THE UNIVERSITY OF HONG KONG 香港大學
faculty of architecture 建築學院

iLab @HKURBANlab the urban big data lab

Urban Semantics in BIM & GIS

From source to sea

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Outline

1 ***'Source'*: Semantics focused in BIM & GIS**

2 **One *'stream'*: Semantic registration**

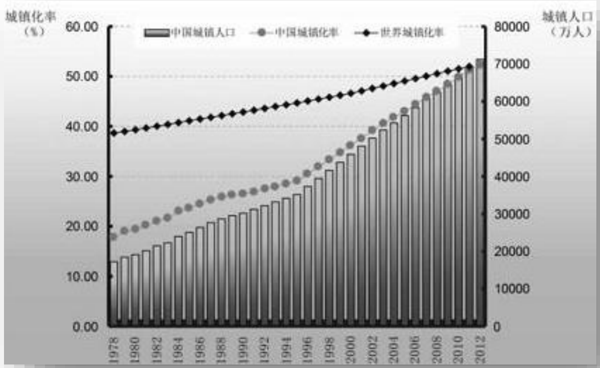
3 ***'Sea'*: For smarter prospects**

Section 1

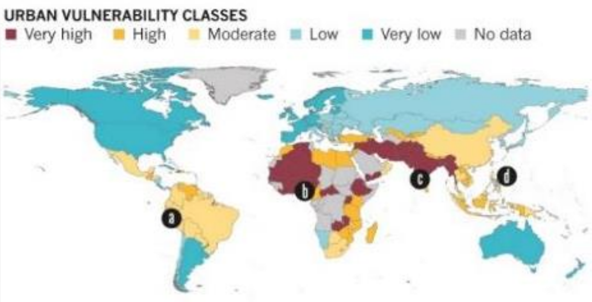
‘SOURCE’
SEMANTICS FOCUSED IN BIM & GIS

1.1 Background

- Global urbanization
  - By 2050, 65% world's population will live in cities (WHO, 2015)
  - Irreversible; Even faster in China
- Leads to urban vulnerability (a.k.a. 'urban diseases')
  - 'Dead' space/landscape, low familiarity with surroundings,
  - Poor waste treatment, environment (air, water) pollution,
  - Heritage destruction, aging town blocks, inefficient traffic,
  - Disasters (earthquake, climate change), resource crisis, …
- Demands smarter and more resilient development
  - (a) Smarter decision supports in multiple disciplines
  - (b) On basis of accurate, timely urban semantics



China's and global urbanization rates
source: gov.cn



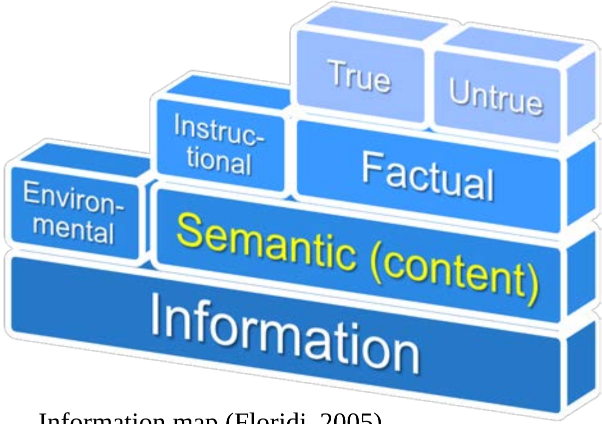
Global urban vulnerability level (Birkmann et al, 2016) *source: nature.com*

1.1 Urban semantics

- Information is the meaning of data (Rowley & Hartley, 2017)
  - *Abstracted*, inferred from data
  - Answering interrogative questions (*what*, *who*, *where*, *when*)
  - Semantics is a subset of information (Floridi, 2005)
- Urban semantics
  - Geometric / Non-geometric facts:
    - Size, location / function, materials, history, etc.
  - Instructions (how-to):
    - Manufacturing, installation, access
- Urban semantics databases
  - BIM & GIS

Data: Digital pixels (0~255 R, G, B)

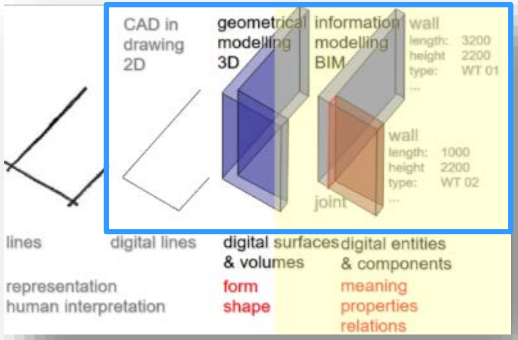
Information: Car, building, tree, …



Information map (Floridi, 2005)

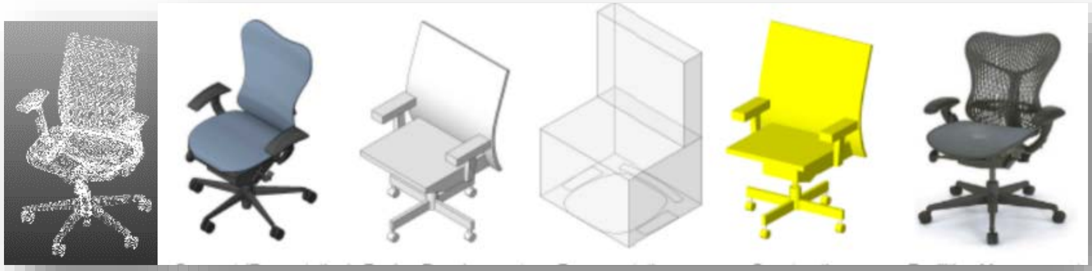
1.2 BIM

- BIM (building information model/modeling)
  - “M” “I”
  - *A <u>digital representation</u> of physical & functional <u>characteristics</u> of a <u>facility</u>.* (NIBS, 2015)
  - “B”
  - *A <u>shared</u> … resource for information about a facility, forming a reliable basis <u>for decisions</u> during its life cycle from inception onward.* (NIBS, 2015)
  - Evolved from CAD (computer-aided design) (Penttilä, 2007)



An evolution view of CAD/BIM (Penttilä, 2007)

- Essence
  - Urban semantics database
  - Component (unit facility) based
    - “Family” and “instance”
- A quiz: Which is *not BIM*?



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1.2 Semantics focused in BIM

iLab

- BIM LOD (Level of Development)
  - Previously "Level of Detail"
  - LOD 100：For concept presentation
  - LOD 200：For design development
  - LOD 300：For 2D documentation
    - LOD 350 construction 3D documents
  - LOD 400：For construction stage
  - LOD 500：For facilities management
- Focused semantics
  - *Temporal* development
  - Abstracted family > exact geometry

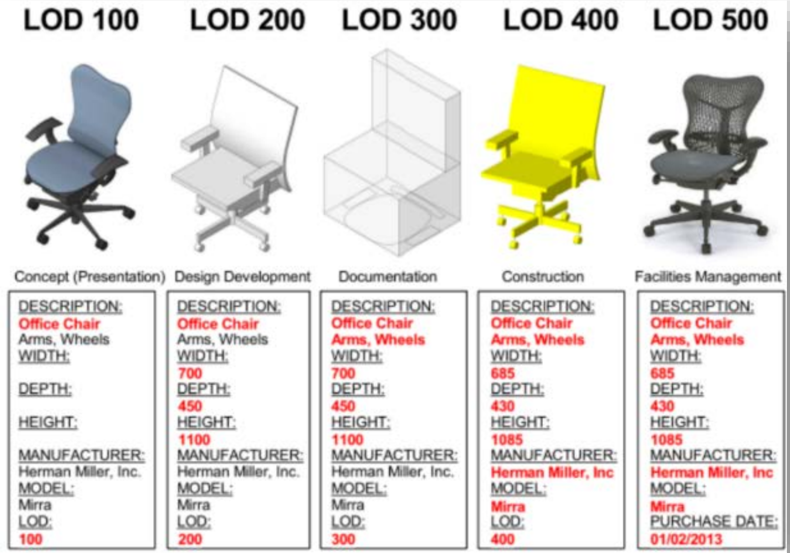
Arch.

Eng.

Const.

O&M

Demo.



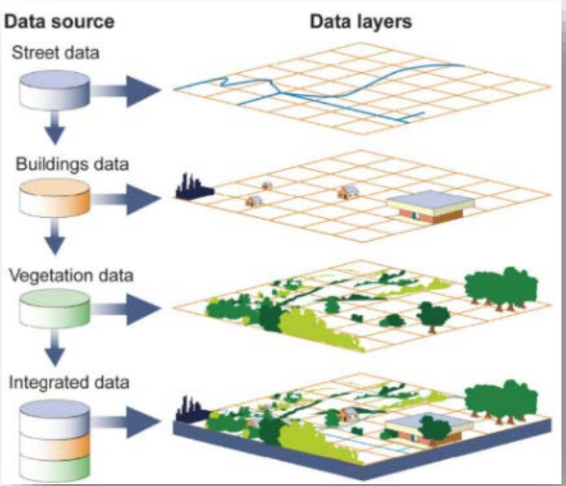
What is called LOD
Source: PracticalBIM.net

No LOD : Data only
data, needs processing to info., then to BIM

1.3 GIS

- GIS (geographic information system)
  - *A computer system for capturing, storing, checking, and displaying data related to* *__positions__* *on* *__Earth's surface__* (NGS, 2012)

    "I" "G"
  - Evolved from DBMS (database management system)
- Essence
  - Urban semantics database
  - Data tables (layers) based
    - *Independent objects (rows) in each table*
    - *A few discussion on component-based GIS, too*
- A quiz: Which is *not GIS?*



GIS interpretation

Source: US Government Accountability Office

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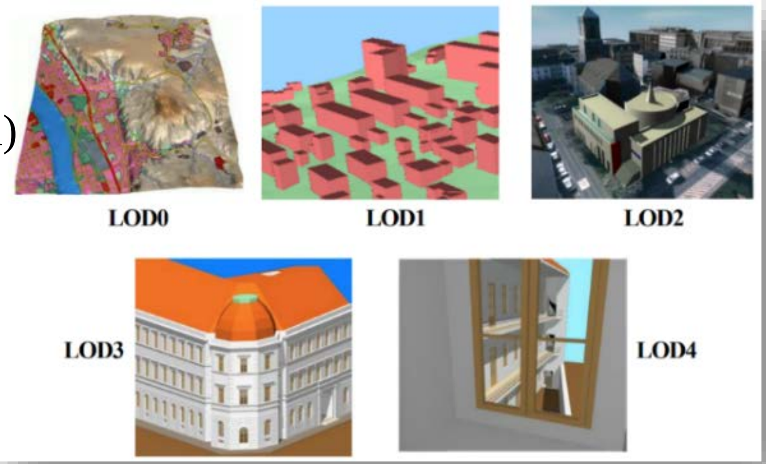
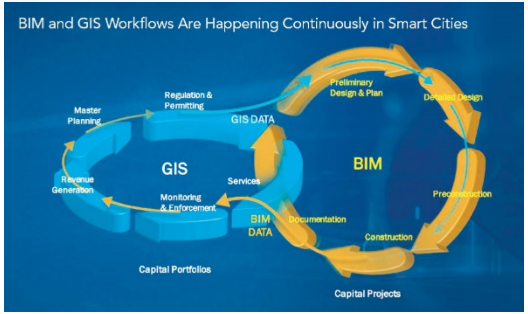
1.3 Semantics focused in GIS

- GIS LOD (Level of Detailing)
  - Defined in CityGML (by Open GIS Consortium)
  - LOD0 : Region and landscape
  - LOD1 : + Prismatic buildings model (flat roof)
  - LOD2 : + Roof and thematic surfaces
  - LOD3 : + Detailed exterior (wall and roof)
  - LOD4 : + Interior (indoor)
- Focused semantics
  - *Spatial* details
  - Exact geometry > abstracted concepts
- BIM/GIS integration
  - In both academia and industry



GIS Level of Detailing (Gröger et al., 2007)



BIM-GIS integration *Source: ESRI.com*

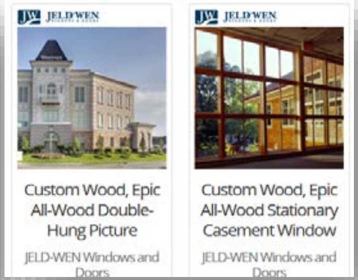
Section 2

ONE 'STREAM'
SEMANTIC REGISTRATION

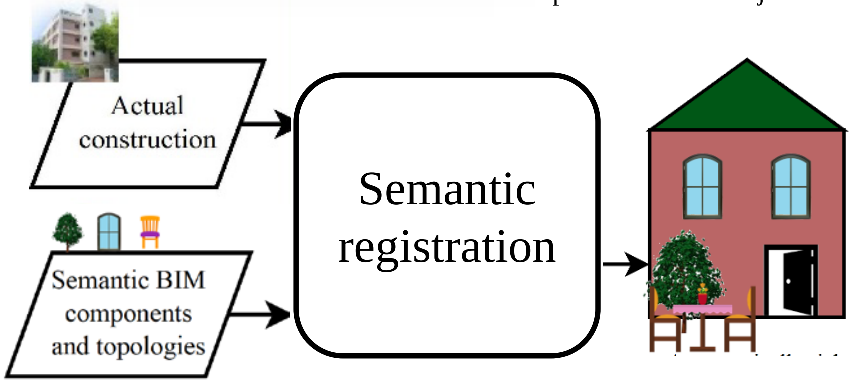
2.1 The task of semantic registration

- A dilemma of urban semantics in BIM/GIS
  - *Inadequacy*: Poor semantics in the models
  - *Overload*: Rich online open BIM/GIS resources
    - With fact-nongeometric & instructional
- Semantic registration
  - Registering semantics to low LOD models
  - Input 1: Geometric measurement
  - Input 2: Semantic components
- Performance metrics
  - Computational time
  - Precision = true positive / registered
  - Recall = true positive / actual

Google Map/Earth? ~*LOD2*



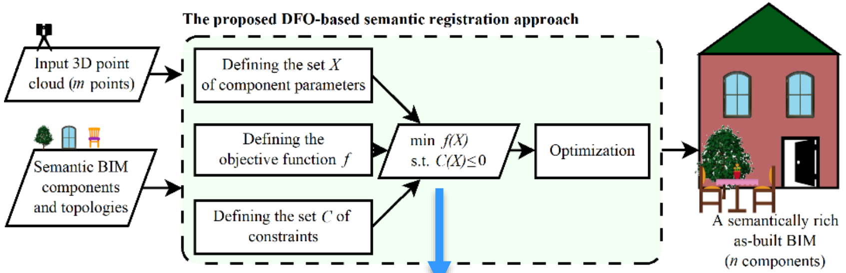
BIMobject.com has >*300,000* parametric BIM objects



Semantic registration as a process

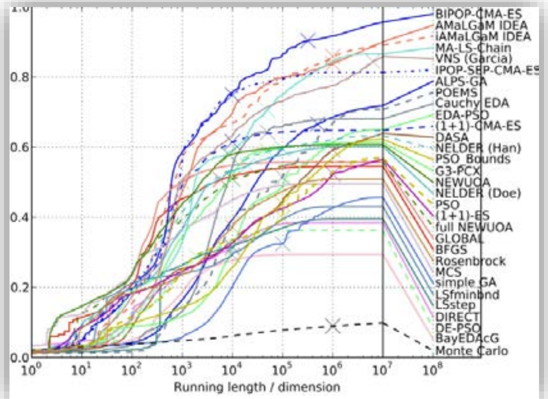
2.2 A derivative-free optimization (DFO) approach

- Semantic registration is a decision task
  - Can be automated through optimization
- Problem formulation (Xue et al., 2018a)
  - Input 1: E.g., 3D point cloud
  - *Variables* (*X*): transformation parameters
  - *Objective function* (*f*): minimum geometric error
  - *Constraints* (*C*): Topological regularity
- DFO algorithms (Conn et al., 2009)
  - Solves problems comprising too complex derivatives
  - Succeeded in many science and engineering problems
    - E.g., Protein folding (Nicosia & Stracquadanio, 2008), aircraft wing design (Lee, et al., 2008)



$$\min \; f(X) \quad \text{s.t.} \; C(X) \leq 0$$

DFO-based Semantic registration (Xue et al., 2018a; 2018b)

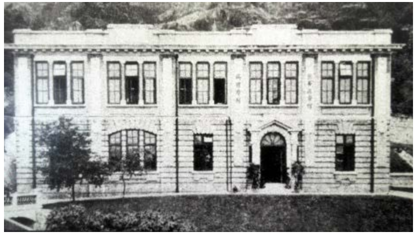


Comparison of DFO algorithms for BBOB-2009 (Auger et al., 2010) *Source: Inria*

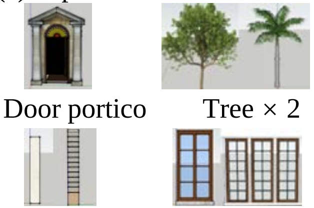
2.3.1 An outdoor case (Xue et al., 2018a)

- 2D photo + free BIM objects → LOD3/300 3D models
  - Automatic, error tolerant, recoverable from wrong objects
  - Segmentation-free, topological relationships involved

- Time: 2.5h
- Precision: 0.92
- Recall: 0.92



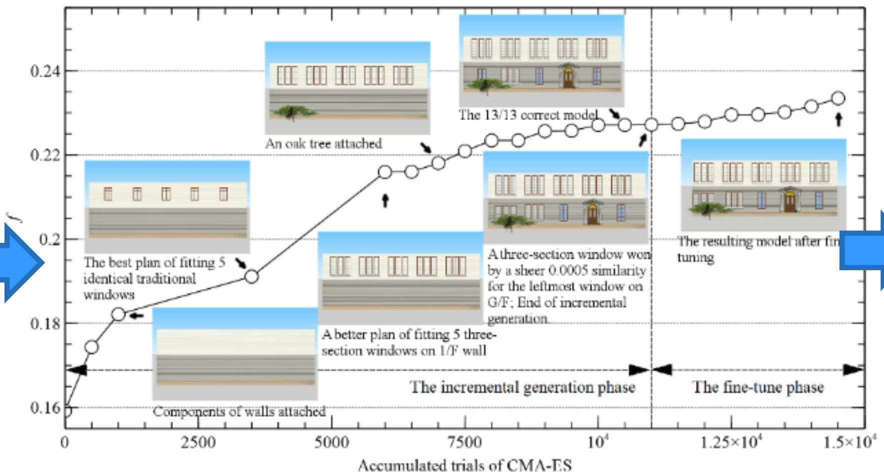
(a) A photo of a demolished building

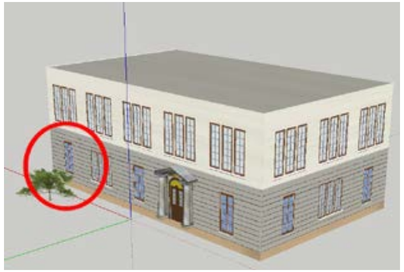


Door portico Tree × 2

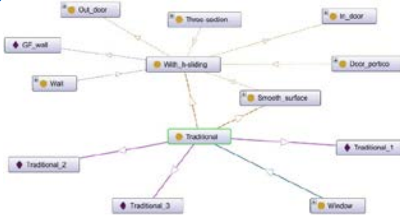
Wall × 2 Windows × 2

(b) Semantic components from web





(c) Approximate building mode



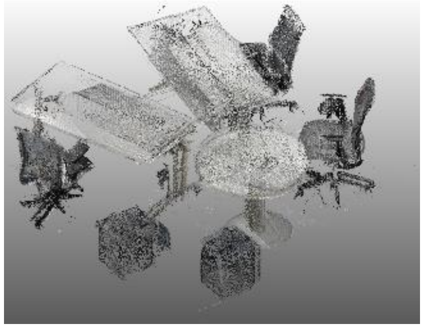
(d) Semantic/topological links

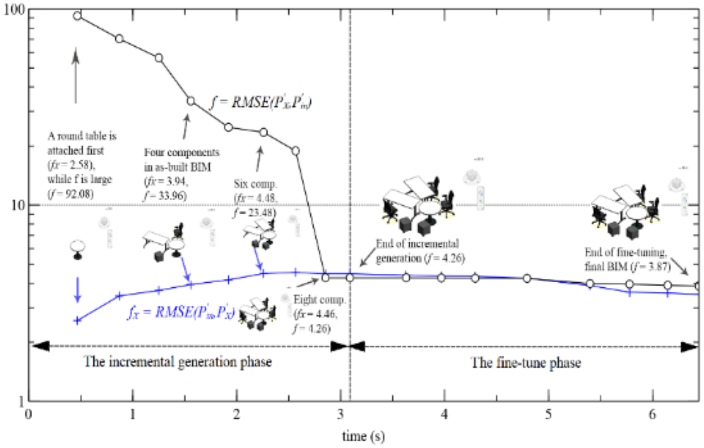
(Language: C++, Ruby; Data formats: SketchUp, Bmp, Google earth)

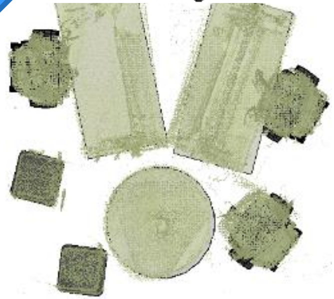
2.3.2 An indoor case (Xue et al., 2018b)

- Point cloud + BIM objects → LOD 4/500 indoor model
  - Automatic, saved 98% time from manual modeling
  - *RMSE* = 3.87cm, equal to experienced modelers

- Time: 6.44s
- Precision: 1.0
- Recall: 1.0



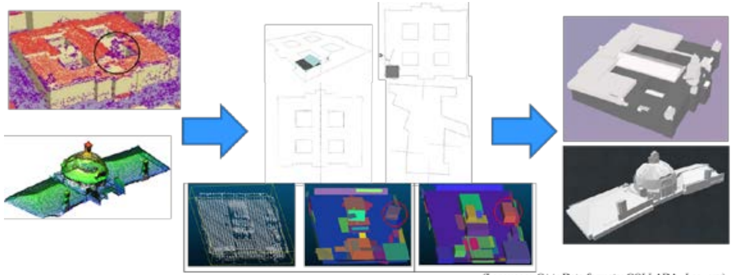




(Language: C++, CLR; Data formats: Autodesk Revit, Stanford polygon)

2.4 Other semantics ‘streams’ at iLab

- LOD1 + point cloud = LOD2 (Chen et al., 2018)



(Language: C++; Data formats: COLLADA, Las, csv)

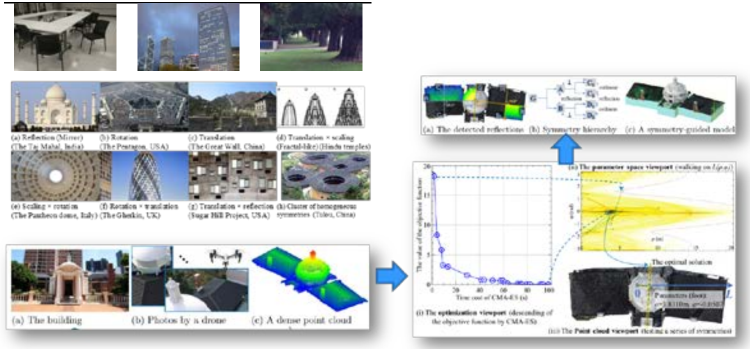
- Non-geometric semantic learning

Generated rooftop objects from point clouds

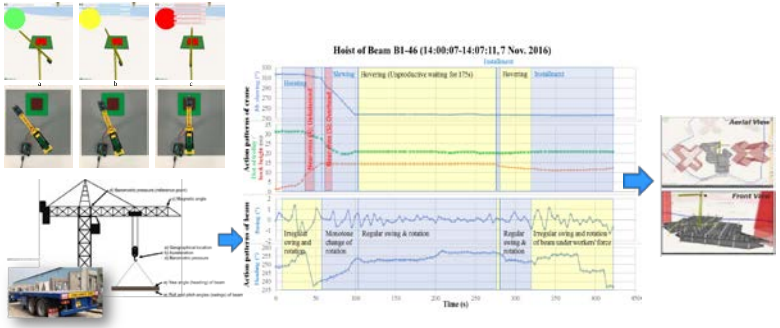
Identified green roof areas by machine learning

(Language: C++, R; Data formats: GeoJSON, Las, csv)

- Semantic discovery (Xue et al., 2018c)



- BIM localization (Wang et al., 2018)
- Real-time motions, behavior (Niu et al., 2018)



- Smart facility (Xu et al., 2018)
- Smart walkability (Xue et al., 2018d)

Section 3

‘SEA’
FOR SMARTER PROSPECTS

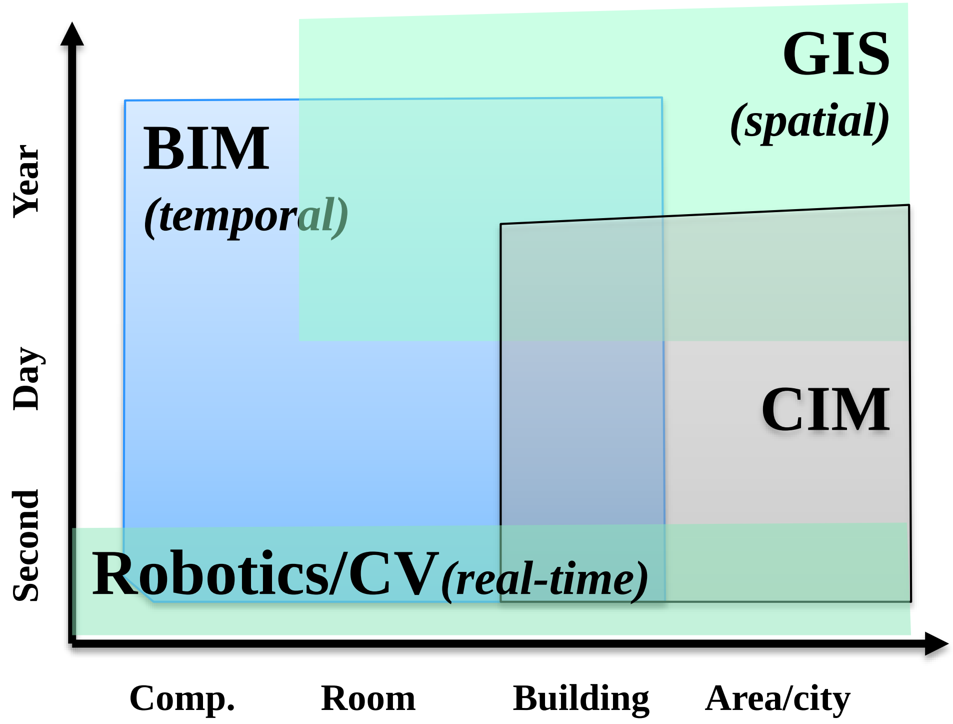
3.2 Target semantics, *e.g.*, building facts (Chen et al., 2018b)

	Geometric	Non-geometric
Construction	• Site information (coordinate's data and layout) • Building spaces (floor, zones, rooms, openings) • Utility lines • Dimension of building components	• Construction materials (status, quality, category, manufacturer) • Precast elements (quality, category, manufacturer) • Equipment attributes (ID, type, status) • Financial data • Location of labor, materials, and machine • Project performance data • Construction schedule • Construction activity status • Site environment
Operation & maintenance (O&M)	• Building services (location, relationship) • Building spaces (floor, zones, rooms, openings) • Utility lines • Specification of exterior enclosure products • Furnishing	• Building services (identification number, manufacturer) • Status of mechanical, electrical, & plumbing equipment • Maintenance record • Indoor environment • Attributes of replaced components • Maintenance status • Maintenance schedule • Operation records

3.2 List of semantics standards (Wang et al., 2018)

Research/ industry	Application Scenario	Object Parameters
Pratt (2004)	BIM object contents exchange	Functional type; Geometry; Attributes; Relations between objects; Behavioural rules.
Belsky et al. (2016)	Semantic enrichment for BIM objects	Function; Geometry; Material; Identity; Aggregation relationships; Composition relationships.
Chen and Wu (2013)	Parametric BIM object modelling	Basic Object Data (Identification, Classification, Geometry, Quantities, and Phasing); Representation data (Material)
Open Geospatial Consortium (OGC, 2007)	Object data description in CityGML for virtual 3D city and landscape	Geometrical, Topological, Semantic, and Appearance properties.
Autodesk Revit (2017)	Modelling and professional analysis (e.g. thermal)	Identification (number, name, type, description); Classification (OmniClass code and description); Geometry; Material; Quantities; Manufacturer; Cost; Phasing; LEED, Thermal and Structural Properties, etc.
RIBA, UK (2014)	Object data description defined in NBS BIM Object Standard	Authorship, Identification (name, Uniclass code, and product link), Manufacturer, NBS description, and reference, etc.
NIBS, USA (2012)	Information Collection via Cobie to improve handover to owner-operator	Authorship, Identification (created by, category, Description, type, code, etc.) Manufacturer, Warranty, Geometry, Material
CIBSE, UK (2016)	Product description for manufacturer defined in Product Data Templates(PDTs)	Manufacturer, Construction, Application, Dimension, Performance, Electrical, Controls, Sustainability, Operations and Maintenance

3.3 Urban semantics technologies for smarter city



The spatial-temporal matrix of the interests of BIM, GIS, CIM. CV

- BIM, GIS, CIM, Robotics/CV
  - Complementary and overlapping
  - On the same urban objects
    - With focused semantics
- Integrated urban semantics is then
  - Digital twin of the built environment
  - Recognizable by machines
- For smarter city applications
  - 4D, *n*D, temporal (building): BIM
  - 4D, *n*D, temporal (area): CIM
  - Spatial analysis (area): GIS
  - Real-time control: Robotics/CV

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THANK YOU !