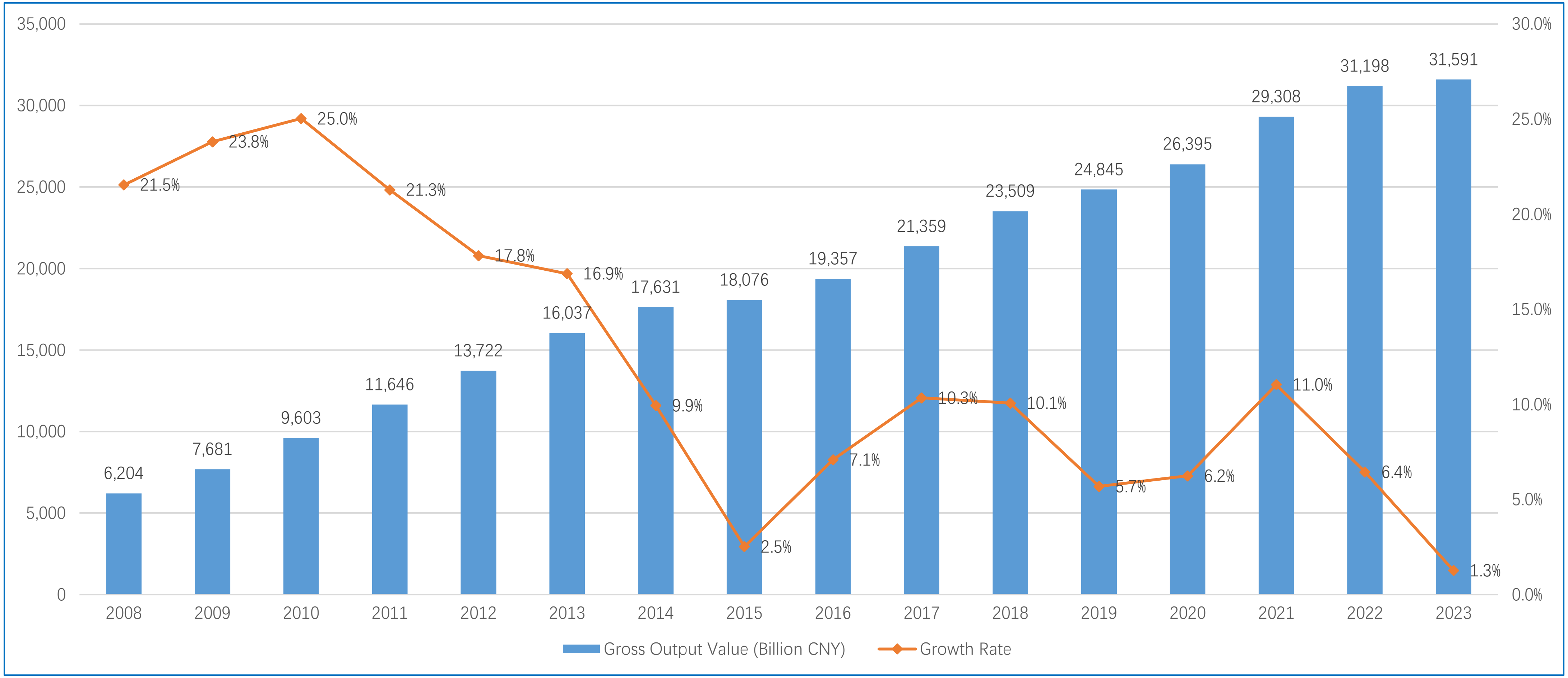
My background

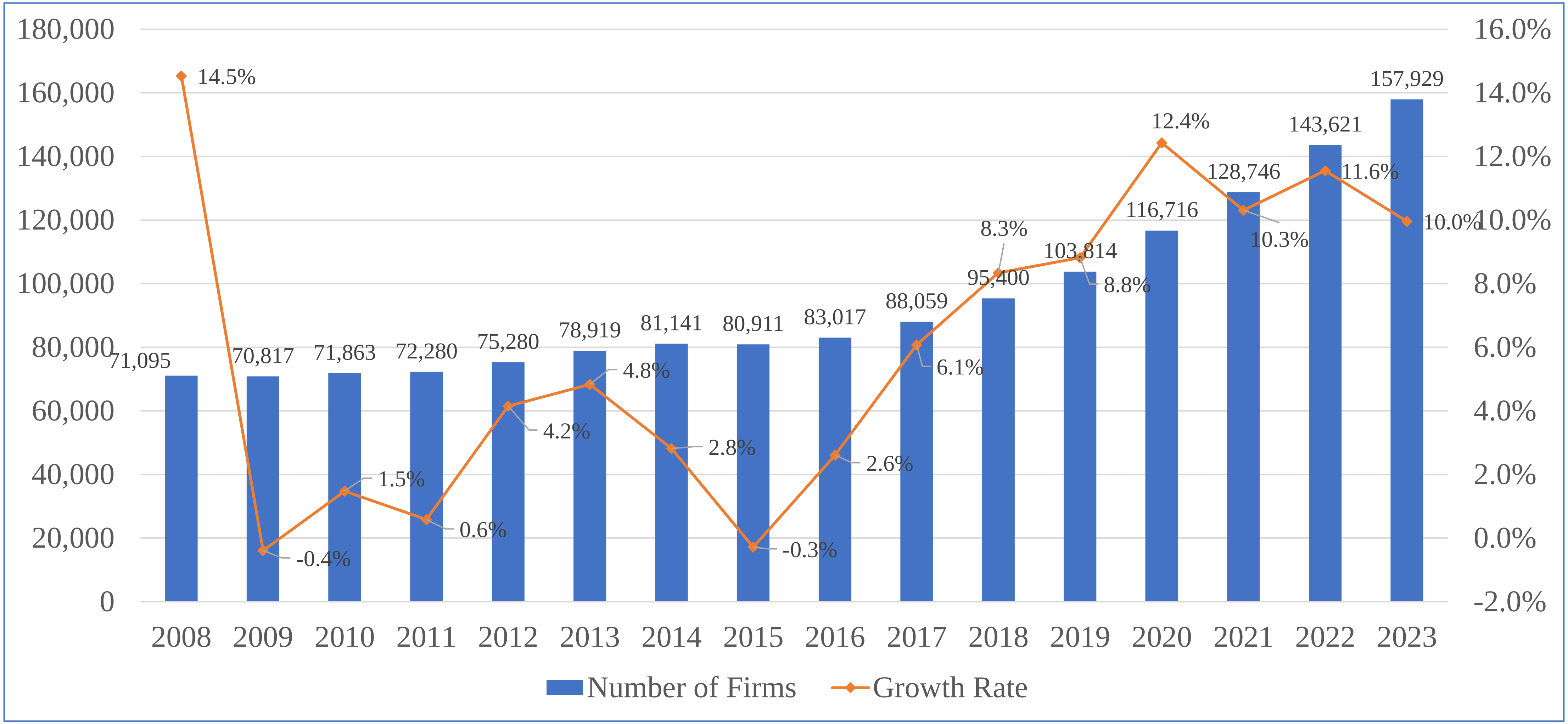
- 1986 obtained Bachelor Degree in Civil Engineering at Tsinghua University, China
- 1989 obtained Master Degree in Civil Engineering at Nagoya University, Japan
- 1992 obtained PhD in Civil Engineering at Nagoya University, Japan
- 1993 Joined Tsinghua University to teach and research on Application of Information Technology in Civil Engineering

Agenda

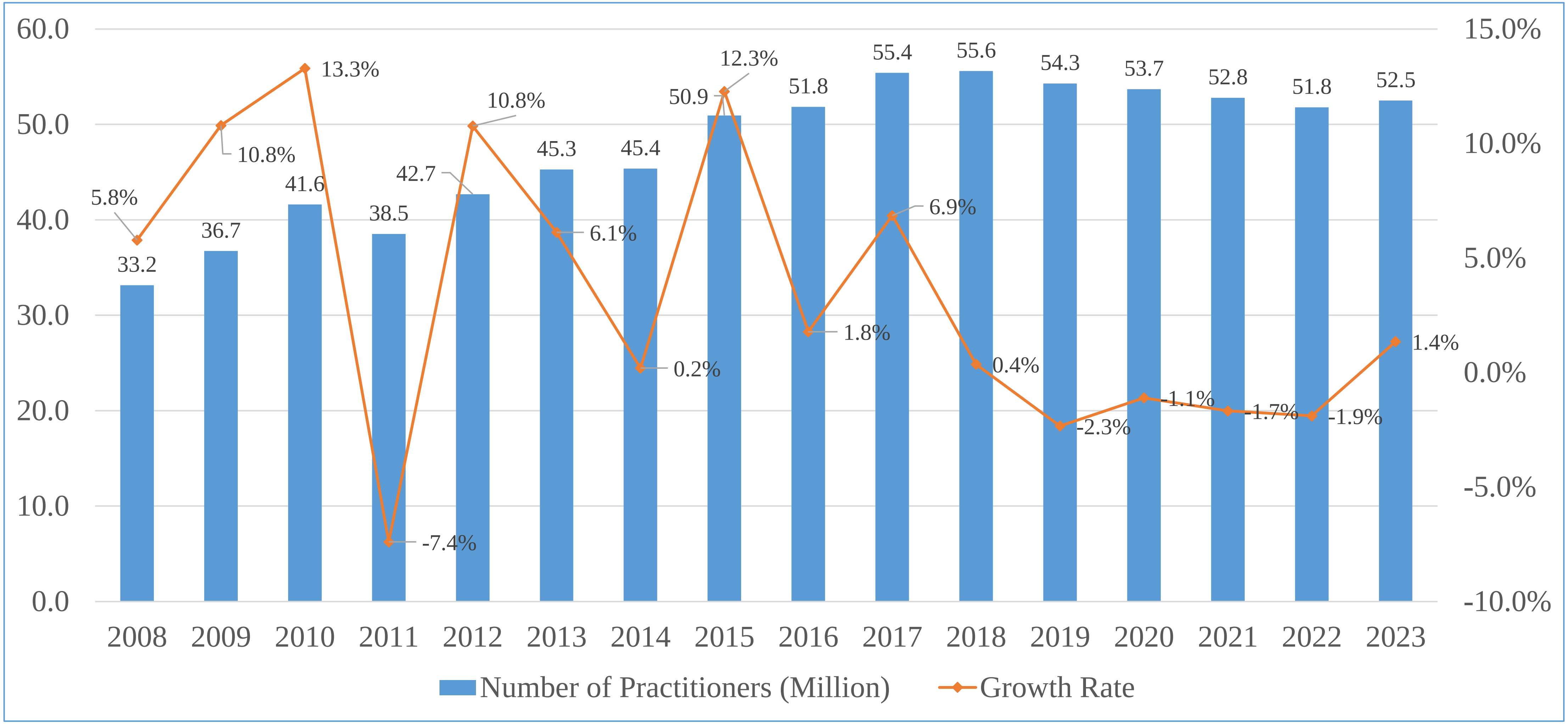
1. Big data about construction industry



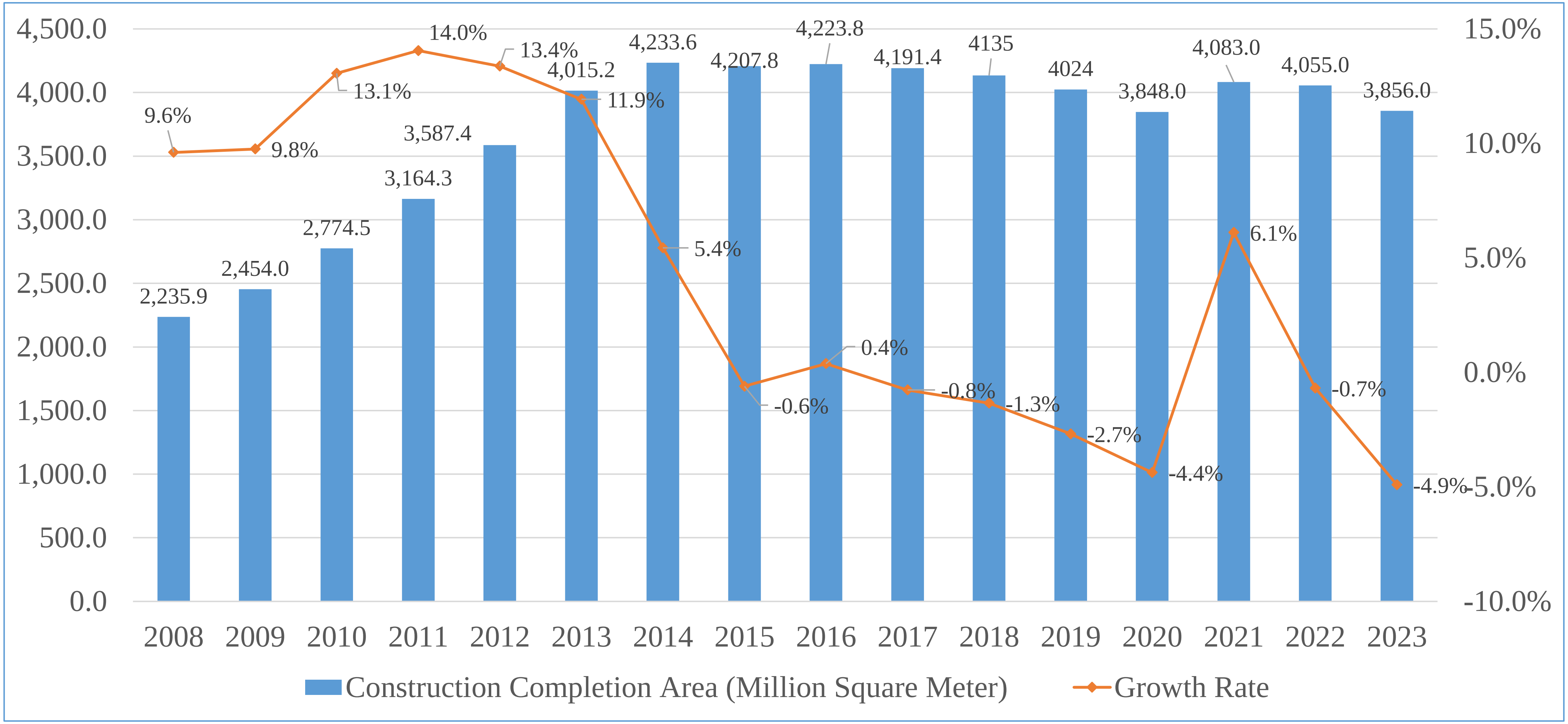
Gross output and its growth rate of construction industry in China from 2008 to 2023



Number of firms and its growth rate of construction industry in China from 2008 to 2023



Number of total practitioners and its growth rate of construction industry in China from 2008 to 2023



Construction completed floor area and its growth rate of construction industry in China from 2008 to 2023

Construction industry of China vs. Germany on the relative aspects

	Population (Million)	Gross Output Value 2023 (Billion USD)	Growth Rate of Gross Output Value 2023	Number of Firms 2023	Number of Practitioners 2023 (Million)
German	81	202.4	5.5%	15,312	2.5
China	1,390	4,325	1.3%	157,929	52.5
Ratio	1 : 17	1 : 21	4 : 1	1 : 5	1 : 21

2. Origin

- Intelligent construction is a major trend

  Ministry of Housing and Urban-Rural Development (MHURD) et al.

  July, 2020

  Guiding Opinions on Promoting the Collaborative Development of Intelligent Construction and Construction Industrialization

  - By 2035, entering the ranks of world powers on intelligent construction

  September, 2020

  Several Opinions on Accelerating the Development of New Construction Industrialization

  - Promote the development of intelligent construction technology

- Industry Development Reports on Intelligent Construction
  - By Information Center of MHURD
  - Published in 2021 and 2023
  - Expert group established
  - Ontline formulated
  - Best experts invited to write
  - Questionnaire survey conducted
  - Reviewed several rounds
  - Both theory and case studies included

- Intelligent Construction: Definition

  A pattern of construction

  which facilitates

  the phases of design, manufacturing and construction

  of engineering projects,

  to raise the intelligent level of the processes

  through applying intelligent systems,

  so as to obtain economic and social benefits

- Intelligent System and Intelligent Level

  Intelligent systems

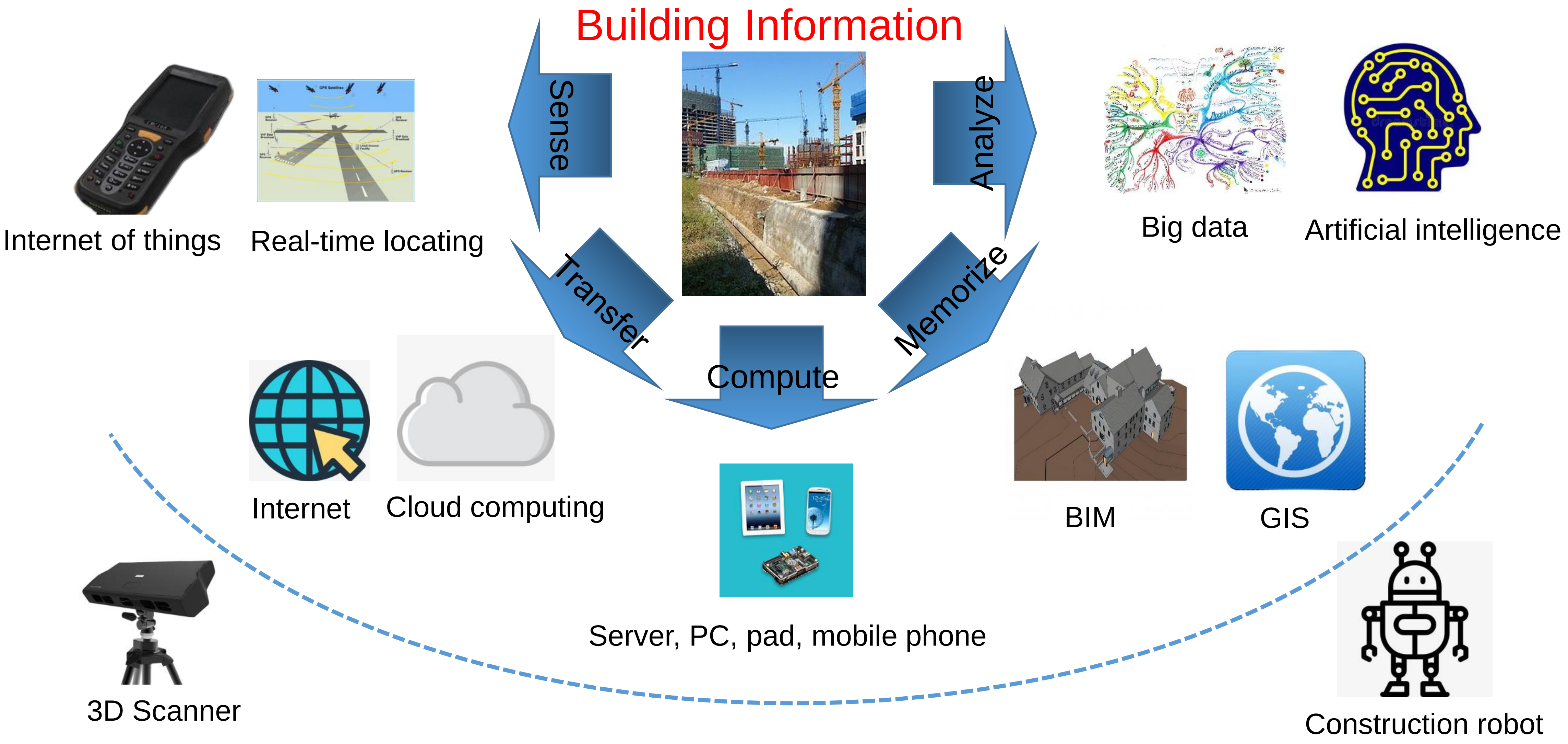
  represent the intelligent technology and relevant technologies-based computer systems that

  possess the abilities that only human beings possess

  and are used to replace human beings or reduce the requirement for human beings

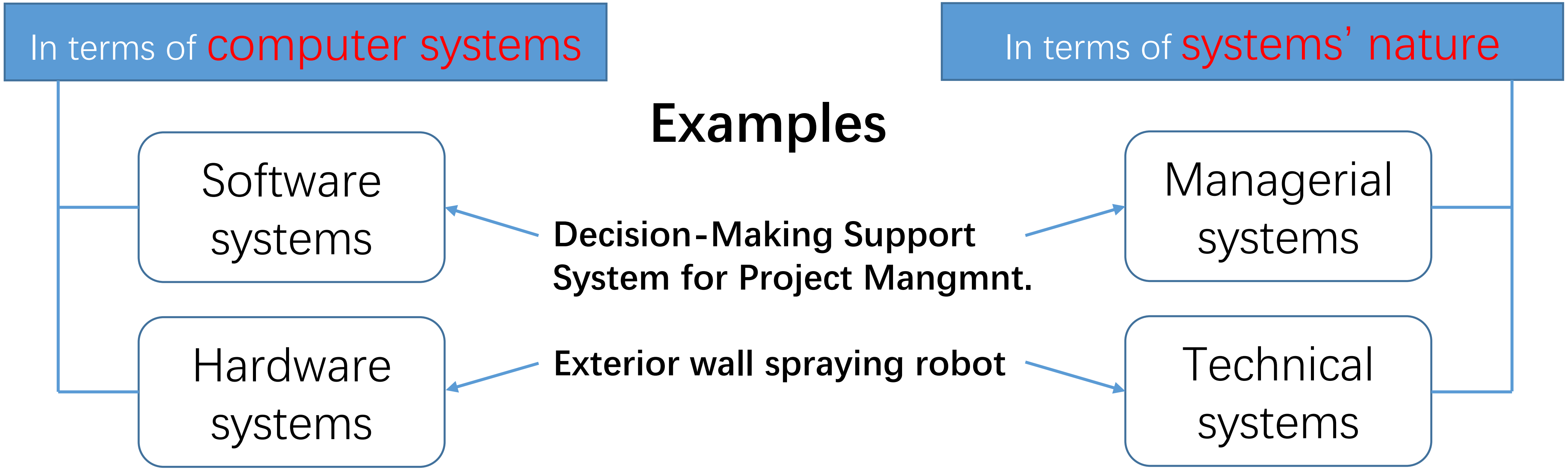
  Intelligent level

  represents the level for replacing human beings or reducing the requirement for human beings



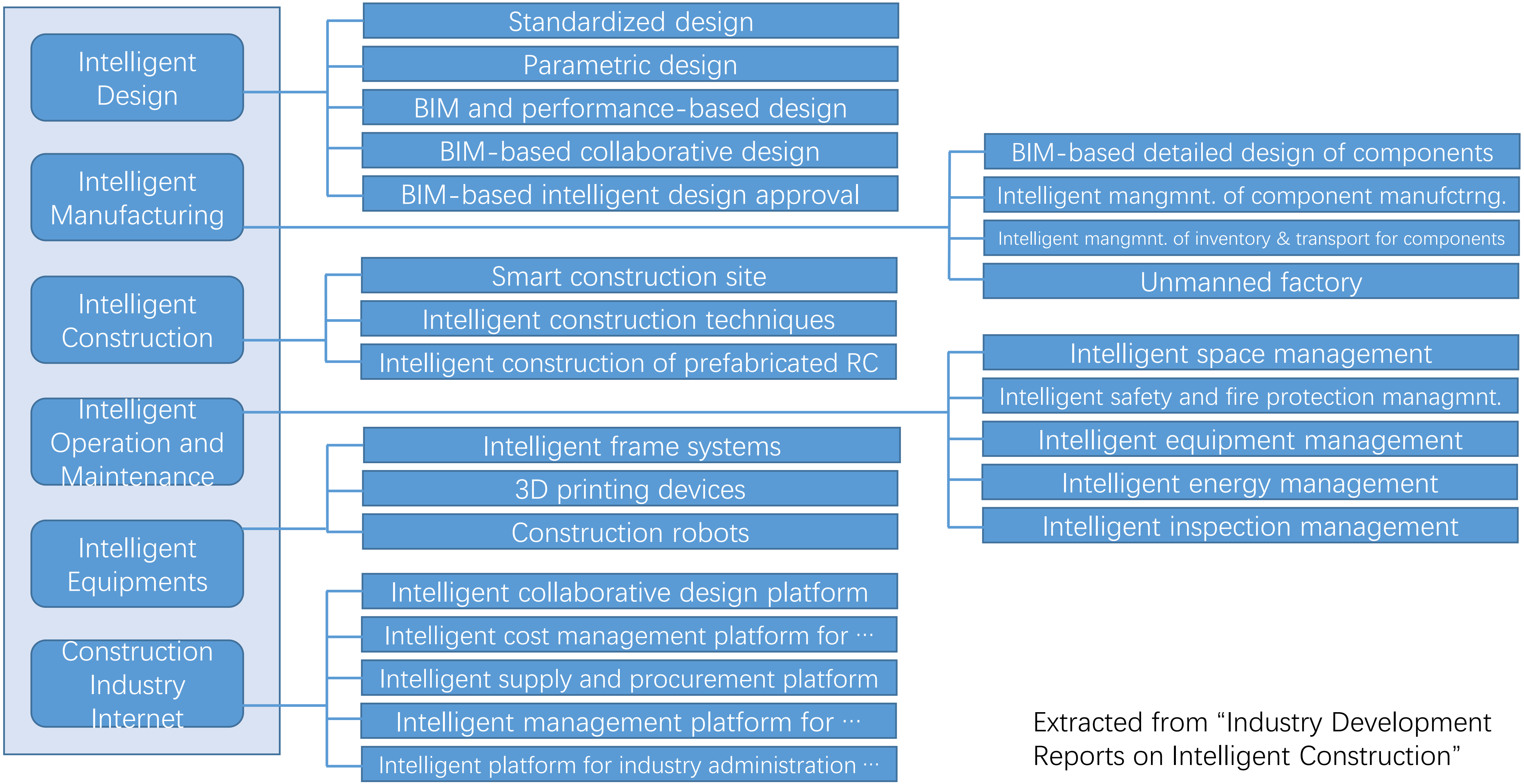
Intelligent technology and relevant technologies

- Classification of Intelligent Systems



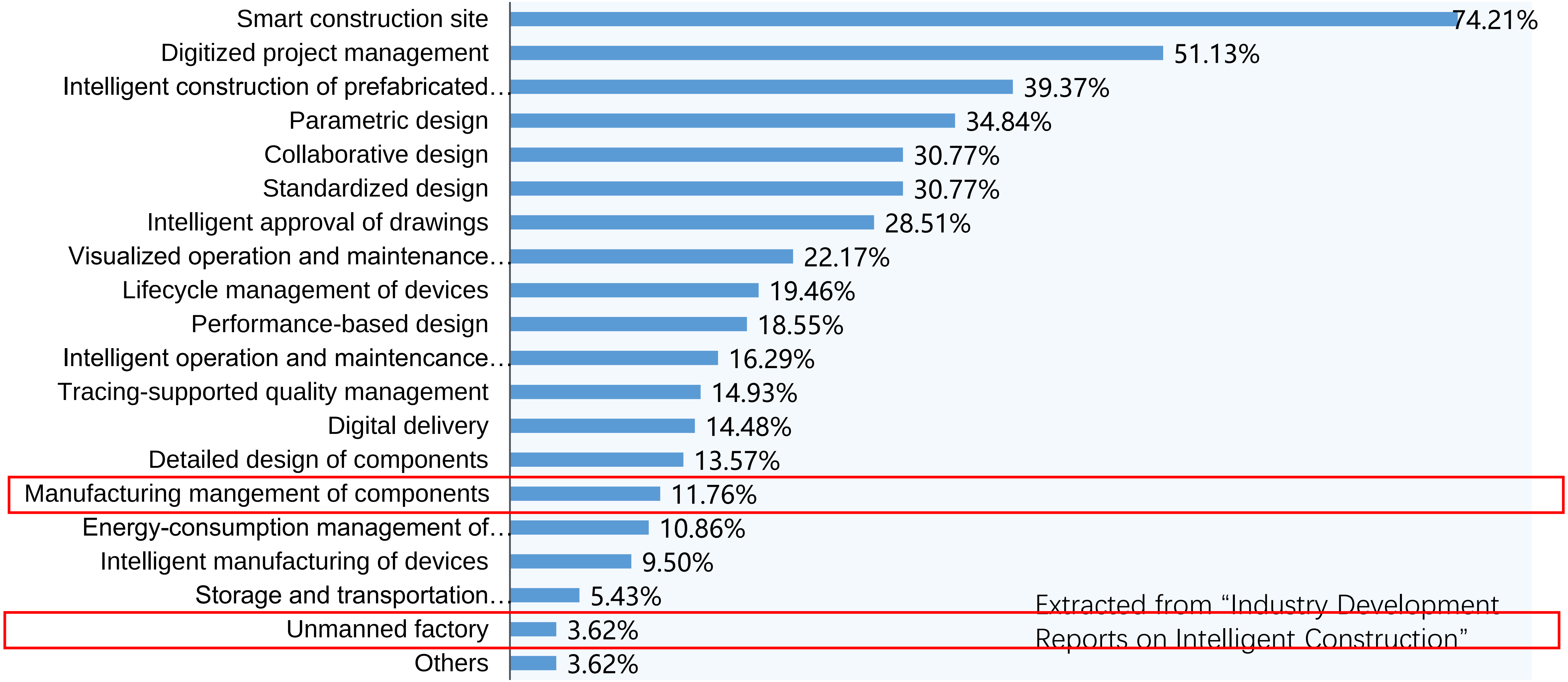
3. State-of-the-art

- Hot Application Points: Definition and Classification
  - Definition
    - Hot and typical scenario for applying intelligent systems
  - Classification: 6 categories
    - According to separate phases
      - Intelligent design, ~ manufacturing, ~ construction, and ~ operation and maintenance
    - According to common items to some phases
      - Intelligent equipment and Construction industry internet



Extracted from “Industry Development Reports on Intelligent Construction”

Hot application points of intelligent construction in China

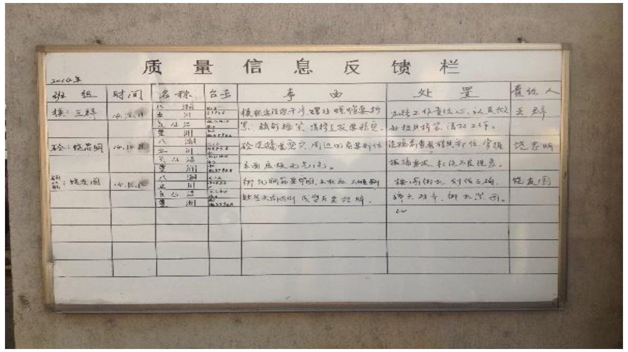


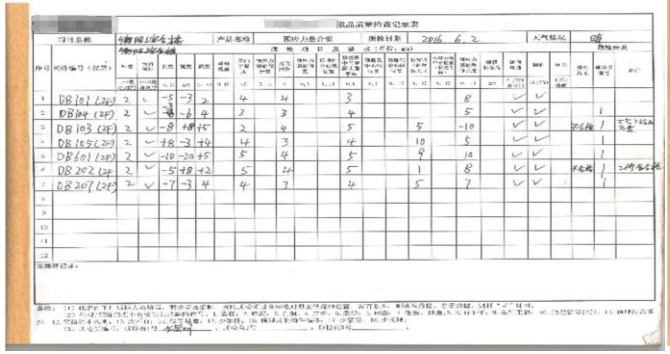
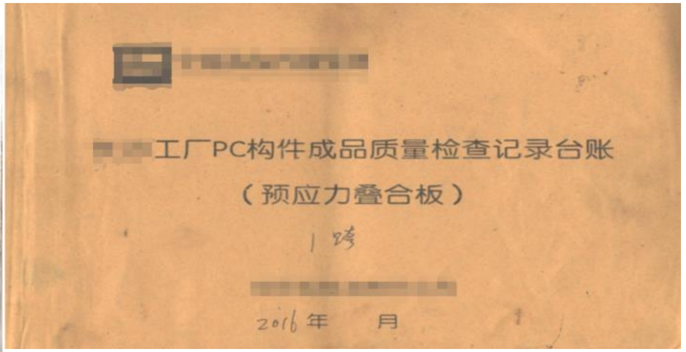
Implementation ratio of hot application points computed from the questionnaire results
(Valid returns 221: Construction firms 57.01%; Owners and developers 20.81%, Others 22.18%)

Case 1 Internet plus-based management system for manufctrg. of precast concrete (PC) components: Tsinghua Univ.

- Background

A few years ago: backward techniques and management tools

- Key problems

  Low working efficiency, inability to effectively utilize production capacity, poor schedule controllability

- Objectives

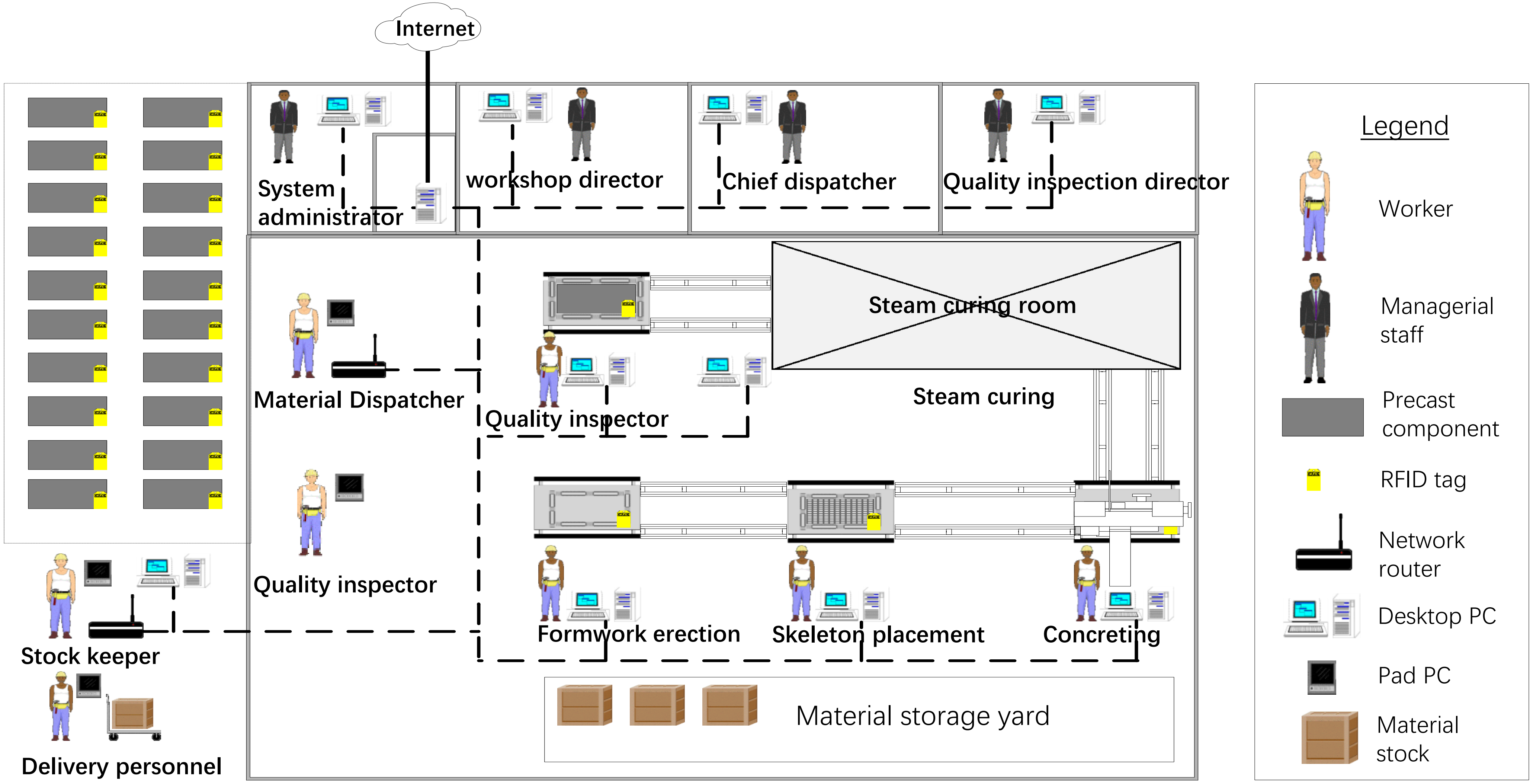
  By utilizing internet plus technologies (including BIM, IoT, and mobile terminals etc.) and optimum techniques

  To develop an intelligent system to facilitate

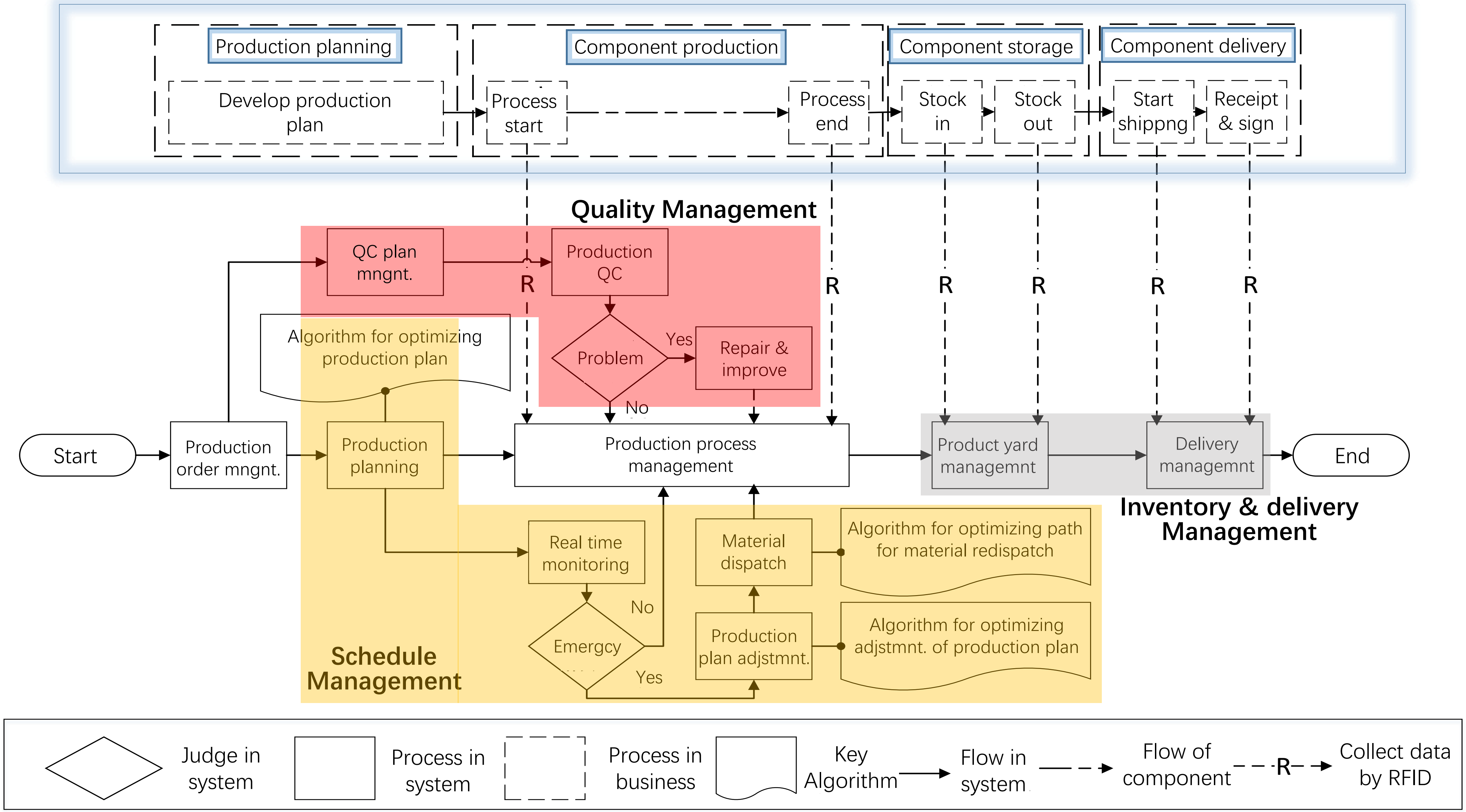
    real-time monitoring and control of manufacturing process

    and optimized decision-making support

Typical User Interface of System



System Configuration



Business process and functional modules

- Key technical innovative elements
  - Taking advantage of intelligent technology and relevant ~
    - BIM, Mobile terminal, IoT(RFID)
  - Supporting large scale, automatic and agile production
  - Facilitating
    - Optimization of production planning
    - Optimization of adjustment of production plan
    - Optimization of path for material re-dispatch

Model for optimization of production planning

- Optimization objectives
  - Minimization of Workstation Idle time
  - Minimization of Contract penalty and Storage cost
  - Minimization of makespan
  - Minimization of Type Change of precast components

- Formulas for optimization objectives

$$\text{Min } f_{WI} = \sum_{l=1}^{L}\sum_{k=1}^{6}\left[C\left(J_{l,n_l}, M_{l,k}\right) - \sum_{i=1}^{n_l} P_{l,i,k}\right]$$

$$\text{Min } f_{DI} = \sum_{l=1}^{L}\left\{\sum_{i=1}^{n_l} \tau_{l,i} * \text{Max}\left[0, C\left(J_{l,i}, M_{l,6}\right) - d_{l,i}\right] + \sum_{i=1}^{n_l} \varepsilon_{l,i} * \text{Max}\left[0, d_{l,i} - C\left(J_{l,i}, M_{l,6}\right)\right]\right\}$$

$$\text{Min } f_{MS} = \text{Max}_{\forall l \in N^+ | l \le L} C\left(J_{l,n_l}, M_{l,6}\right)$$

$$\text{Min } f_{TC} = \sum_{s=1}^{S}\left\{ETN_s + \alpha * ECT_s\right\}$$

- Optimization constraints
  - Constraint of productivity
  - Constraint of the size of curing rooms
  - Constraint of the eight-hour day working
  - Constraint of the buffer size between workstations
  - Constraint of the quantity of molds
  - Constraint of the quantity of production pallets

- Formulas for constraints

$$S\left(J_{l,i}, M_{l,k}\right) \ge \begin{cases} \text{Max}\left[C\left(J_{l,(i-1)}, M_{l,k}\right), C\left(J_{l,i}, M_{l,(k-1)}\right)\right], & \text{if } k \ne 4 \\ C\left(J_{l,i}, M_{l,(k-1)}\right), & \text{if } k = 4 \end{cases}$$

$$C\left(J_{l,i}, M_{l,k}\right) \ge S\left(J_{l,i}, M_{l,k}\right) + P_{l,i,k}$$

$$S\left(J_{l,i}, M_{l,4}\right) \ge \text{Max}_{\forall y \in N^+ | y < i}^{Y_l^{th}} C\left(J_{l,y}, M_{l,4}\right)$$

$$C\left(J_{l,i}, M_{l,3}\right) \ge \begin{cases} T, & \text{if } T \le 24D + H_W + H_E \\ 24(D+1) + P_{l,i,k}, & \text{if } T > 24D + H_W + H_E \end{cases}$$

$$C\left(J_{l,i}, M_{l,4}\right) \ge \begin{cases} T, & \text{if } T < 24D + H_W \\ 24(D+1), & \text{if } 24D + H_W \le T \le 24(D+1) \\ T, & \text{if } T > 24(D+1) \end{cases}$$

$$C\left(J_{l,i}, M_{l,k}\right) \ge \begin{cases} T, & \text{if } T < 24D + H_W \text{ and } k = 1,2,5,6 \\ T + H_N, & \text{if } T \ge 24D + H_W \text{ and } k = 1,2,5,6 \end{cases}$$

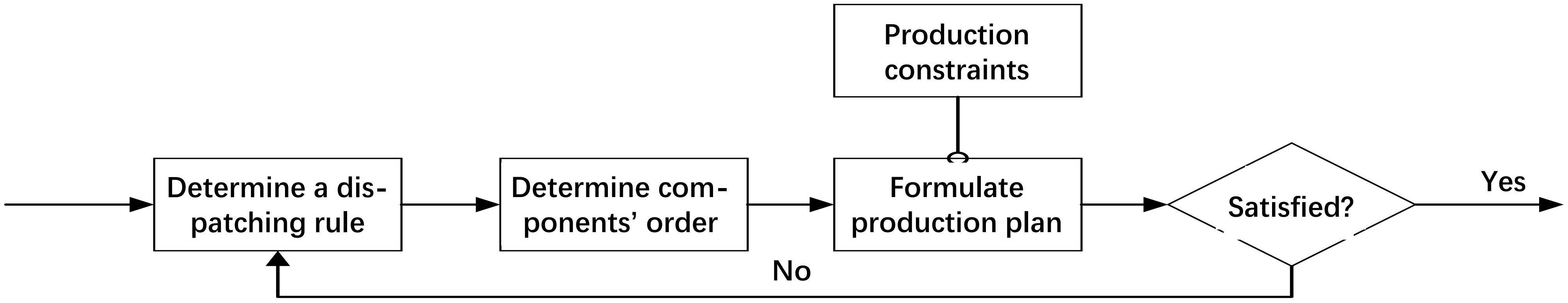
$$C\left(J_{l,i}, M_{l,k}\right) \ge S\left(J_{l,(i-B_{l,k})}, M_{l,(k+1)}\right)$$

$$S\left(J_{l,i}^{j,\$}, M_{l,1}\right) \ge \text{Min}\left\{\text{Max}_{\forall l \in N^+ | l \le L, \forall y \in N^+ | y \le i, \forall x \in N^+ | x < j}^{Q_\$}\left[C\left(J_{l,y,x,\$}, M_{l,6}\right)\right]\right\}$$

$$S\left(J_{l,i}^{j}, M_{l,1}\right) \ge \text{Min}\left\{\text{Max}_{\forall l \in N^+ | l \le L, \forall y \in N^+ | y \le i, \forall x \in N^+ | x < j}^{P}\left[C\left(J_{l,y,x}, M_{l,6}\right)\right]\right\}$$

Comparison with current approach

- Dispatching rule-based approach



- Typical dispatching rules
  - Earliest delivery date
  - Minimum makespan
  - Minimum margin time
  - Critical path

1. Highly depends on the experience of schedulers and sometimes trial and error is needed
2. Optimization is not guaranteed

References

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Automation in Construction

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Optimized flowshop scheduling of multiple production lines for precast production

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Zhitian Yang [a], Zhiliang Ma [a,*], Song Wu [b]

[a] Tsinghua University, Beijing, China
[b] University of Huddersfield, Huddersfield, UK

ARTICLE INFO

Article history:
Received 19 January 2016
Received in revised form 22 June 2016
Accepted 15 August 2016
Available online 27 August 2016

Keywords:
Precast production
Flowshop scheduling
Optimization
Genetic algorithm

ABSTRACT

The current approach in practice to pro
technique, which does not guarantee
production line to optimize the schedu
ever the models cannot be used for mu
jectives were missing in the models,
production. Both issues hinder their w
paper proposes a Flowshop Schedulin
and develops a corresponding optimi
proach was validated preliminarily by
strated that optimized schedules can b

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Optimized rescheduling of multiple production lines for flowshop production of reinforced precast concrete components

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Zhiliang Ma [a,*], Zhitian Yang [a], Shilong Liu [a], Song Wu [b]

[a] Tsinghua University, Beijing, China

adopted as the major type of production of reinforced precast concrete components and
nts on shop floor schedules than other types, especially that from rescheduling. However,
proach for the optimization of the shop floor rescheduling has been proposed in spite of its
research proposes an approach for optimizing shop floor rescheduling of multiple pro-
hop production of reinforced precast concrete components. The approach comprehen-
assigned time, which is the difference value between the assigned production time and
production step for a precast component to deal with production emergencies. Meanwhile,
t of schedules at minimum to avoid massive material re-dispatch. First of all, the opti-
d constraints of optimized shop floor rescheduling of multiple production lines for
ction are analyzed and a mathematic model is thus formulated. Then, the solver of the
using genetic algorithm. Finally, the approach is validated by case studies. It is concluded
ributes to the effective and efficient optimized rescheduling of multiple production lines
roduction.

第 45 卷第 10 期　　同济大学学报(自然科学版)　　Vol. 45 No. 10
2017 年 10 月　　JOURNAL OF TONGJI UNIVERSITY(NATURAL SCIENCE)　　Oct. 2017

文章编号：0253-374X(2017)10-1446-08　　DOI:10.11908/j.issn.0253-374x.2017.10.005

预制混凝土构件生产物料重调配路径规划方法

马智亮，杨之恬
（清华大学 土木工程系，北京 100084）

摘要：分析预制混凝土构件生产中物料重调配路径规划问题的优化目标和限制条件，建立载具路径规划模型(vehicle routing model for redispatching parts of precast components，VRM-RPP)及其求解方法．该方法通过优化分配和利用载具资源，合理规划行进路径，以提高重调配工作效率，确保车间尽早开工．算例验证结果表明，该方法可用于优化预制生产中物料重调配路径．

关键词：遗传算法；优化；预制生产；物料重调配；路径规划
中图分类号：TU741.2　　文献标志码：A

架、预埋件及构造件等物料需依照生产作业计划，提前若干天调配到对应生产线的堆场，以避免因物料调配不及时耽误生产．相比其他生产组织形式，流水式预制生产中各工序衔接更为紧密，关系更为复杂，物料调配对其更为重要．当施工延期、设计变更、大规模生产质量问题等突发事件发生时，需要对作业计划进行调整，重新分配生产任务．由于不同型号预制构件所需物料不同，此时需进行物料重调配，即在现有物料配置的基础上，利用若干辆载具，将物料依据新作业计划在生产线的堆场间重新配置，若有多

Case 2 Intelligent manufacturing system for steel structures: CSCEC Steel Structures Corporation

- Background

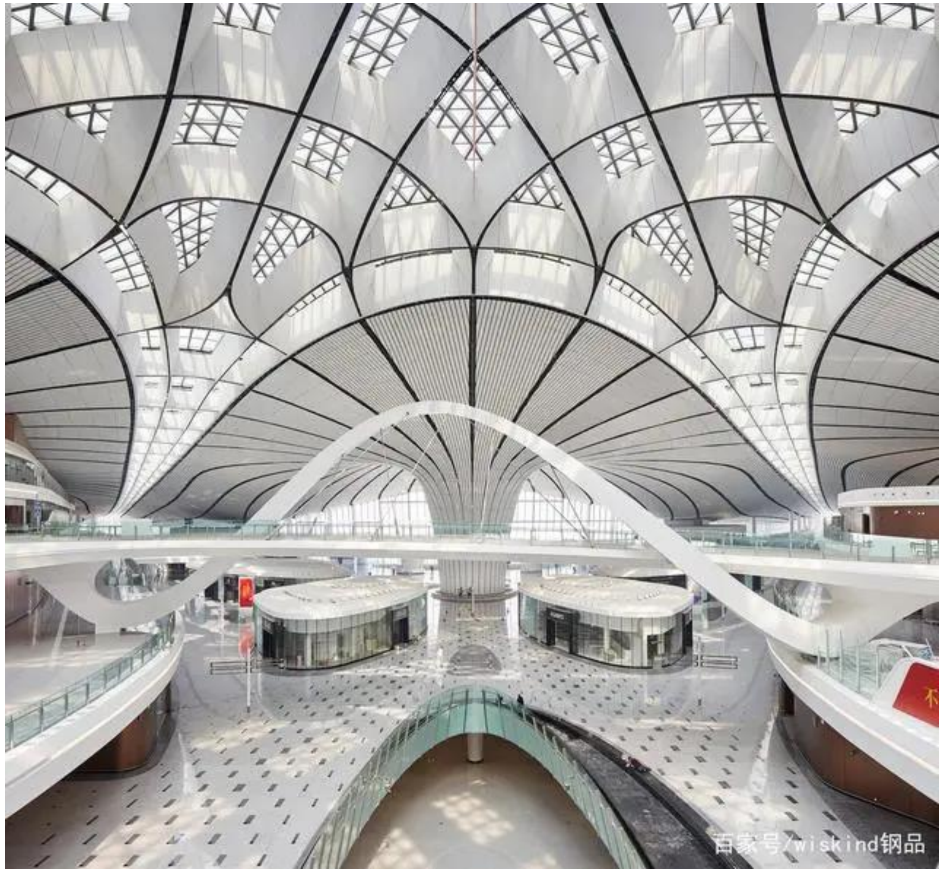
  Characteristics of steel structures in China

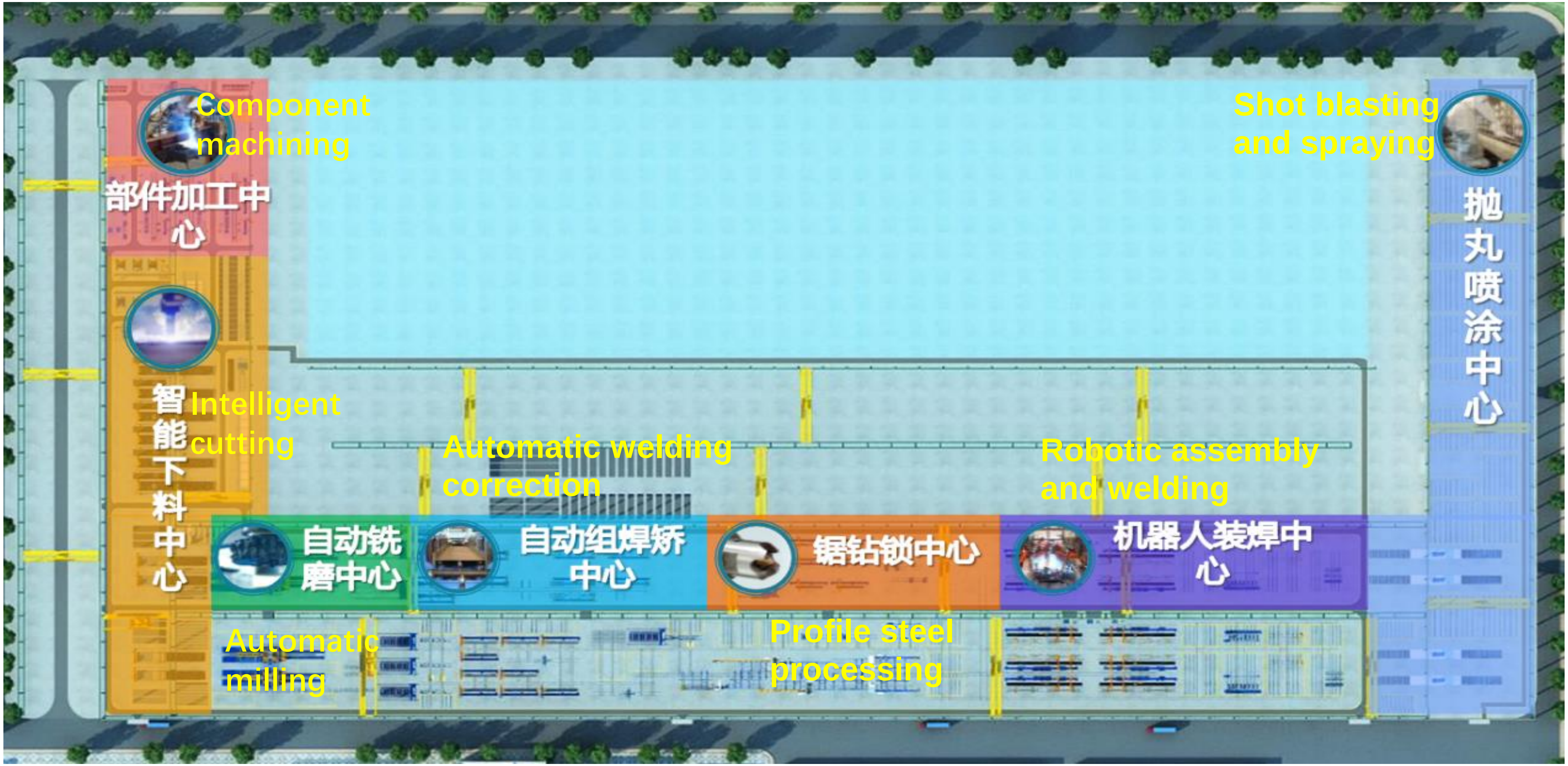
  There exist many unique joints

  The equipment of western countries is not fully applicable

  Dedicated manufacturing system is required

  The company developed a comprehensive production line





Layout of intelligent production line of steel structures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重量6400Kg
←Y-
B
ARCMAN
重量6400Kg
中建科工集团提供

摘自《中国建筑业信息化发展报告（2021）——智能建造应用与发展》

- Benefits
  - Working efficiency: 20% up
  - Operation cost: 20%+ down
    including human cost
  - Manufacturing time: 30%+
    shortened
  - Defect rate of products: 20%+
    down

References

Case Study

ASCE

Construction Automation and Robotics: From One-Offs to Follow-Ups Based on Practices of Chinese Construction Companies

Shiyao Cai[1]; Zhiliang Ma[2]; Miroslaw J. Skibniewski[3]; and Jianfeng Guo[4]

Abstract: The follow-up issue is one of the major factors that limit the application of construction automation and robotics. Specifically, many research results with fundamentally good ideas end up gathering dust on a shelf without any follow-up research and development (R&D) or applications. Nevertheless, some construction companies have successful experience in the follow-up issue. Therefore, this study presents and analyzes the processes from R&D to follow-ups of four representative Chinese construction companies that developed their own automation and robotic products and implemented them continuously. Based on the four cases, an intercase analysis was conducted, and 11 influential factors that lead to successful follow-ups were identified. To understand the identified factors effectively, they were then categorized according to an existing theoretical framework, i.e., the technology–organization–environment (TOE) framework, which is widely used in studies on innovation adoption. As a result, four technological factors (interdisciplinary cooperation, continuous R&D, pilot test, and technological foresight), five organizational factors (company size, human resources, development strategies, organizational structure, and management system), and two environmental factors (market demand and competitive pressure) are obtained. Suggestions are proposed for both the technology providers and adopters, such as establishing industrial alliances, training interdisciplinary personnel and skilled workers, and expanding the business scope to promote wider implementations. It is expected to be valuable for the stakeholders in many countries and regions with the need to implement construction automation and robotics because the analysis has not been confined to the practice in China. **DOI:** 10.1061/(ASCE)CO.1943-7862.0001910. *© 2020 American Society of Civil Engineers.*

Author keywords: Automation and robotics; Research and development (R&D); Follow-up issue; Construction company.

4. Tendencies

- Development of intelligent construction

  Current level of development is still low

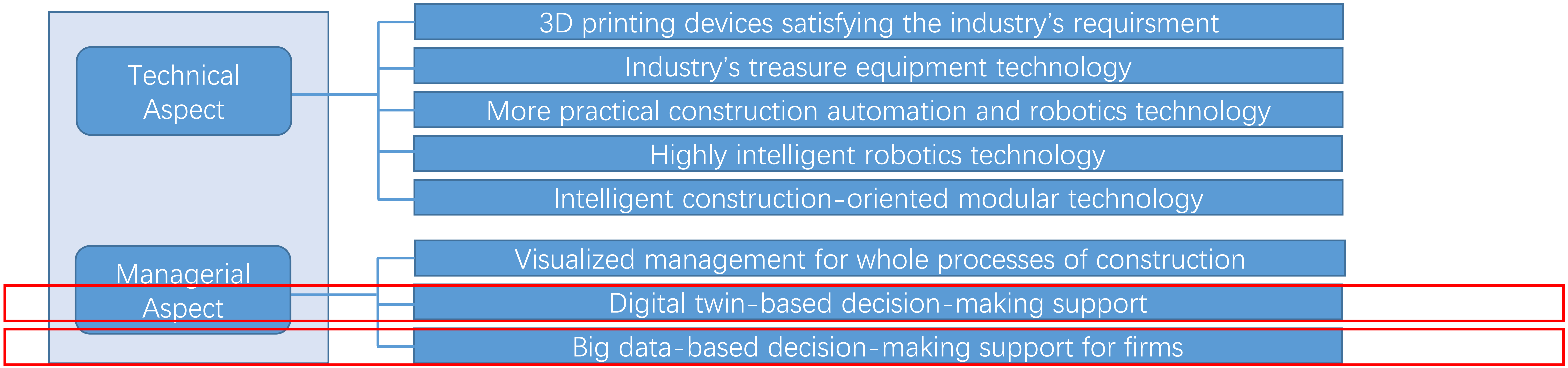
  The goal should to develop more advanced intelligent systems

  The key is to innovation both in industry and academia

  Two aspects are categorized for innovation

    Technical aspects and managerial aspects

  Major trendy points are proposed with regard to the two aspect



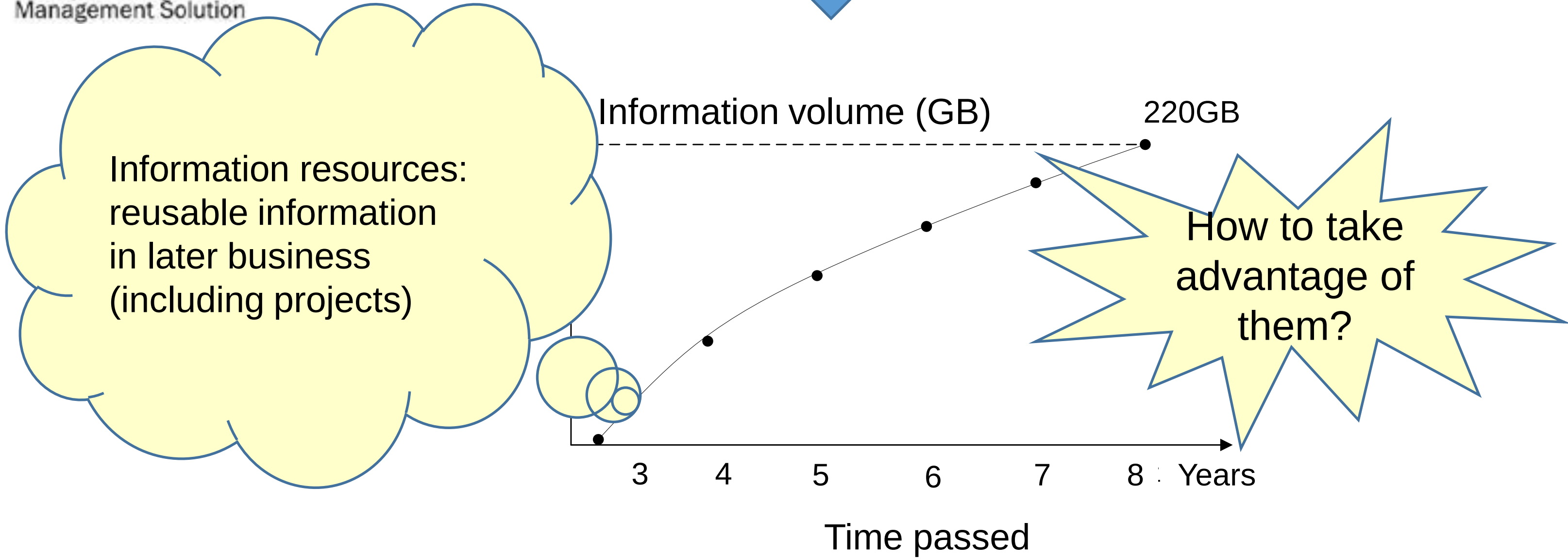
Extracted from “Industry Development Reports on Intelligent Construction”

Trendy points of intelligent construction in China

Case 3 Intelligent system for reuse of information resources of building construction firms in decision-making process: Tsinghua Univ.

- Background

Various management information systems are being used in construction firms and their projects



- Research objectives

  Based on BIM technology, develop an innovative approach taking advantage of information resources.

    Identify major information resources

    Establish framework for utilizing information resources based on BIM technology

    Develop a prototype system

  BIM is used as a base because it provides a standard way for storing information to facilitate its management

Classification of decision-making activities

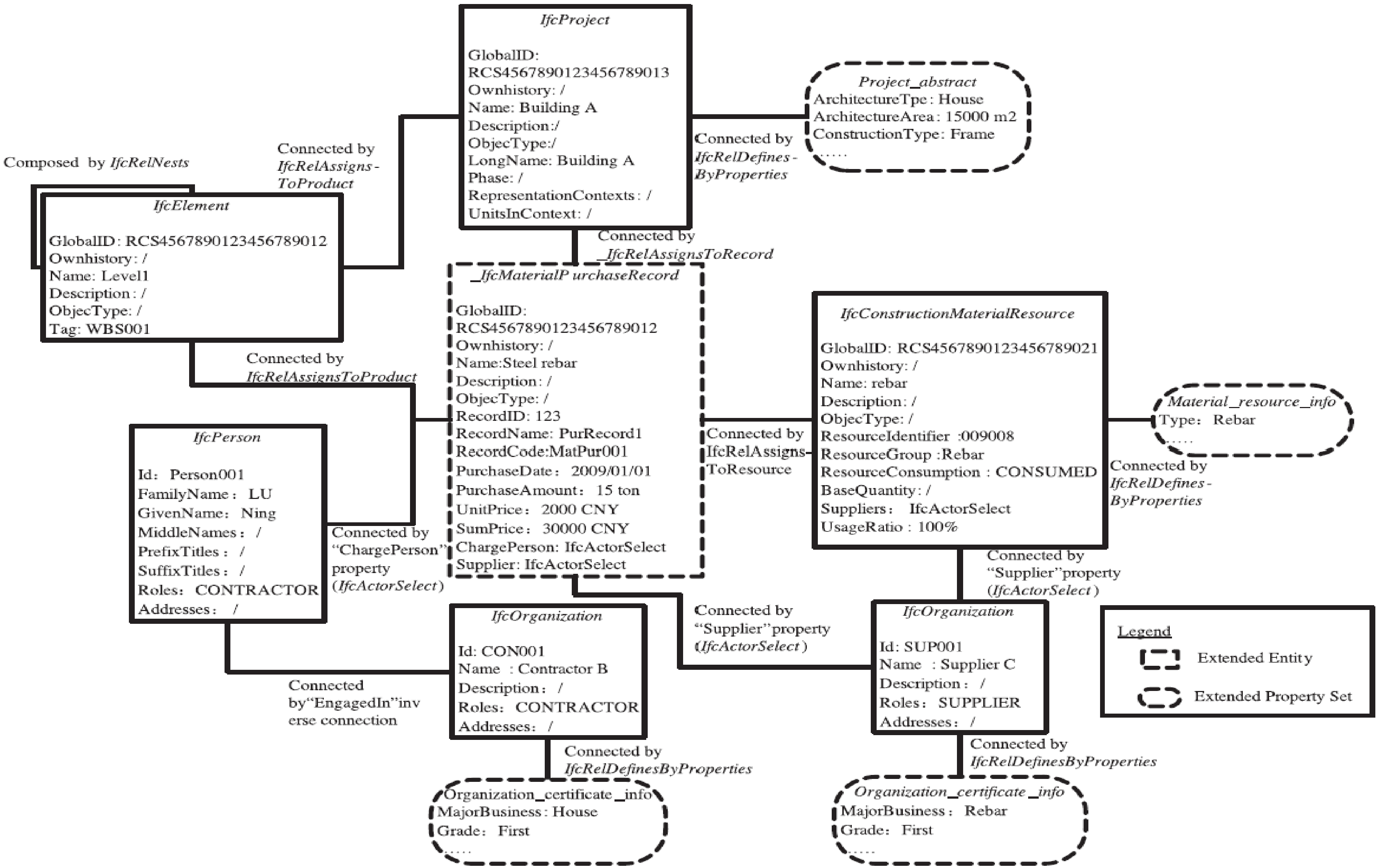
Project phase	Code	Project management decision activities	Managerial subject	Code	Firm management decision activities
Bidding	PA1	Decide construction method	Plan	EA1	Develop plan
	PA2	Develop overall schedule	Business	EA2	Control project bidding
	PA3	Decide bidding price		EA3	Control project contractor
	PA4	Prepare bidding document		EA4	Control project schedule
Contracting	PA5	Select sub-contractor		EA5	Control project cost
	PA6	Assess risk		EA6	Control project quality
Preparation	PA7	Decide construction layout		EA7	Control project safety
	PA8	Develop detailed schedule	Technology	EA8	Decide construction method
	PA9	Develop cost plan		EA9	Update firm quota
	PA10	Develop material plan	Material	EA10	Decide material procurement
	PA11	Develop equipment plan		EA11	Coordinate material
	PA12	Develop labor plan	Equipment	EA12	Decide equipment procurement
	PA13	Develop quality control plan		EA13	Coordinate equipment
	PA14	Prepare constr. plan document	Human resource	EA14	Predict labor need
Construction	PA15	Control project contract		EA15	Deploy employee
	PA16	Control project schedule		EA16	Assess employee
	PA17	Control project cost	Finance	EA17	Estimate cost
	PA18	Control project quality		EA18	Account cost
	PA19	Control project safety		EA19	Evaluate client
Maintenance	PA20	Evaluate sub-contractor/supplier	Client/sub-contractor/supplier	EA20	Evaluate sub-contractor
	PA21	Evaluate project		EA21	Evaluate supplier
	PA22	Decide maintenance method			

Classification of construction firm information resource items

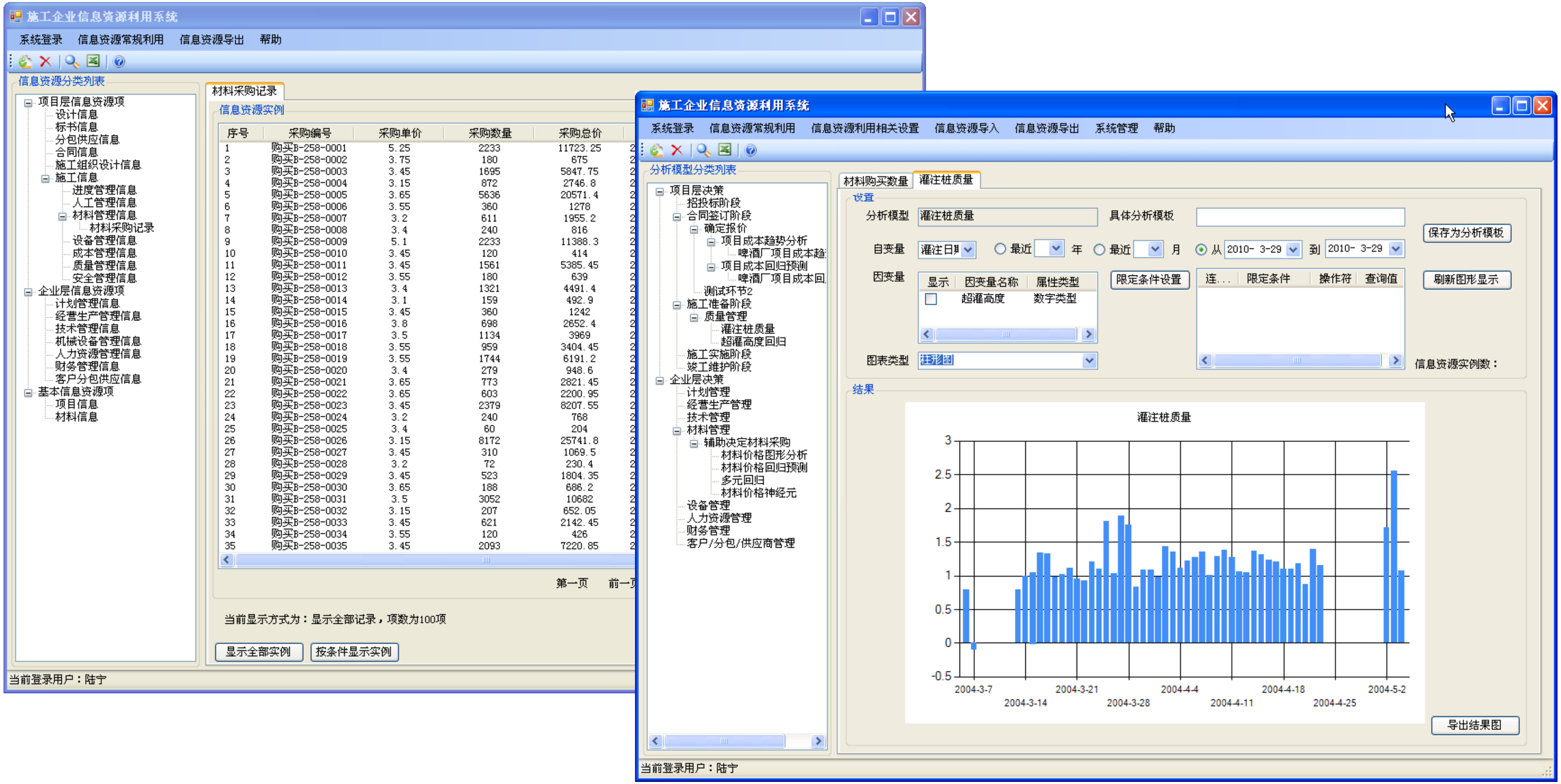
Category	Code	Information resource items	Category	Code	Information resource items
Plan	EI1	Long-term plan	Material	EI14	Material transportation record
	EI2	Annual plan	Equipment	EI15	Equipment procurement/rent record
	EI3	Quarter plan		EI16	Equipment use record
Business	EI4	Project bidding record		EI17	Equipment maintenance record
	EI5	Project contract record	Human resource	EI18	Employee performance record
	EI6	Project schedule record		EI19	Deployment of staffs record
	EI7	Project cost record	Finance	EI20	Cash flows record
	EI8	Project quality record		EI21	Income and expenditure record
	EI9	Project safety record		EI22	Cost accounting record
Technology	EI10	Construction method	Client /sub-contractor/supplier	EI23	Client record
	EI11	New tech./material record		EI24	Client cooperation record
Material	EI12	Material procurement record		EI25	Sub-contractor/supplier record
	EI13	Material in/out record		EI26	Sub-contractor/supplier cooperation record

Classification of project information resource items

Category	Code	Information resource items	Category	Code	Information resource items
Design	PI1	General info. of design	Construction plan	PI20	Quality control plan detail
	PI2	Design change record		PI21	Construction plan document
	PI3	Design document/drawing		PI22	Construction layout drawing
Bidding	PI4	General info. of bidding	Schedule	PI23	Planned schedule detail
	PI5	Overall schedule		PI24	Actual schedule detail
	PI6	Project bidding detail	Labor	PI25	Labor work record
	PI7	Bidding document	Material	PI26	Material procurement record
Sub-contractor/supplier	PI8	Certificate info.		PI27	Material in/out record
	PI9	Cooperation record		PI28	Material consumption record
Contract	PI10	General info. of contract		PI29	Material inspection record
	PI11	Claim record	Equipment	PI30	Equipment procurement/rent record
	PI12	Contract change record		PI31	Equipment in/out record
	PI13	Contract document		PI32	Equipment consumption record
Construction plan	PI14	General info. of constr. plan		PI33	Equipment inspection record
	PI15	Schedule detail	Cost	PI34	Direct cost record
	PI16	Cost plan detail		PI35	Indirect cost record
	PI17	Material plan detail	Quality	PI36	Quality inspection record
	PI18	Equipment plan detail	Safety	PI37	Safety method record
	PI19	Labor plan detail			



IFC entities and expanded entities used to represent data of material procurement



Interfaces of BIM-based System for Information Reuse of Construction Firms

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Advanced Engineering Informatics 25 (2011) 612–624

Contents lists available at SciVerse ScienceDirect

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journal homepage: www.elsevier.com/locate/aei

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Identification and representation of information r...

Zhiliang Ma [a,*], Ning Lu [a,1], Song Wu [b,2]

[a] Dept. of Civil Engineering, Tsinghua University, Beijing 100084, PR China
[b] School of Built Environment, University of Salford, Maxwell Building, Salford M5 4WT, United Kingdom

A R T I C L E I N F O

Article history:
Available online 10 September 2011

Keywords:
Construction firms
Management
Information resources
IFC
Expert workshop
Object-oriented

A B S T R A C T

Large amounts of information are being acc
construction firms. Among them, the reus
resources' and two approaches have been
eral-purpose software such as Microsoft C
Intelligence) software. Identifying and repre
approaches. This research identified decisio
reviews and two expert workshops: an eval
of information resource items was evaluate
workshop. A way to represent information
was developed and validated based on the
construction firms in utilizing the informat
sion-making in their project and enterprise

ISSN 1000-0054 清华大学学报（自然科学版）2012 年 第 52 卷 第 6 期 18/26
CN 11-2223/N J Tsinghua Univ (Sci & Tech), 2012, Vol. 52, No. 6 836-842

利用面向对象数据库与关系数据库管理 IFC 数据的比较

陆 宁， 马智亮

面向对象方法表示信息、覆盖项目全生命
循开放数据标准。目前 BIM 技术主要
ndustry foundation classes)标准进行数
示准基于面向对象方法定义数据结构。
，符合 IFC 标准的数据(以下简称 IFC
过 IFC 文件进行存储与管理[1]或通过 IF
进行存储与管理[2]；涉及多专业的综合
由于其数据量大，应用复杂，且需要多
据模型的协同操作和处理，文件管理方

ISSN 1000-0054 清华大学学报（自然科学版）2009年 第 49卷 第 12期 w2
CN 11-2223/N J Tsinghua Univ (Sci & Tech), 2009, Vol. 49, No. 12 http://qhxbw.chinajournal.net.cn

施工企业信息资源再利用的概念框架

马智亮， 陆 宁

(清华大学 土木工程系，北京 100084)

摘 要：“施工企业信息资源”是施工企业已有信息系统所积累的信息中有再利用价值的部分。为促进施工企业信息资源的有效利用，从而提高现有施工企业的管理水平，提出了施工企业信息资源利用的概念框架，综述了已开展的相关研究及亟待解决的问题，归纳出施工企业信息资源利用的研究方向，包括：信息资源的自动提取、信息资源的标准化、信息资源的高效管理、以及信息资源的易于挖掘。该研究对促进施工企业信息资源利用具有参考价值。

关键词：施工企业；信息资源；信息标准；信息管理；信息挖掘

决策支持系统；6.8%拥有企业资源规划系统；6.8%拥有大型数据库系统。这些信息系统在提高管理人员工作效率和质量的同时，也在不断地为施工企业积累大量信息。这些信息涉及人员、机械、材料等对象，覆盖进度、成本、质量、技术等方面；其中有再利用价值的部分，可称为“施工企业信息资源”(以下简称信息资源)。可以预见，充分利用信息资源可为施工企业管理决策提供依据，从而提高现有施工企业的管理水平[2]。

5. Conclusions

This keynote presents

the state-of-the-art and

the tendency

of intelligent construction in China

Hope that it is helpful to you.

Thank you
for your attention