THE UNIVERSITY OF HONG KONG 香港大學
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iLab @ HKURBANlab
the urban big data lab

第六届全国BIM学术会议——青年论坛
“后疫情时代的建筑业数字变革”

后疫情时代的建筑区块链：原理、案例和新机遇

Blockchain for Construction in the Post-COVID-19 Era

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7 November 2020, Taiyuan, China

Outline

iLab

1 原理 Principles

2 案例 Cases

3 机遇 Opportunities

0.1 港大 iLab 实验室

- HKU iLab **城市大数据实验室**: The urban big data hub
  - Director: Prof. Wilson Lu 主任：吕伟生教授
  - Urban big data hub at Faculty of Architecture, HKU 港大建筑学院
  - multi-dimensional and multi-disciplinary *urban big data* collection, storage, analysis, and presentation to inform decision-making in urban development
  - Focusing on information technology (IT)
    - *Building Information Modeling* (BIM)
    - *Geographical Information System* (GIS)
    - *Global Navigation Satellite System* (GNSS)
    - *Urban Remote Sensing* (URS)
    - *Internet of Things* (IoT)
    - Blockchain (BC/DLT)

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iLabHKU

fac.arch.hku.hk/iLab

2020 New Year dinner

Xue, F. (2020). Blockchain for Construction in the Post-COVID-19 Era. The 6th China BIM Conference - Youth Forum, 11 November 2020, Taiyuan, China

0.2 About myself 自我介绍

- A mixed background **背景**
  - BEng in Automation, CAUC
  - MSc in Computer Science, CAUC
  - PhD in System Engineering, HKPU
  - PDF/RAP/AP in Construction IT
- Research interests **方向**
  - Automation/IT in construction 智慧建造
  - Urban sensing and computing 城市计算
  - Applied operations research, ML, etc. 优化算法
- Professional **专业协会**
  - MACM, SMCGS, MIEEE, MHKGISA
  - Sec. ACM-HK, CM. CGS-BIM (appl.)

2004

2007

2012

- Engineering **工程**
  - ISE, CEM, EIE
- Computer Science **计算机**
  - AI, OR, ML, SE, DBA
- Economics **经济**
  - SCM

Homepage for new updates (free full-texts)

0.2 My research projects 主持项目（约500万港币）

On-going 在研

- PI: HK RGC GRF/ECS (17201717, 17200218, 27200520), HKU (102009917, 201910159238)
- Co-PI: ITF (ITP/029/20LP), Key R&D Guangdong (2019B010151001), HKU PTF (102009741)
- Co-I: NSFC General (71671156), NSSFC Key (17ZDA062), HK SPPR (S2018.A8.010.18S), HK ECF (111/2019)

Completed 完成

- PI: HKU (201702159013, 201711159016, 201811159177), HKU-Tsinghua SPF (20300083),
- Co-I: NSFC General (60472123), HK PPR (2018.A8.078.18D)

Job vacancy (1 PhD + 10 RAs openings) 职位空缺

- RA/PhD (Web BIM, LoWaWAN/Nb-IoT hardware, Blockchain, software engineering), transferable to PhD (vision, rigor, & performance)
- HK$200,000~400,000/year

Keywords 关键词

- BIM/ CIM/ DTB/ DTC
  - **数字孪生城市**
- 3D point cloud **三维点云**
- Derivative-free optimization (DFO)
- Construction blockchain

Sponsors of projects as PI/Co-PI

Section 1

原理
PRINCIPLES

1 What is a blockchain? 定义、三要件

- Blockchain **区块链**
  - Linked-list-like incremental Block data storage systems
    - Saved distributed, identically on each "node"
    - Verified by "miners" for rejecting Bad
    - Each "solved" Block becomes immutable
  - Less related to Bitcoin **比特币**, Ethereum **以太坊**, DApp
  - Maturity level
    - Blockchain 1.0; 2.0; 3.0; 4.0 (?) ... **新瓶旧酒？鸡尾酒？**
- Three old components "wine" in any blockchain "bottle"

Sects. 1.1, 2.1 ▣ Distributed storage (1970s) 分布式存储

Sect. 1.2 ▣ Consensus mechanisms (1990s) 共识

Sects. 2.2, 2.3 ▣ Cryptographic tools (1990s) / smart contract (1990s) 加密/合约

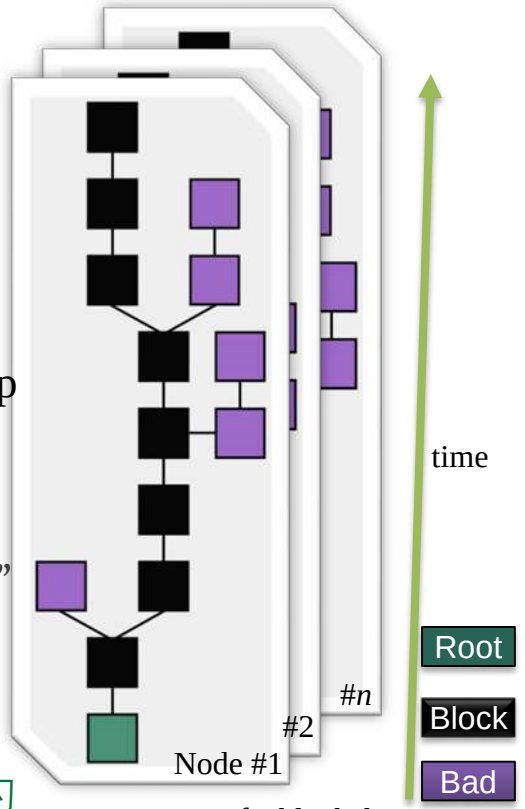
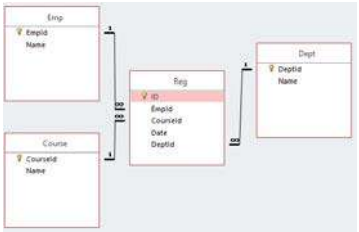


Diagram of a blockchain (miners hidden)

1.1 Distributed storage (1970s) 【1】分布式存储

- In database management system (DBMS) domain, the 1970s contributed
  - New hardware
    - Hard disk computer **机械硬盘**
    - Solid State Disk (SSD) 1970 **固态硬盘**
  - New software
    - Relational DBMS
    - E.g., SQL/DS, SEQUEL, DB2
    - Distributed data storage **分布式存储理论**
      - Rosenkrantz et al. (1978)
      - Hevner and Yao (1979)
  - New data system:
    - Data warehouse

IBM System/38 (1978), specified database computer (Source: Wikipedia.org, Author: CarstenSchulz)



Relational data tables (Source: Author)

1.2 PoW consensus 【2】工作量证明共识

- Invented against Email spam (junk email)
  - Appeared in early 1990s
  - 90+% world emails were spam by 2014
  - Reason 1: Spamming cost ~ 0;
  - Reason 2: Assuming-people-are-good Email protocols
- Dwork & Naor (1992): 'Proof of computational efforts'

计算量证明

  - "If I don't know you and you want to send me a message, then you must prove that you spent, say, ten seconds of CPU time, just for me and just for this message." (Dwork et al. 2003)
- Jakobsson & Juels (1999): 'Proof of work'

工作量证明

  - Where a prover demonstrates to a verifier that he has expended a certain level of computational effort in a specific time interval

1.2 PoW consensus: On hard-to-solve, easy-to-check math problems ——NPC问题

- Sudoku puzzle 数独
  - Each column, each row, and each of the nine 3×3 grids
    - All nine digits (1-9)
  - Hard to solve, easy to check
  - Nondeterministic Polynomial time-Complete (NPC) when $n > 3$
- And Max clique, Boolean satisfiability, Subset sum, ...
  - NPC （数学/计算复杂度领域：NP完全问题）
- And, e.g., hashcash PoW (Back 1997; 2002) 早期的“工作量证明”文献
  - PUBLIC: $H()$, k
    - *k: difficulty*
  - MINT: solving = $O(2^k)$ complexity
  - VALUE: checking = $O(k)$ complexity

5	3			7				
6			1	9	5			
	9	8					6	
8				6				3
4			8		3			1
7				2				6
	6					2	8	
			4	1	9			5
				8			7	9

PUBLIC: hash function $\mathcal{H}(\cdot)$ with output size k bits

$\mathcal{T} \leftarrow \text{MINT}(s, w)$: **find** $x \in_R \{0,1\}^\star$ **st** $\mathcal{H}(s\|x) \overset{\text{left}}{=}_w 0^k$; **return** (s, x)

$\mathcal{V} \leftarrow \text{VALUE}(\mathcal{T})$: $\mathcal{H}(s\|x) \overset{\text{left}}{=}_v 0^k$; **return** v

1.2 PoW consensus: How it works

- Proof of work (PoW) 工作量证明
  - A class of consensus
  - Sender / prover / miner side
    - Hard to solve (e.g., Soduko, hashing, ...)
  - Server / verifier / node side
    - Easy to check

- Examples 例子（红框的例子，可在中标麒麟Linux上测试）

1. Hashcash PoW (Back 1997; 2002)
   - X-Hashcash: 1:52:380119:calvin@comics.net:::9B760005E92F0DAE
   - $ echo -n 1:52:380119:calvin@comics.net:::9B760005E92F0DAE | openssl sha1

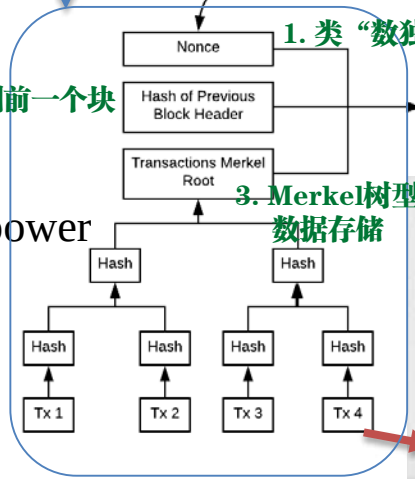
     $ **0000000000000**756af69e2ffbdb930261873cd71 (✓ correct; 13 hex (52 binary) 0s in <1us)
2. Email attaches a key to the Sudoku's initialized by sender + content + Email time

1.3 Nakamoto (2008)'s Bitcoin 【3】BTC数据加密

- Bitcoin = BC 1.0 app **比特币=区块链1.0应用**
- Immutable **不可篡改**
  - 1 block = many transactions
  - 1 trans = 1 sender + 1 receiver + amount
- Anonymous **匿名**
  - Hash "wallets"
- Secure (and expensive) **可靠（浪费）**
  - ~ 125EH/s (1.2 $\times 10^{20}$ H/s) computational power
  - ~100TWh/year
    - 2 × Google, 4 × Ireland, or US$10B bill
- Decentralized (pseudo?) **（伪）分布式**
  - But, > 65% in China, > 35% in Xinjiang (Gogo 2020)

Number	Hash	Time	Transactions	Total BTC	Size (kB)
356987	141a6f95b2...	2015-05-18 13:28:14	1714	17353.00313324	749.227
356986	13cff723ec...	2015-05-18 13:11:53	2114	23805.24520712	749.204
356985	1128aa2601...	2015-05-18 12:27:49	594	6119.90095486	392.306
356984	140b0f27b9...	2015-05-18 12:20:14	1087	7849.33374079	544.102
356983	d1ea5bc1c7...	2015-05-18 12:08:01	830	7799.27270534	455.006
356982	76634b52be...	2015-05-18 11:58:42	221	1706.08443753	152.745

Proof of Work **区块（平均10分钟一个，难度*d*调节）**



1. 类"数独"的解

2. 链接到前一个块

3. Merkel树型数据存储

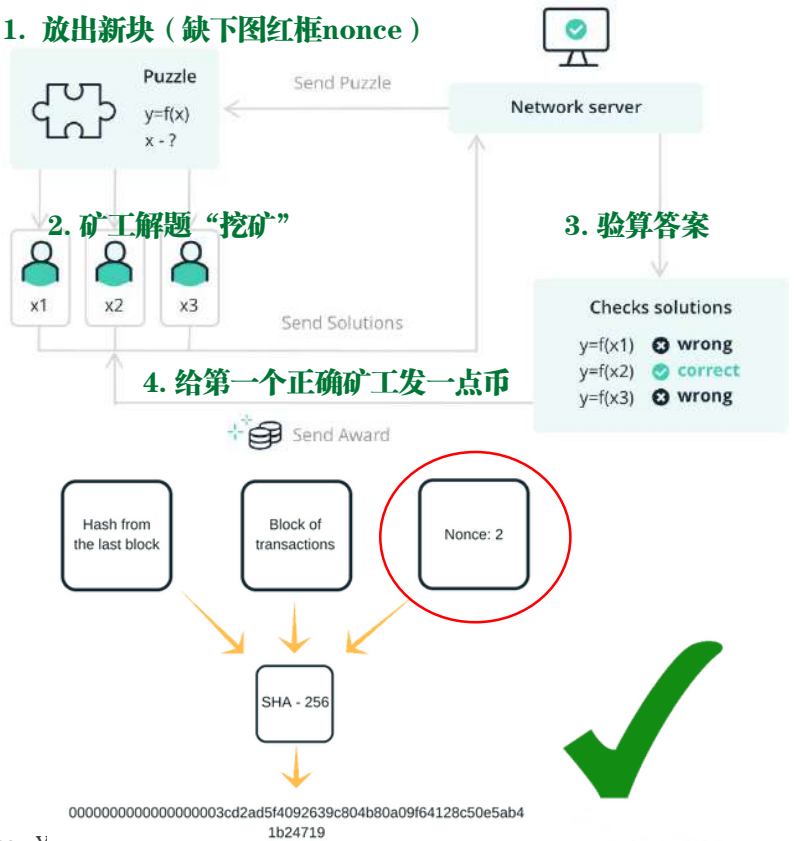
LATEST TRANSACTIONS

汇款人	收款人	BTC
1isA21Xgj7Uw	1l62Tqm53p5	0.011
1BOB13hEMr4...	1ANNA8c1x37...	3.000 BTC
1r6q8G84Kt51...	1b93lJfV2aQ2...	12.345 BTC
1s62Tqm53p9...	1p12qo29w83...	0.639 BTC
1bF90Se24Tiu...	1k430f2jGG5s...	0.730 BTC
1eb4He3kL2o1...	1pASdmG34G...	0.067 BTC
17aS3nef3l7er...	1S4nf7a947lh...	15.230 BTC

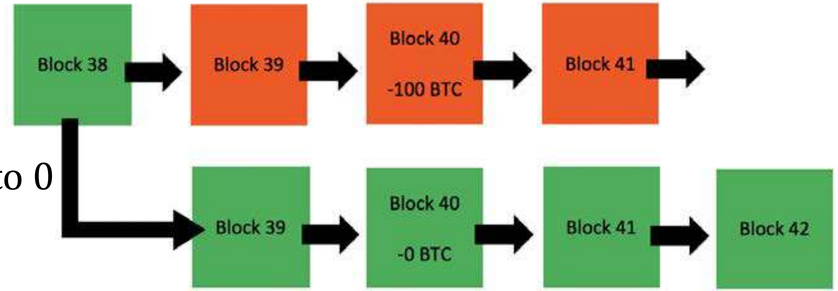
4.（全世界所有）比特币支付记录

1.3 Bitcoin's consensus: 为啥“挖矿”能挣“钱”？

- A “miner” is a prover **矿工：证明账单纪录**
  - Solves the hashcash PoW
    - Data content = trans + hash pointer
    - Return ‘nonce’ to server
  - Receives reward as BTC
- Server / node validator **服务器/客户验证**
  - Collects and packs transactions
  - Opens a puzzle for millions of machines
    - Flexible difficulty: every 10 mins per block
  - Awards the winner with 6.25 BTC (now)
- The ledger (> 200 GB now) **总账单**
  - Live on millions of devices (Space redundant)



1.3 PoW's cons: 51% attack and more 并非100%安全



- **A malicious miner 恶意矿工**
  - Tries to modify transactions
    - E.g., change his/her -100 BTC to 0
    - (by US$1M goods for free)
  - Can succeed if > 50% computing power
- **Other cons 其他问题**
  - Competitiveness between miners
    - Root cause of 51% attack
    - Too much energy cost
  - 21 million hard cap BTC
  - Easy coins before 2010
    - 97% bitcoins were held by 4% of addresses
    - Regardless of those unregistered

PoW 51% Attack Cost

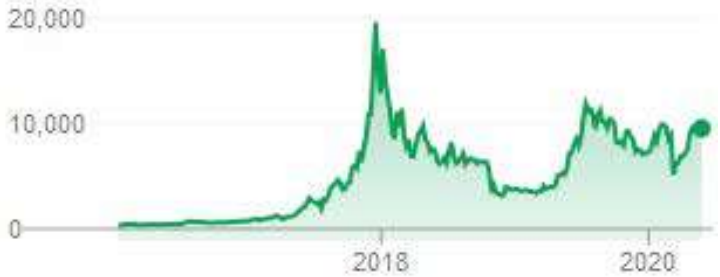
Name	Symbol	Market Cap	Algorithm	Hash Rate	1h Attack Cost	NiceHash
Bitcoin	BTC	$123.38 B	SHA-256	33,511 PH/s	$582,622	2%
Ethereum	ETH	$52.58 B	Ethash	216 TH/s	$364,099	3%
Bitcoin Cash	BCH	$15.79 B	SHA-256	4,013 PH/s	$69,773	13%
Litecoin	LTC	$6.47 B	Scrypt	309 TH/s	$65,298	7%
Monero	XMR	$2.51 B	CryptoNightV7	370 MH/s	$20,048	14%
Dash	DASH	$2.39 B	X11	2 PH/s	$17,106	27%
Ethereum Classic	ETC	$1.50 B	Ethash	6 TH/s	$10,344	89%
Bytecoin	BCN	$986.84 M	CryptoNight	164 MH/s	$637	219%
Zcash	ZEC	$933.60 M	Equihash	458 MH/s	$50,028	24%

1.4 Blockchain take-away 小结

- **Blockchain** = a (distributed, encrypted, trustworthy) **database** **区块链 = 数据库**
- Some characteristics meet smart construction requirements
  - Immutability
  - Distributedness
  - Transparency
  - Security

要点： (1) **区块链不是“加密币”** (2) **“加密币”不是货币**

- Blockchain is not equal to “crypto-currency” (not currency)
  - Good medium of exchange ✓ 便于交易
  - Poor store of value × 价值储蓄
    - See the right picture
  - Inappropriate unit of account × 信用的度量单位
    - Countless new ‘coins’ (> 5,000 now)



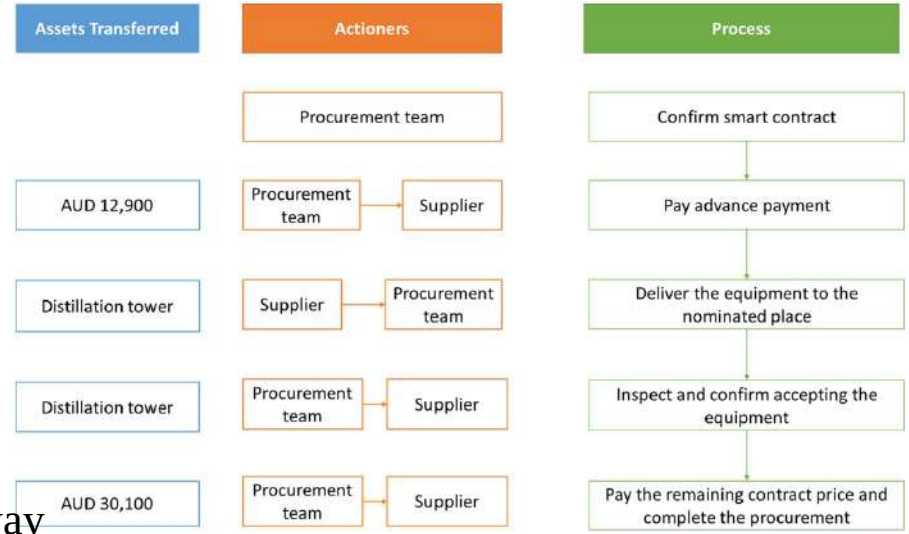
Bitcoin price

Section 2

案例
CASES

3.1 Case 1 案例1: Procurement 采购 (Yang et al. 2020)

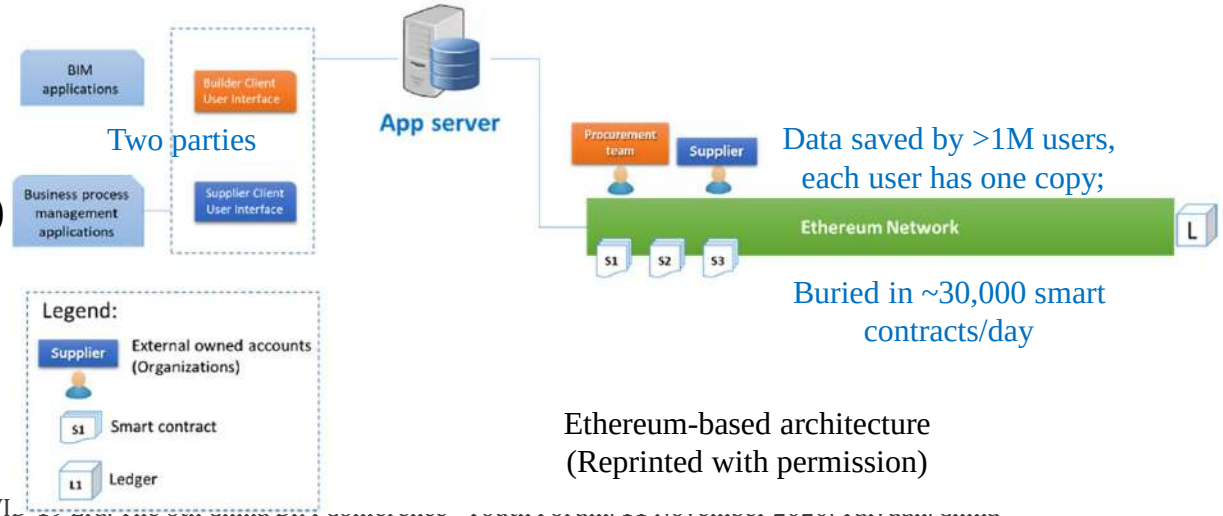
- Construction procurement **采购**
  - Multiple parties, distributed
  - Having possible trust/compliance problems
  - Involving payment, quality assurance
- Yang et al.'s (2020) example
  - Purchasing a distillation tower 买蒸馏塔
  - In five steps 五个步骤
- Objective **目的**
  - Blockchaining the procurement
    - E.g., "pay AU$ 30,100"
  - On Ethereum (Blockchain 2.0) as a 1.0 way



Processing of purchasing construction equipment
(Reprinted with permission)

3.1【1】Data storage 存储: From 2 to >1 million

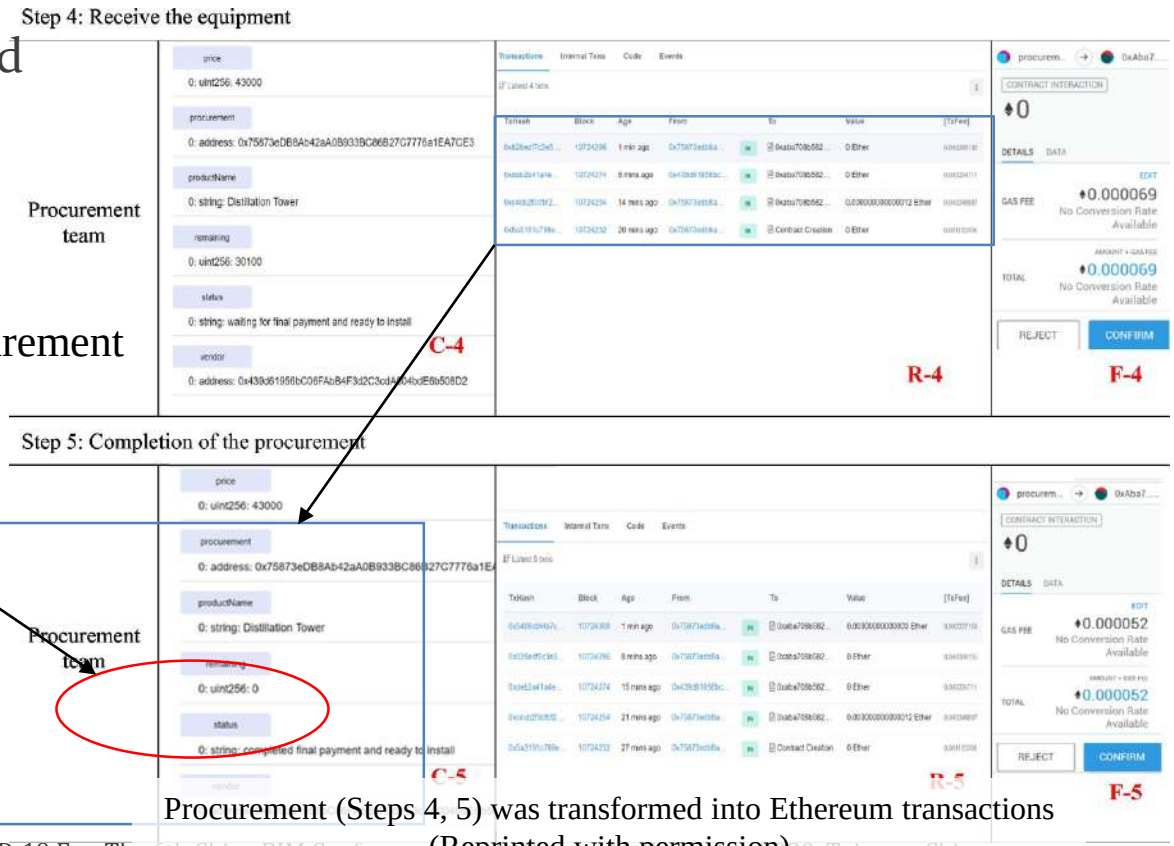
- Model mapping as a smart contact **流程建模**
  - Modeled in “App server”
  - A “World state” computer in a Ethereum “virtual machine”
- Data in the application layer (top left) **数据**
  - Two parties
  - 6 world states, 5 steps
- On chain **链上**
  - > 1M user (data copies)
  - ~ 30,000 similar smart contracts per day



Ethereum-based architecture
(Reprinted with permission)

3.1 ETH transactions 以太坊的交易建模

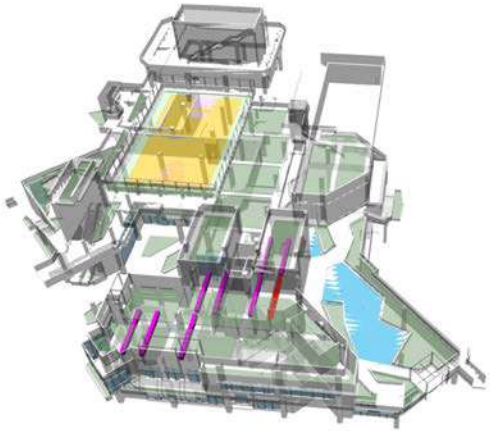
- Each step is transformed
  - To a ETH transactions
- ETH's Transaction fee
  - ~HK$0.1 / step
  - ~HK$0.5 for each procurement
- Note:
  - Payment was offline



Procurement (Steps 4, 5) was transformed into Ethereum transactions (Reprinted with permission)

3.2 Case 2 案例2 : Supply Chain 供应链 (Lu et al. 2020)

- Cross-border construction supply chain **大湾区建筑业供应链**
- Trackability and traceability **可追踪性、可追查性**
  - IoT 物联网
  - GPS/北斗等定位信号
- Problems **问题**
  - Unstable communication
  - Possible false signals
- Lu et al.'s (2020) blockchain solution
  - smart construction objects (SCOs) enabled blockchain oracles (SCOs-BOs)
  - Smart contracts 四类智能合约
    - Service, aggregator, oracle, and reputation

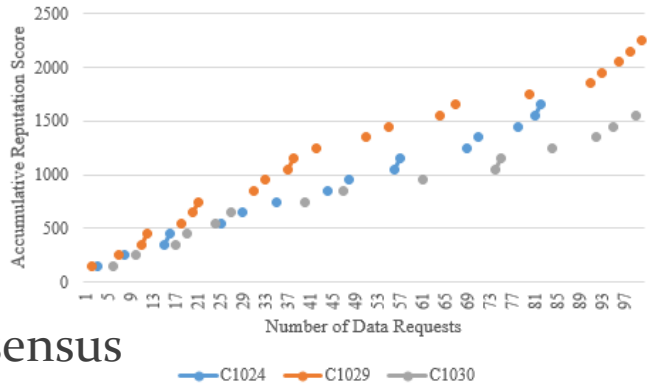


(物联网驱动的全自动区块链)

Source: (Lu et al. 2020)

3.2 Smart contracts 智能合约组合（主链+分链）

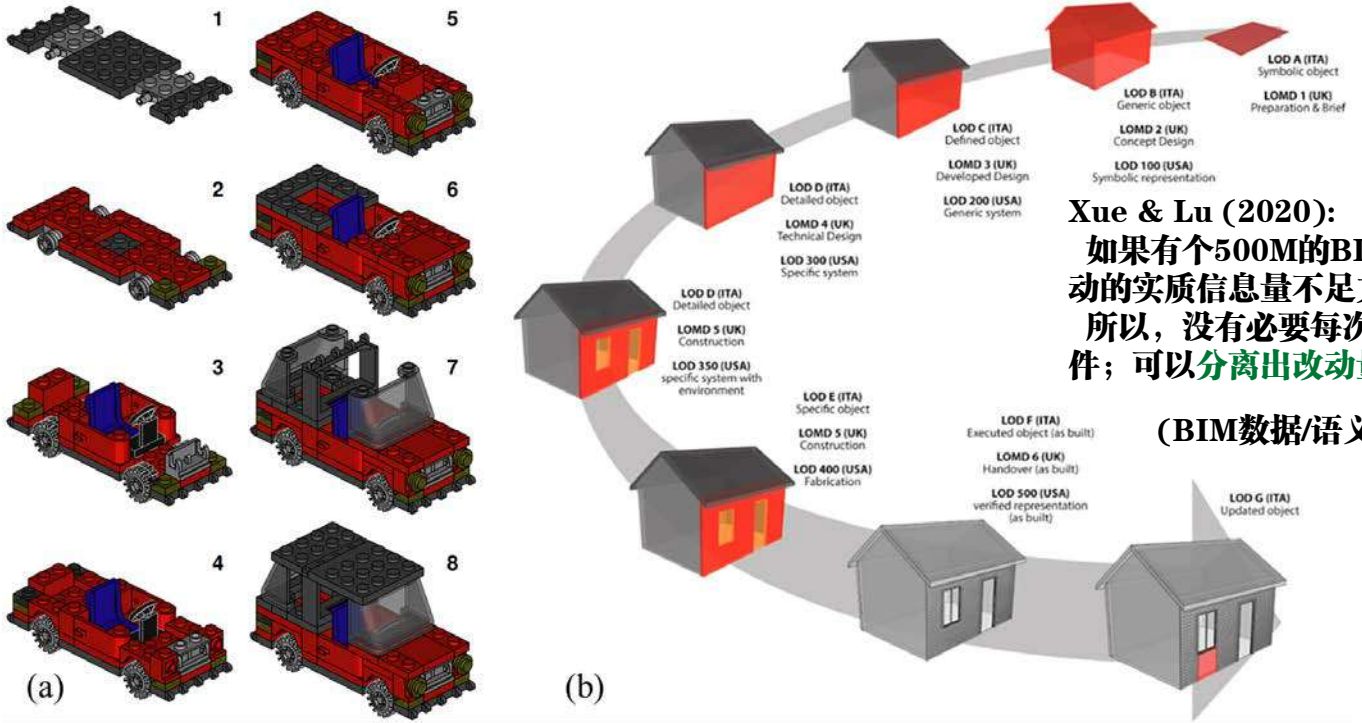
- Two on main chain **主链有2个智能合约**
  - Service 服务
    - Data inquiry
  - Aggregator 共识整合
    - >51% SCOs for consensus
- Two on side chains **分链有2个智能合约**
  - Oracle 沟通者
    - Unbiased randomization **无偏随机化**
  - Reputation 声望
    - Accumulated reputation over time **时序声望积累**
- Results: Two-chain secure of IoT locations consensus
- Note: (Lu et al. 2020) is under review, citable



Source: (Lu et al. 2020)

3.3 Case 3 案例3: BIM changes BIM变更 (Xue & Lu, 2020)

- Rome wasn't built in a day; so wasn't BIM. "BIM不是一天画成的"



(a) Incremental in geometry, (b) in geometric + non-geometric semantics (Ellis 2019)

Xue & Lu (2020):
如果有个500M的BIM，每分钟的改动的实质信息量不足文件的0.01%。
所以，没有必要每次交换整个BIM文件；可以分离出改动量用区块链同步。

(BIM数据/语义复用问题)

3.3 Semantic differential transaction 语义差分记录

- IFC (Industry Foundation Classes)
  - The best open BIM standard
  - STEP (Standard for the Exchange of Product Data) format
  - Clear, [hardly] readable
  - But massive, involving many random global IDs
- Our in-house program for the SDTs. **语义差分记录**

主要任务1: 清除随机ID 干扰
主要任务2：计算最小变化量

procedure compute_SDT
input: ifc_0, ifc_1 // IFC changed between t_0 and t_1

1 $\sigma_0 \leftarrow$ semantic_interoperability (ifc_0); // To call "semantic interoperability"
2 $\sigma_1 \leftarrow$ semantic_interoperability (ifc_1);
3 $\sigma^* \leftarrow \sigma_0 \cap \sigma_1$; // The intersection (unchanged) tree
4 $\sigma_{0c} \leftarrow \sigma_0 - \sigma^*$; // To purge the unchanged instances
5 $\sigma_{1c} \leftarrow \sigma_1 - \sigma^*$;
6 $\Delta_\sigma \leftarrow$ tree_diff (σ_{0c}, σ_{1c}); // Difference between changed objects
7 **return** Δ_σ

Example IFC

```
ISO-10303-21;
HEADER;
FILE_DESCRIPTION(('ViewDefinition [CoordinationView, …);
FILE_NAME('example.ifc','2008-08-01T21:53:56',('Architect…);
FILE_SCHEMA(('IFC2X3'));
ENDSEC;
DATA;
#1=IFCOWNERHISTORY(#84,#71,$,.ADDED.,$,$,$,1217620436);
#2=IFCAXIS2PLACEMENT3D(#11,#4,#8);
#3=IFCCARTESIANPOINT((0.0,0.0));
#4=IFCDIRECTION((0.0,0.0,1.0));
#5=IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,1.0E-5,#75,$);
#6=IFCWALLSTANDARDCASE('3yB2YO$MX4xv5uCqZZG05x',#1,'Wall …);
#7=IFCWINDOW('0LV8Pid0X3IA3fLVDPidY',#1,'Window xyz','…);
#8=IFCDIRECTION((1.0,0.0,0.0));
#9=IFCOPENINGELEMENT('2LcE70iQb51PEZynawyvuT',#1,'Opening …);
#10=IFCCARTESIANPOINT((0.75,0.0));
#11=IFCCARTESIANPOINT((0.0,0.0,0.0));
#12=IFCCARTESIANPOINT((0.0,0.3));
#13=IFCORGANIZATION($,'TNO','TNO Building Innovation',$,$);
#14=IFCPROPERTYSINGLEVALUE('AcousticRating','AcousticRating',…);
#15=IFCPROPERTYSINGLEVALUE('Reference','Reference',IFCTEXT(''),$);
#16=IFCPROPERTYSINGLEVALUE('FireRating','FireRating',IFCTEXT(''),$);
#17=IFCPROPERTYSINGLEVALUE('IsExternal','IsExternal',IFCBOOLEAN(.T.),$);
#18=IFCPROPERTYSINGLEVALUE('ThermalTransmittance',…);
#19=IFCQUANTITYLENGTH('Height','Height',$,1.4);
#20=IFCQUANTITYLENGTH('Width','Width',$,0.75);
#21=IFCLOCALPLACEMENT($,#2);
#22=IFCBUILDING('0yf_M5JZv9QQXly4dq_zvI',#1,'Sample Building',…);
#23=IFCBUILDINGSTOREY('0C87kaqBXF$xpGmTZ7zxN$',#1,…);
#24=IFCLOCALPLACEMENT(#21,#2);
…
END-ISO-10303-21;
```

Xue, F. (2020). Blockchain for Construction in the Post-COVID-19 Era. The 6th China BIM Conference, Xi'an, China. [Invited]

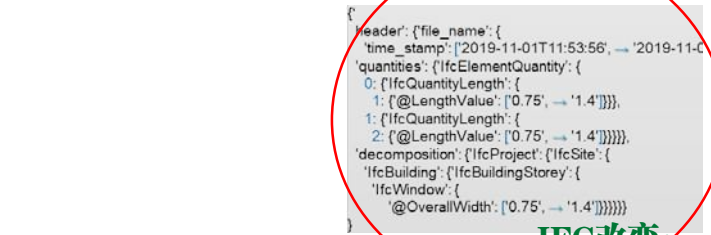
(Xue & Lu 2020)

3.3 SDT tests 举例

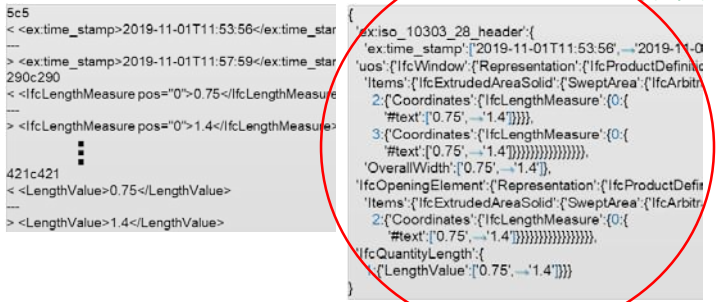
- Changing a window's size

操作：窗口变宽一点

Input	Item	Line-by-line file comparison	The proposed SDT
IFC (7.4KB each)	Size (KB)	1.00	0.36
	Time (s)	0.041	0.003
	SH?*	×	✓
	Output	6 changed lines:	4 changed properties:
IFCXML (32.9KB each)	Size (KB)	0.56	0.89
	Time (s)	0.042	0.012
	SH?*	×	✓
	Output	6 changed lines:	6 changed properties:



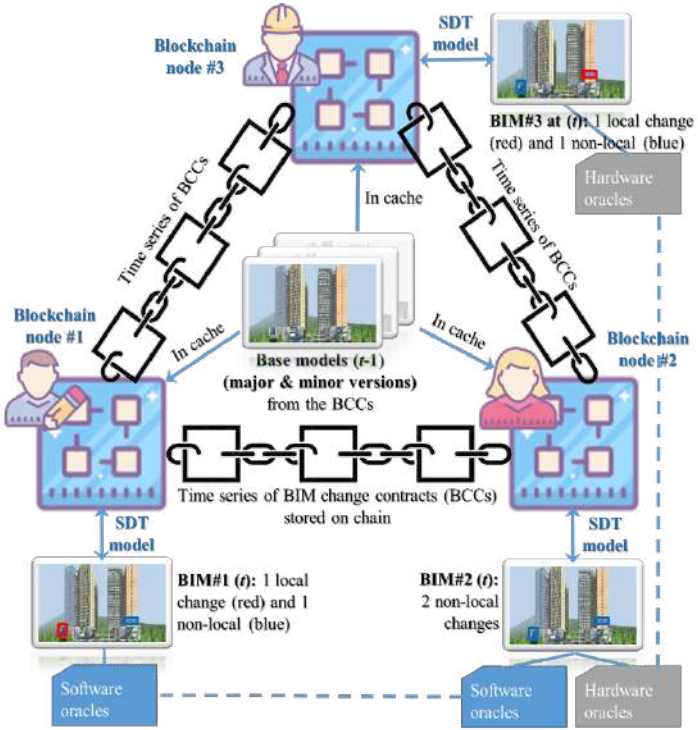
IFC改变：
1. 墙面改变
2. 空缺改变
3. 窗组件改变



*: With semantic hierarchies?

3.2 BIM change contract 变更合约

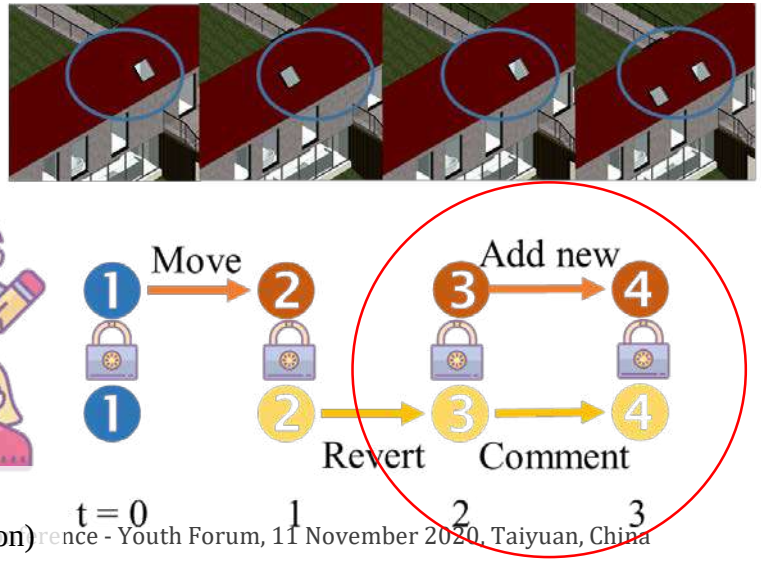
- BIM change contract (BCC)**变更合约**
  - BCC_t: All BIM changes at time t
    - $BCC_i = \bigoplus_n \sigma_i$
    - Note: $\bigoplus$ is the simplest operation for proof-of-concept
  - A BIM can be created from the model at t - 1 and changes at t
    - $ifc_t = ifc_{t-1} + BCC_t$.
  - BIM at any time can be recovered from base BIM and the chained BCCs
    - $ifc_t = ifc_0 + \Sigma_t BCC_i$.
- Data storage **数据存储**
  - Permissioned nodes (stakeholders), not public



Permissioned blockchain architecture
(Reprinted with permission)

3.3 Another test case 大一点的例子 (Xue & Lu, 2020)

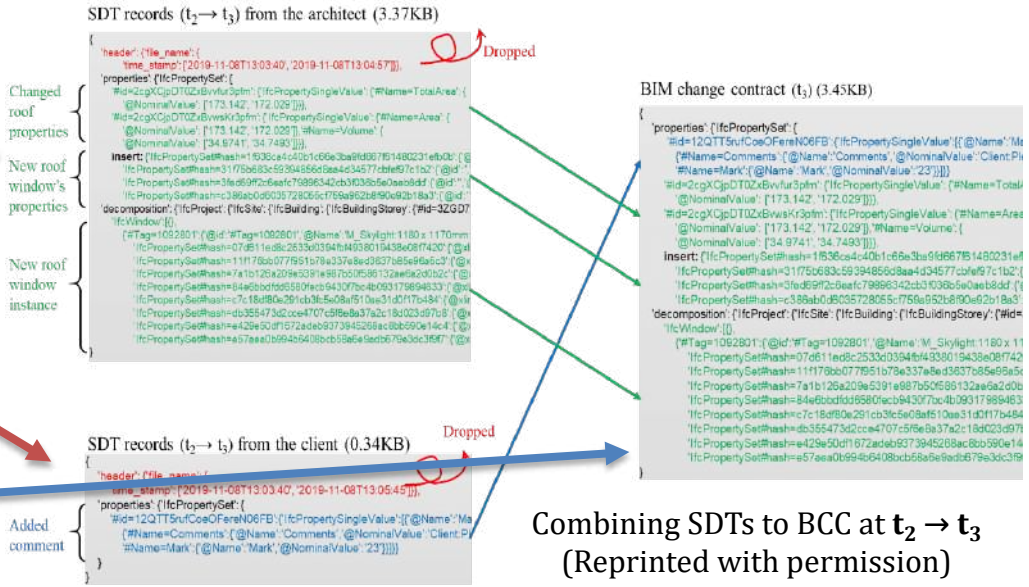
- Autodesk Revit 2018's sample BIM (a modern villa, 27.4 MB in IFC)
- Sequential / simultaneous roof window changes
  - By two BIM users, from t = 0 to 4
  - $t_2 \rightarrow t_3$: Simultaneous changes by two users



A test case
(Reprinted with permission)

3.3 SDT/BCC results 测试结果

- $t_2 \rightarrow t_3$ 前一页的红圈步骤
  - User A: Added a roof window
    - σ_A = top left block
  - User B: Added text comments to another window
    - σ_B = bottom left block
- BCC as the conflict-free merge
  - BCC = right block
- BCC is efficient (<0.02%)
  - 3.37KB out of 27.4MB IFC
  - 0.79s
  - Good for blockchaining

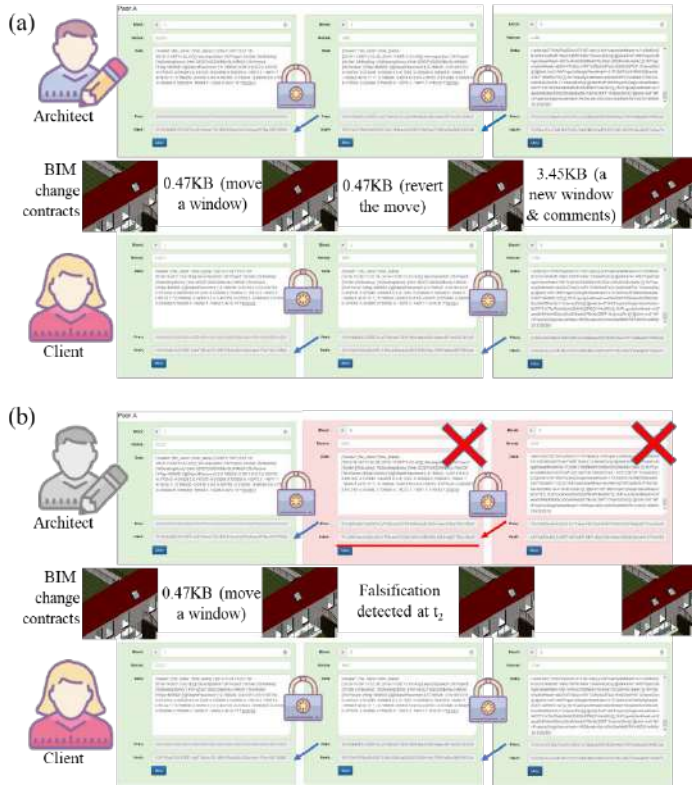


Combining SDTs to BCC at $\mathbf{t_2 \rightarrow t_3}$
(Reprinted with permission)

Input	Change	Line-by-line file comparison Size (KB) (lines)	Time (s)*	SH?#	The proposed BCC/SDT Size (KB)	Interop. time (s)*	SDT time (s)*	SH?#
IFC (27.4MB each)	$t_2 \rightarrow t_3$ (Arch.)	54,700 (533,923)	0.789	×	3.45	6.681	0.463	✓
	$t_2 \rightarrow t_3$ (Client)	53,900 (514,192)	0.756	×				

3.3 SDT/BCC application 1 应用场景1

- Fraud detection **欺诈检测**
- On a simplest blockchain
  - Web-based
  - Easy nonce
  - Visualized blocks
    - Green = verified; red = wrong / hacked
- BIM was immutable from
  - claiming false authorships,
  - destroying evidence, or
  - being hacked, etc.



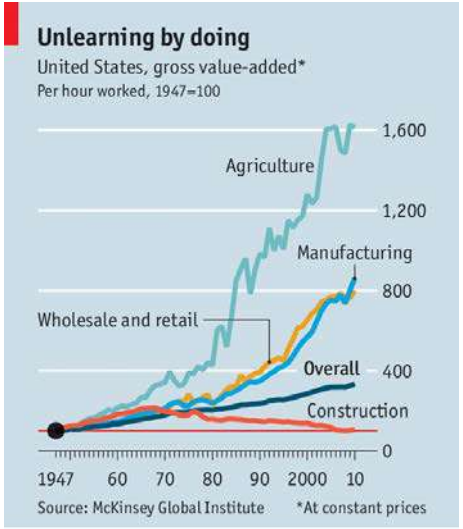
Xue, F. (2020). Blockchain for Construction in the Post-COVID-19 Era. The 6th China BIM Conference - Youth Forum, 11 November 2020, Taiyuan, China

Section 3

机遇
OPPORTUNITIES

3.1 Smart construction 智慧建造

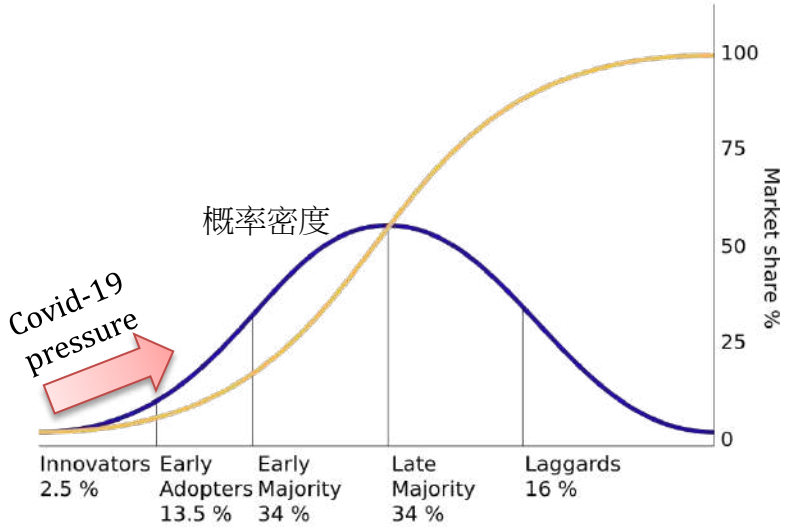
- Construction is known as a “backward industry”
  - Low productivity, labor-intensive (*v.s.* aging workers)
  - Fatality, occupational hazards, management (*e.g.*, cost overrun)
- A consensus of global research institutes (e.g., Harty et al., 2007)
  - Effective (productive, automatic, age friendly) and efficient (safer, profitable, on-time, sustainable) industry
- Construction smartization with new *Information Tech.*
  - Computing power
  - New data, e.g., RFID, LiDAR, GPS, UAV, smart phones, …
  - New technologies, e.g., BIM, GIS, CV, VR/AR, blockchain, …
  - 13部委:《关于推动智能建造与建筑工业化协同发展的指导意见》(建市〔2020〕60号)
  - 9部委:《关于加快新型建筑工业化发展的若干意见》（建标规〔2020〕8号）



USA’s gross value-added by sectors
source: economist.com

3.1 The COVID-19 outbreak 新冠冲击

- COVID-19 impacted and perhaps will change for ever
  新冠影响了，并可能永久改变
  - Construction collaboration
  - Construction procurement
  - Construction supply chain
  - BIM-based project collaboration
  - Etc.
- The silver lining **乐观方面**
  - Promoting new technologies (Agarwal et al. 2020)
    - Cloud meeting (face-to-face)
    - Remote working (office teamwork)
    - Distributed collaboration (traditional)

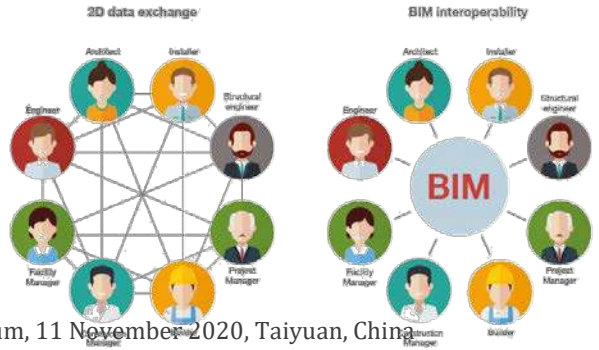


Rogers's (1962) diffusion of innovations model

Xue, F. (2020). Blockchain for Construction in the Post-COVID-19 Era. The 6th China BIM Conference - Youth Forum, 11 November 2020, Taiyuan, China

3.2 A new distributed norm ? BC=分布式新范式？

- Multi-stage construction life cycle
  - Architectural design
  - Engineering design
  - Construction
  - Operation & maintenance
  - Demolition
- Many stakeholders
  - Even more decision makers, professionals
  - Teaming → Coordination→ Collaboration 挑战
- Challenges ahead of blockchain collaboration?
  - Spatially and Temporally
  - Semi-controlled working environment



3.3 Discussion

- Existing blockchain applications for smart construction
  - Works, e.g., blockchaining SCM and BIM changes
  - but preliminary and infantile
- The characteristics of blockchain are appropriate for construction
  - Immutability, transparency, security (e.g., no data loss)
- Challenges ahead
  - Culture, regulation, governance
  - Cost and efficiency (e.g., not widely used to fight spams)
  - Security (e.g., business secrets, privacy) **透明度问题**
    - Channel **加密数据频道**
  - Understanding and acceptance

3.4 Recruitment for a new project

- [World first] “BIM Square”: Blockchain and i-Core-enabled Multi-stakeholder Building Information Modelling Platform for Construction Logistics and Supply Chain Management in Hong Kong. HKITC ITF ($10.36 million)
- **基于区块链、建筑信息模型及物联网的面向香港建造业多持份者的物流及供应链管理平台研发（暂译）【1036万港币，全球第一个同类科研】**
  - 1 RA/PhD: LoRaWAN / Nb-IoT 硬件、通讯、Oracle分链共识和协议
  - 3 RA/PhD: 3D模块装配式建筑：1物流、2品控、3工地DT调度
  - 1 RA/PhD: 面向建筑行业的区块链(3.0, 4.0)理论、架构、实现
  - 1 RA/PhD: 联邦主链云服务、Web BIM、手机App、插件等
  - 1 RA/PhD: IFC语义研究、Open BIM理论和算法
  - 欢迎传播，意向请联系：李骁博士 < 电邮 xli1991@hku.hk >

恰饭时间

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If you want to go fast, go alone.
If you want to go far, go together.
— *African proverb* 非洲谚语

感谢！欢迎提问

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