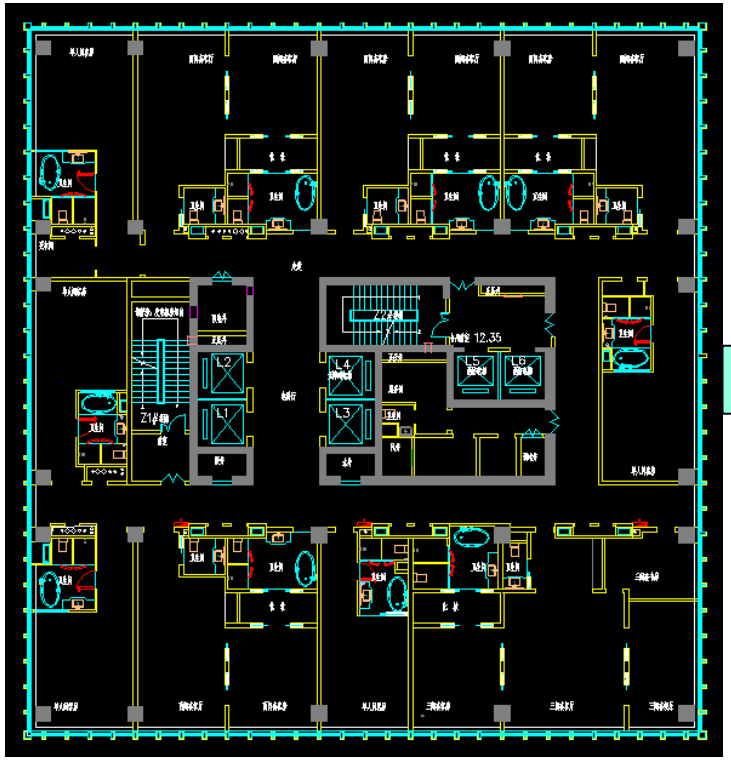
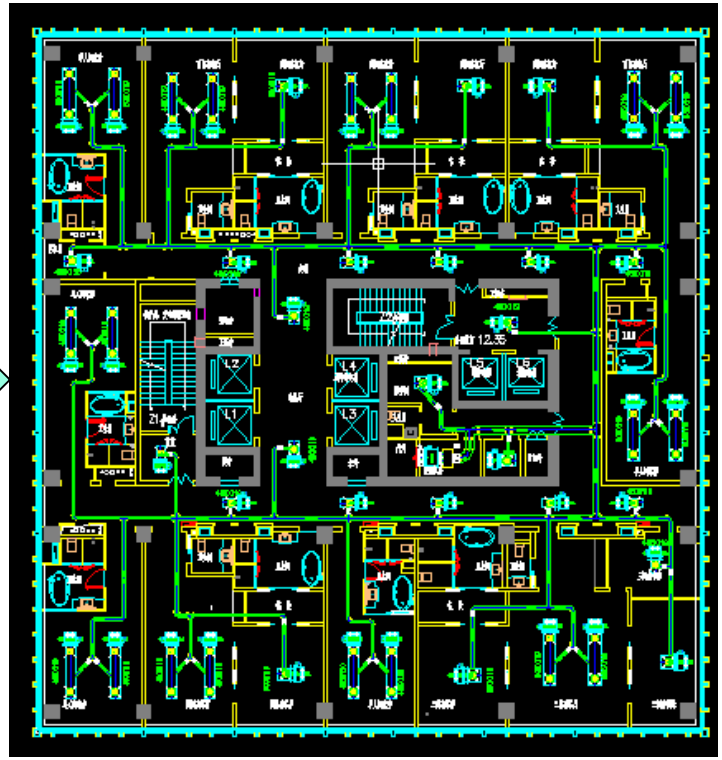
许 鹏 教授 博士 博导
同济大学机械与能源工程学院
Peng Xu Professor,Phd,PE,MBA
Tongji University
College of Mechanical Engineering

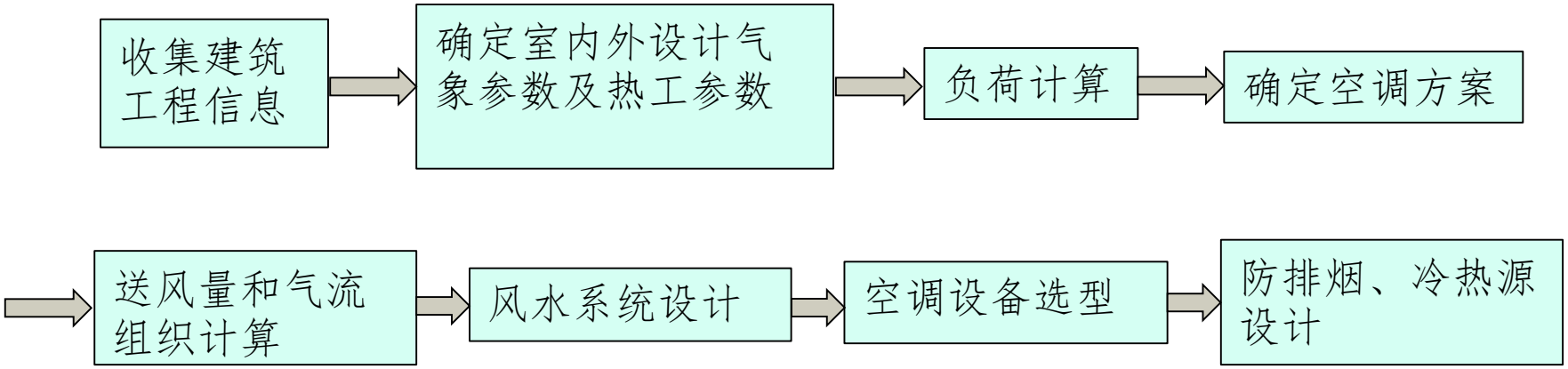
基于IFC的暖通空调全自动设计初探

问 题



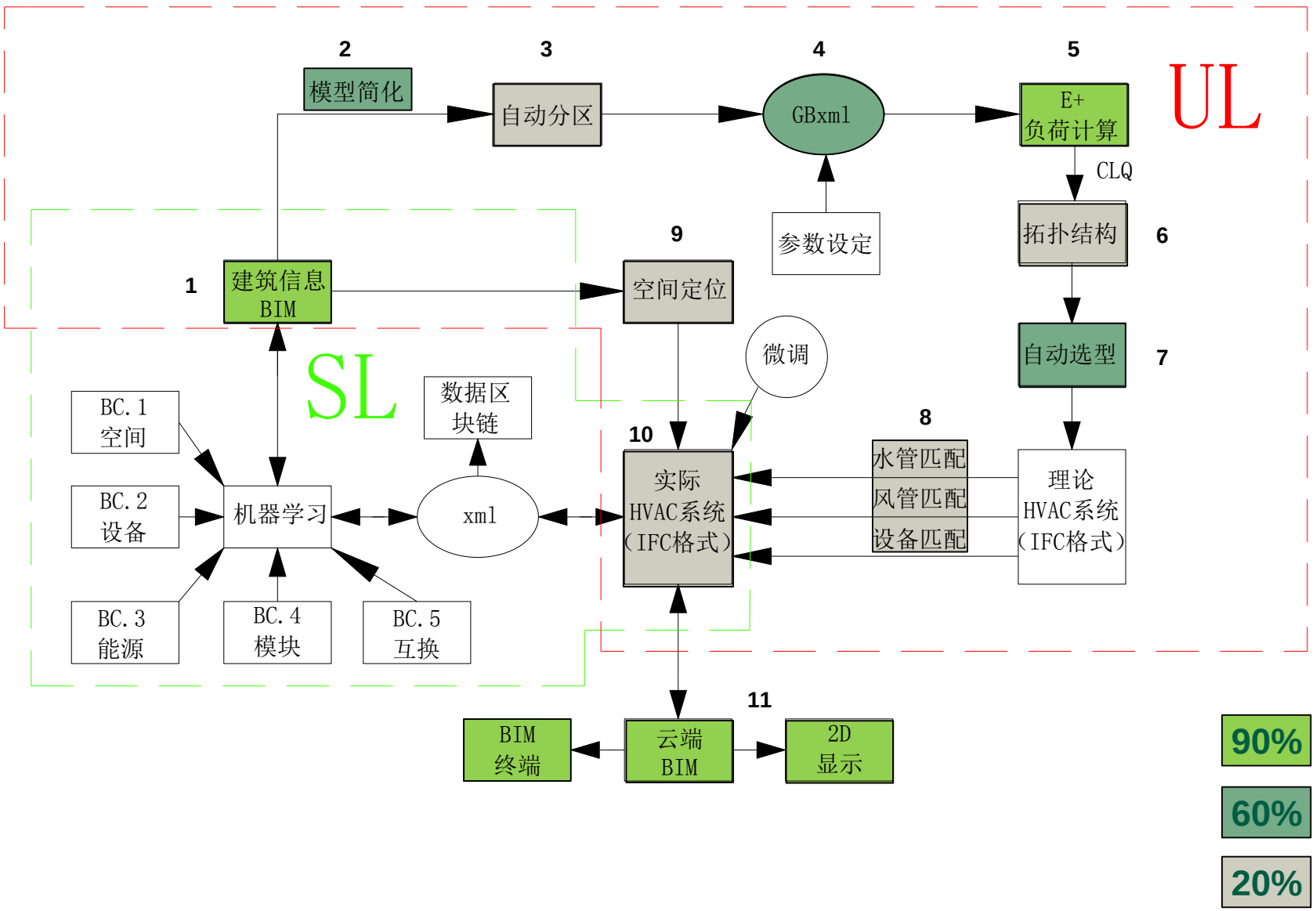


常规流程



- 当前暖通设计**可重复性强**
- **经验、规范**占主要地位
- 处于建筑设计过程中的介入事件比较**滞后**的一个专业子系统。基本上是为解决建筑设计后的一些采暖空调通风问题
- 不可能对建筑物本身的设计形态，设计内容产生本质性的改变

监督学习(supervised learning)和无监督学习(unsupervised learning)



BIM

- 美国国家BIM标准(NBIMS)对BIM的定义，由三部分组成：

- 1.BIM是一个设施(建设项目)物理和功能特性的**数字表达**；

- 2.BIM是一个**共享的知识资源**，是一个分享有关这个设施的信息，为该设施从建设到拆除的**全生命周期**中的所有决策提供可靠依据的过程；

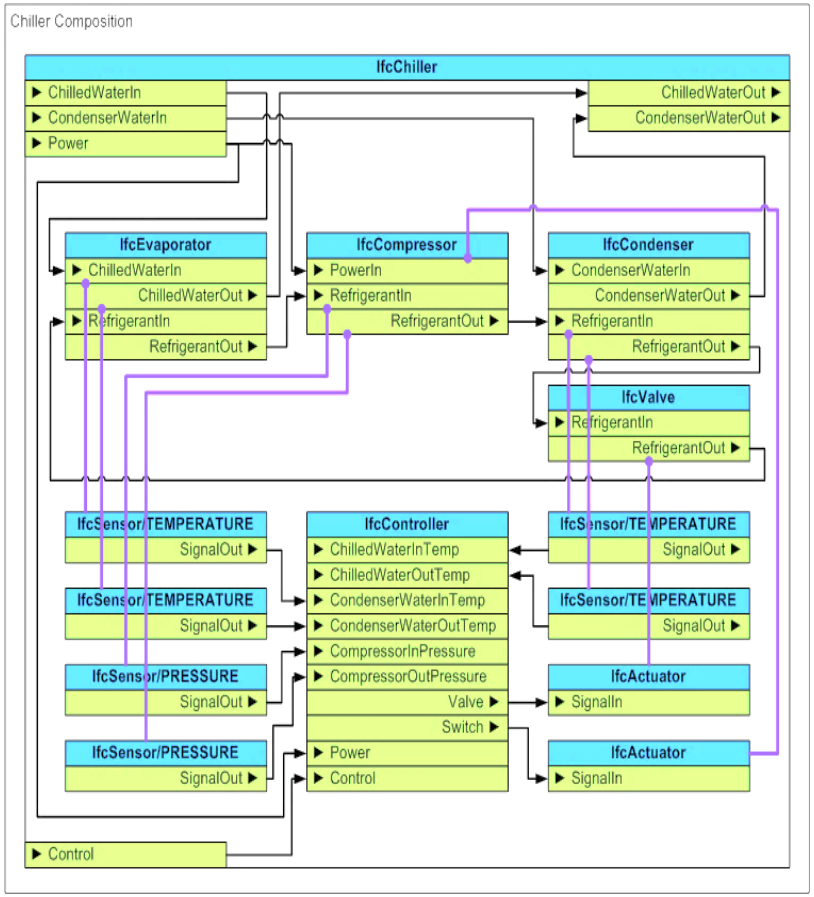
- 3.在项目的不同阶段，不同利益相关方通过在BIM中插入、提取、更新和修改信息，以支持和反映其各自职责的**协同作业**

IFC

- 工业基础类（Industry Foundation Class）是由IAI（International Alliance Interoperability）定义的一种**数据格式**，用于存储信息及模型的数据，用于各个软件、应用之间**交换**数据。

- IFC定义了很多的类别，每个类别有很多的属性来描述它，这其实就是类的概念Class。

- BIM是面向对象的工程设计。IFC作为一种数据结构，便于各个厂商的产品之间交换数据



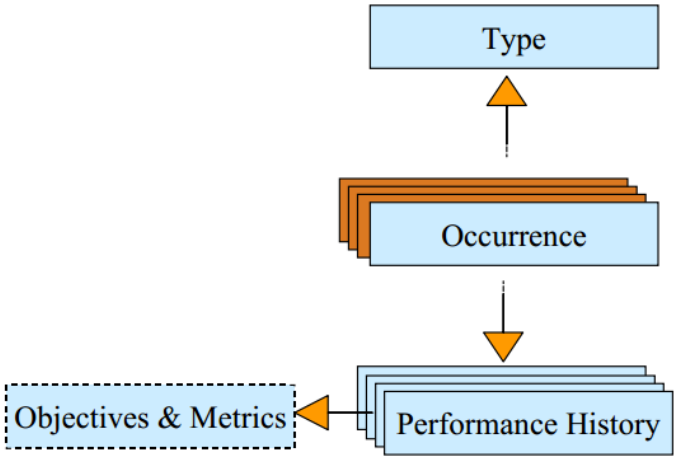


Figure 1: Generic approach for the HVAC component model

Type information-------制造商提供的目录数据

Occurrence information--------在设计、选型及开发过程中决定位置和连接关系

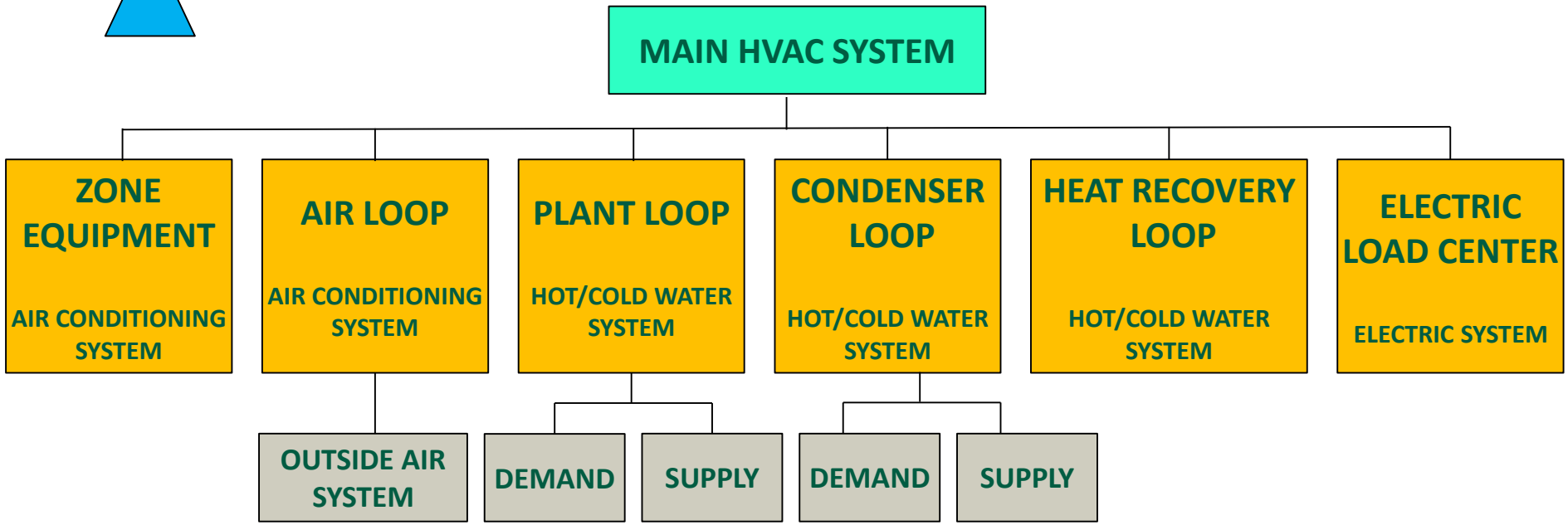
Performance history--------在建筑生命周期中随时间变化的性能

前两者为静态数据，后者为动态数据

Boiler

Name	Description
Type	
TypeEnum	STEAM, WATER
PressureTypeEnum	LOW, MEDIUM, HIGH
OperatingModeEnum	Fix, TwoStep, Modulate,
Material	Link to material resource
PrimaryEnergySource	Link to energy source
AuxiliaryEnergySource	Link to elecEnergy source
HeatTransferSurfaceArea	
PartLoadRatio	Range (maximum,
WaterInTempRange	Range (maximum,
ExpansionVessel	Link to tank
WaterStorage	LINK to tank
DomWaterStorageCap	
Weight	
SoundLevel	
PartialLoadEfficencyCurves	Link to polynomial
EfficiencyTable	Link to table
HeatOutputTalbe	Link to table
ApplicationEnum	DomWatHeater, Heating

Performance History	
WaterQuality	Link to water material
EnergySourceConsumptio	Link to energy source
Efficiency	
FullLoadEfficiency	
CombustionEfficiency	
WorkingPressure	
CombustionTemperature	
PartLoadRatio	
Load	
EnergyConsumption	
AuxEnergyConsumption	
combustionproductMaxLo	link to combustion product
combproduct60%Load	link to combustion product
Fluid connections	
FluidInlet	
FluidOutlet	
MakeUpWaterInlet	
CombustionAirInlet	



Outline of system definition hierarchy

Legend:

PARENT SYSTEM

SUB SYSTEM

SUB SUB SYSTEM

Vladimir Bazjanac, et al. "IFC HVAC INTERFACE TO ENERGYPLUS – A CASE OF EXPANDED INTEROPERABILITY FOR ENERGY SIMULATION

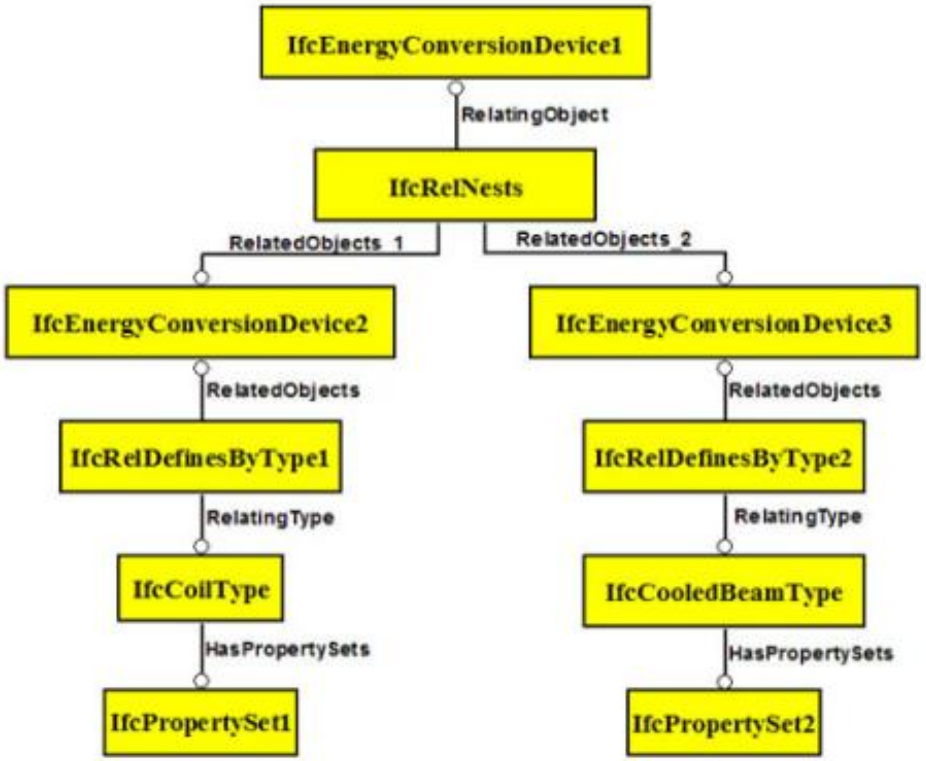


Figure 3 – An example of the concept of containers

Connectivity:

Elements,
Ports,
Connectors

Composition:

Aggregation,
Containment,
Nesting

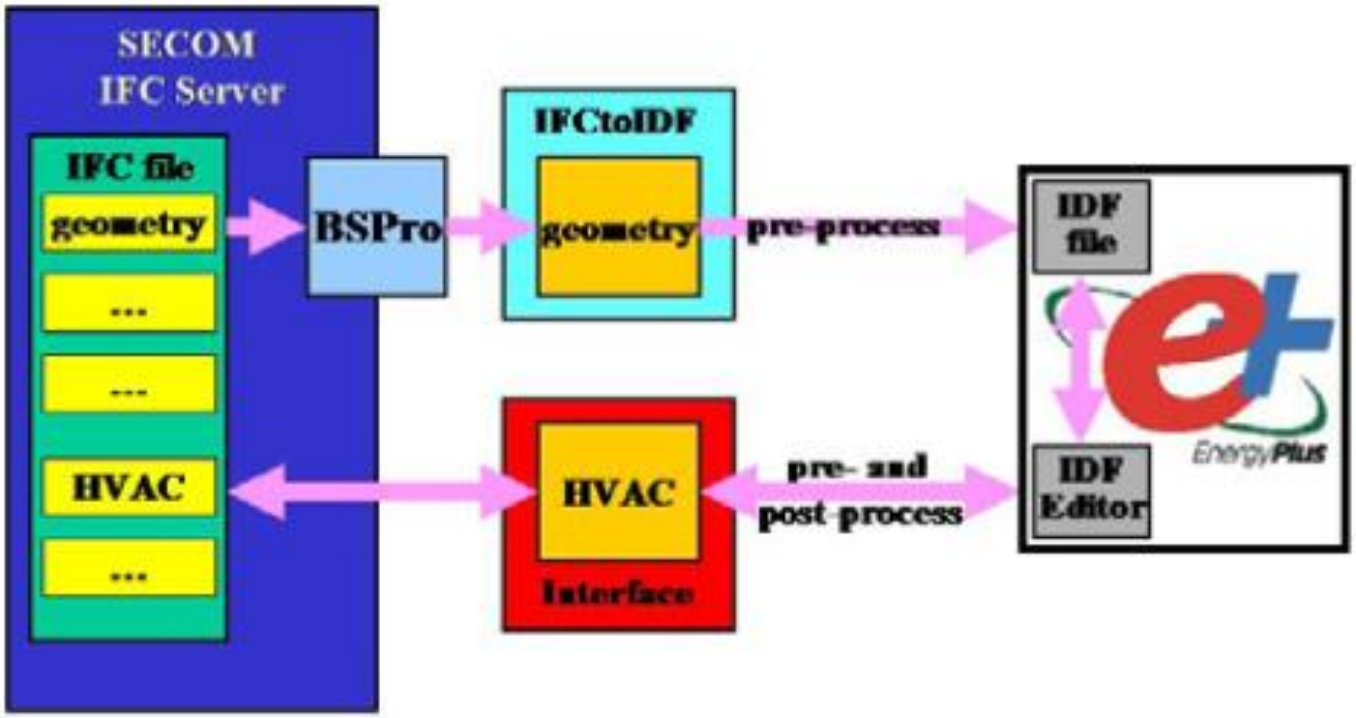
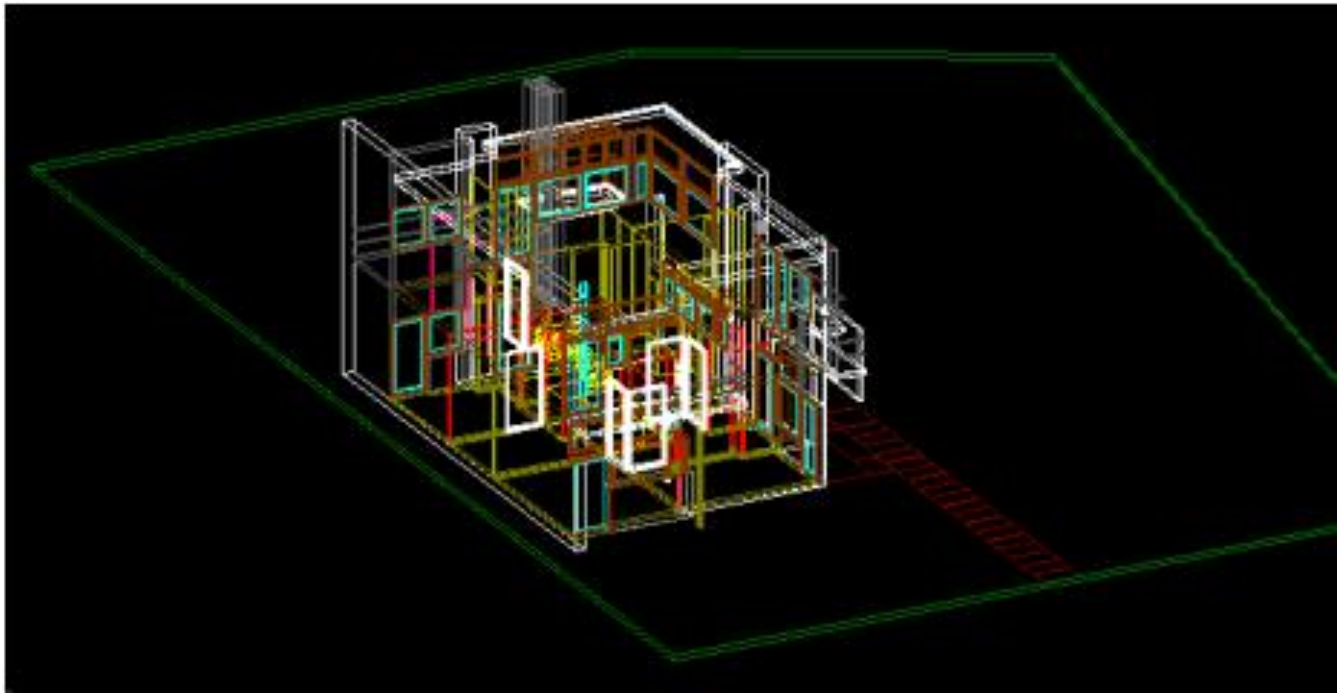


Figure 6 – Diagram of data paths

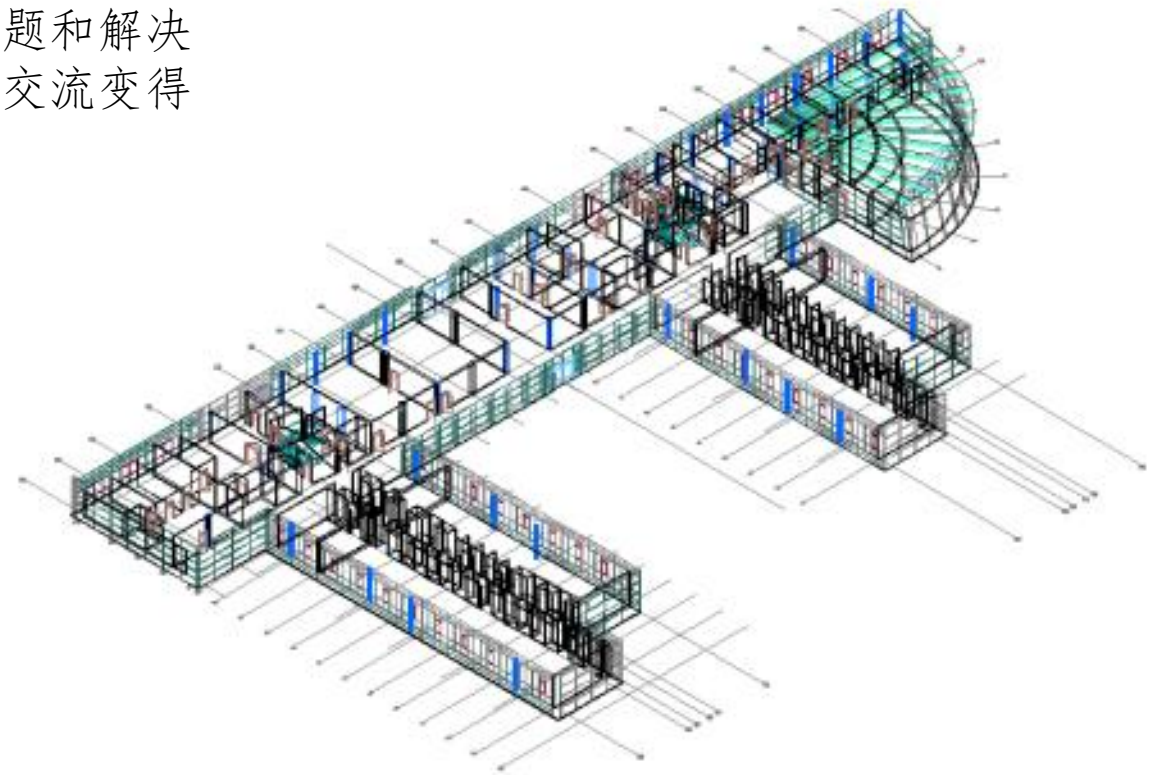
一个著名的例子：风格派建筑的三维模型
修改过的IFCcompliant CAD 文件发送到另一个CAD程序，显示结果精确，再次修改重新显示精度不受影响



Vladimir Bazjanac, et al. "THE IMPLEMENTATION OF INDUSTRY FOUNDATION CLASSES INSIMULATION TOOLS FOR THE BUILDING INDUSTRY."

位于因斯布鲁克的办公大楼的一部分被改造。

展示了设计师、工程师和设施管理人员如何在可互操作的环境中工作，并有效地交换有关后续问题和解决方案的信息。建筑和信息交流变得很重要



所有仿真工具都基于数据来实行仿真。IFC模型提供的数据比例将决定仿真应用程序在多大程度上符合IFC标准：完全、部分或不完全兼容。

Figure 7. Fully IFC-compliant software application

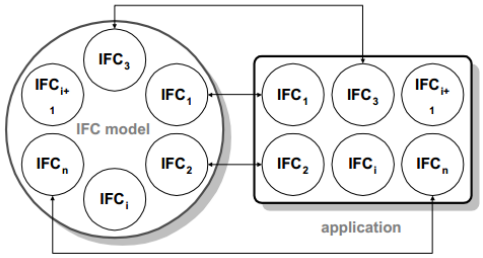


Figure 8. Partially IFC-compliant software application

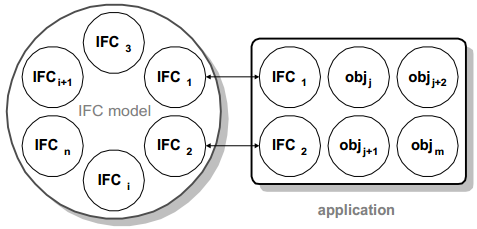
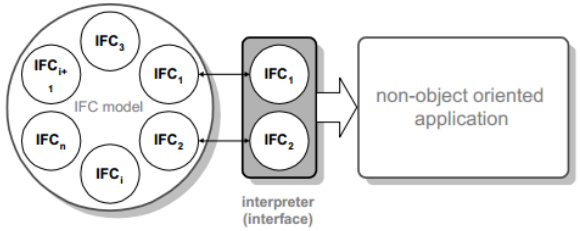
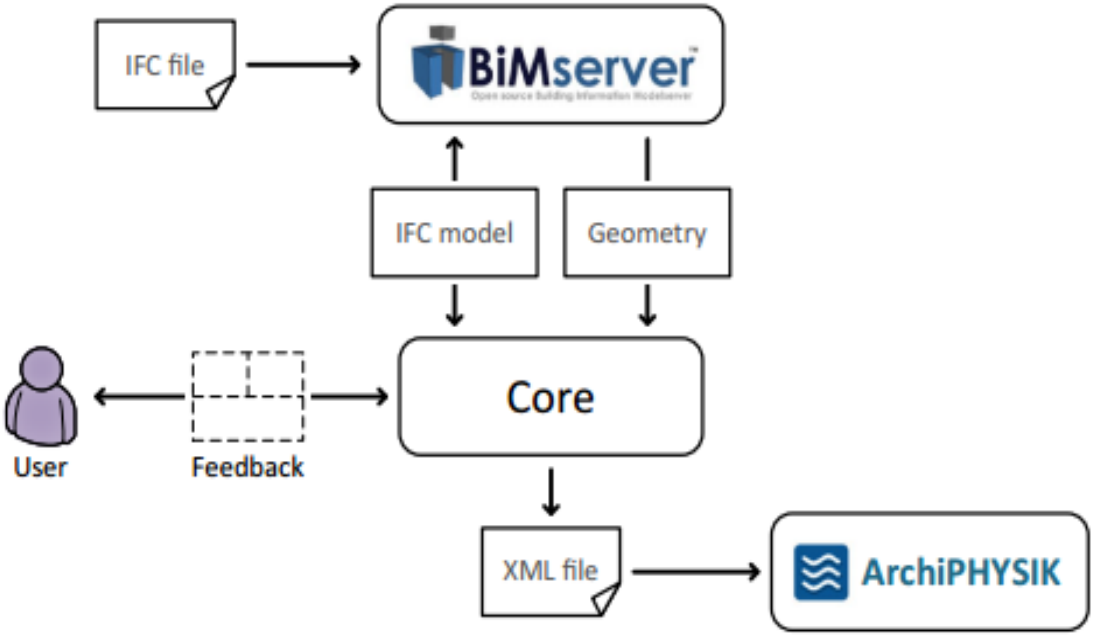
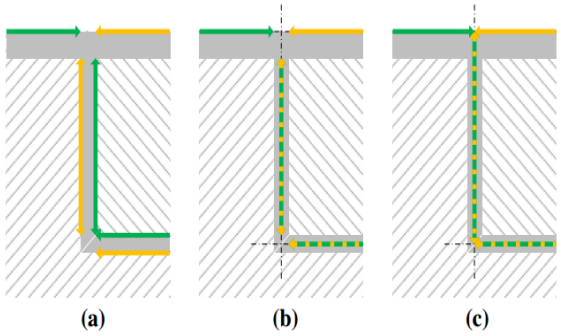


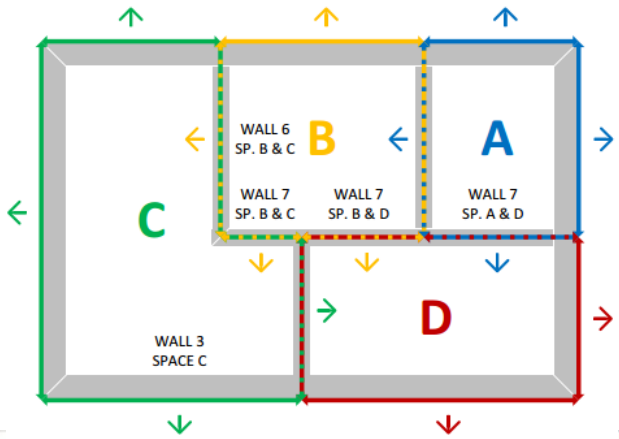
Figure 9. Non-compliant software application

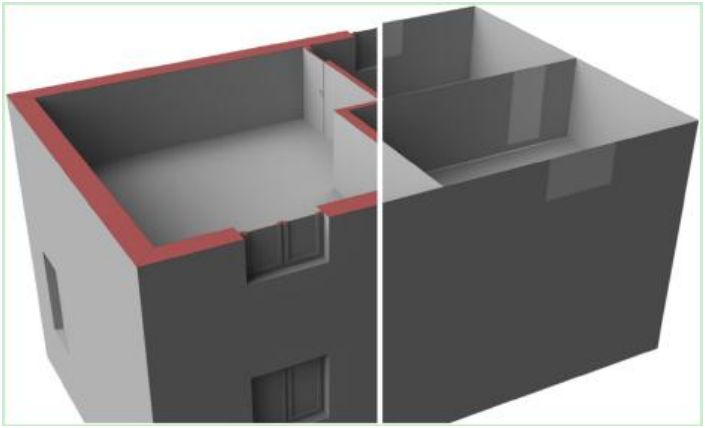


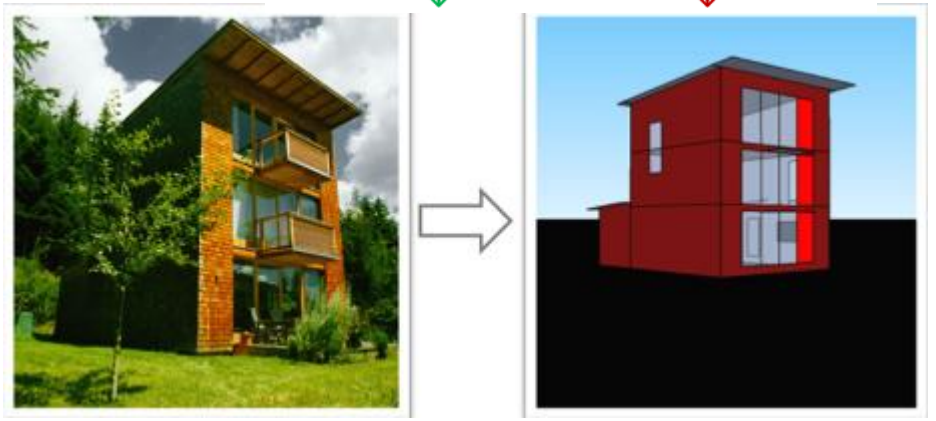
利用IFC兼容的CAD软件开发的工程模型自动、无误地获取建筑几何和其他数据，可以大大减少仿真输入时间和成本，缩短仿真周期











Ladenhauf, D., et al. (2014). "Geometry simplification according to semantic constraints." Computer Science - Research and Development 31(3): 119-125.

自动分区

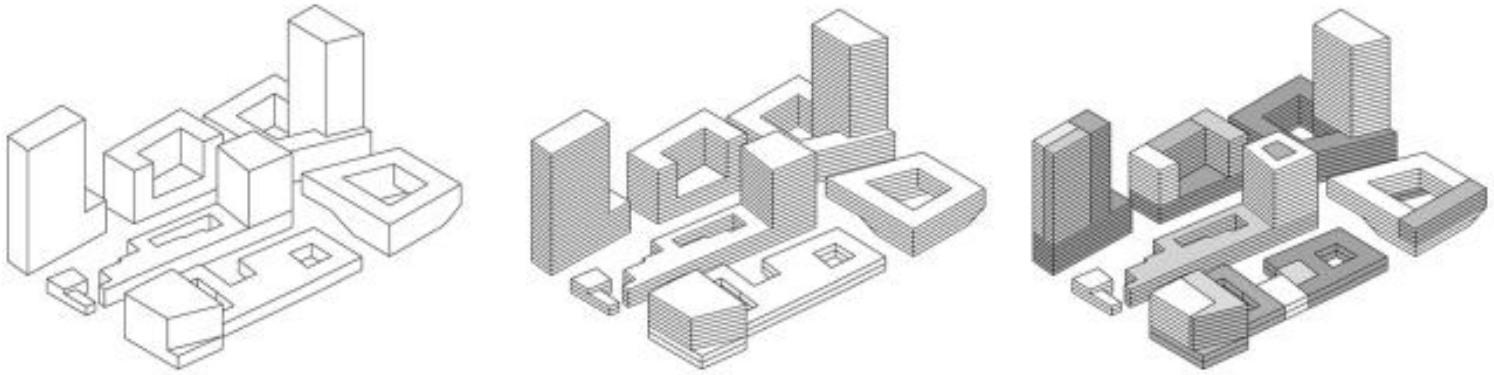


Figure 2. Typical modelling styles of massing models.

- 建筑物建模为单一的量
- “堆叠”地板卷。这增加了“规模”的概念，允许从模型读取地板到地板的高度，它有助于在设计过程中密度的分布
- 堆叠的体积可以被程序/函数进一步细剖和区分

Timur Dogan, Christoph Reinhart & Panagiotis Michalatos (2016) Autozoner:an algorithm for automatic thermal zoning of buildings with unknown interior space definitions,Journal of Building Performance Simulation, 9:2, 176-189

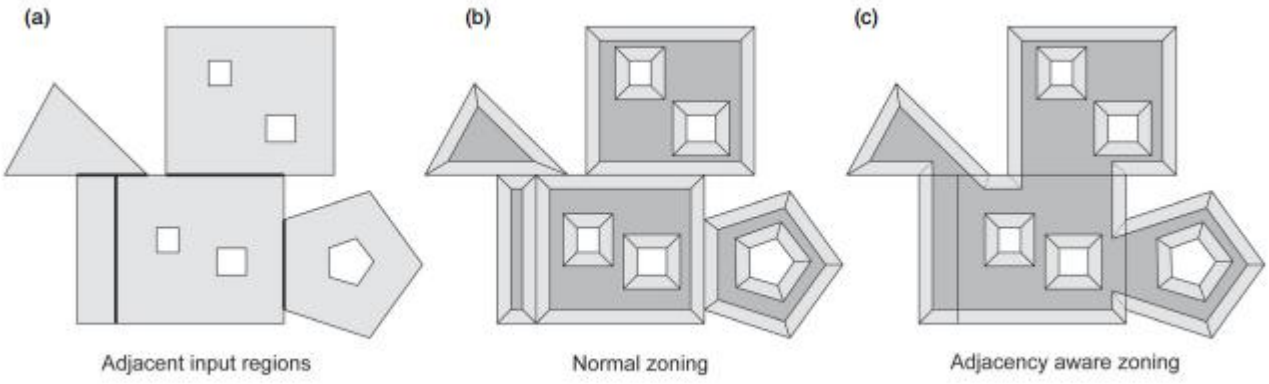


Figure 7. Zoning for adjacent regions.

邻接问题（2D示例）：

- 图中相邻区域的内部墙用粗笔画表示。
- 将所有相邻的地板合并成单一的平面图
- 边界细胞融合
- 结果得到一个2D蜂窝细分

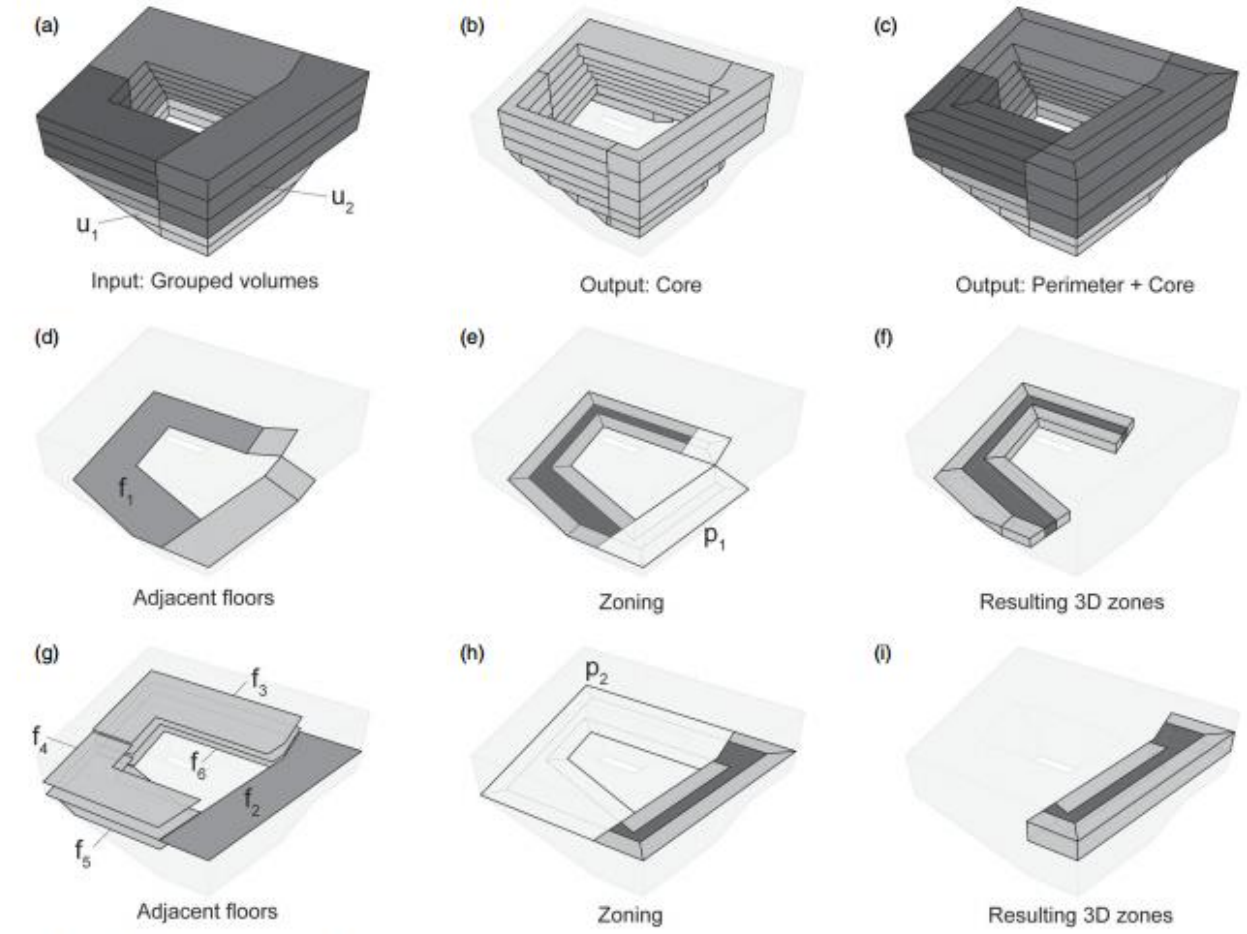


Figure 8. 3D adjacency detection and adjacency aware zoning.

邻接问题（3D示例）

straight skeleton

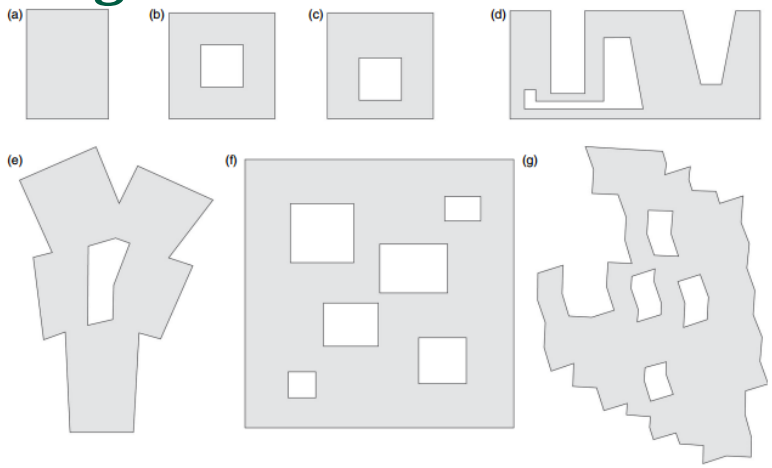


Figure 9. Test shapes of varying complexity: (a) facade area weight ω, (b) percentage error E% and (c) AW-RMSE.

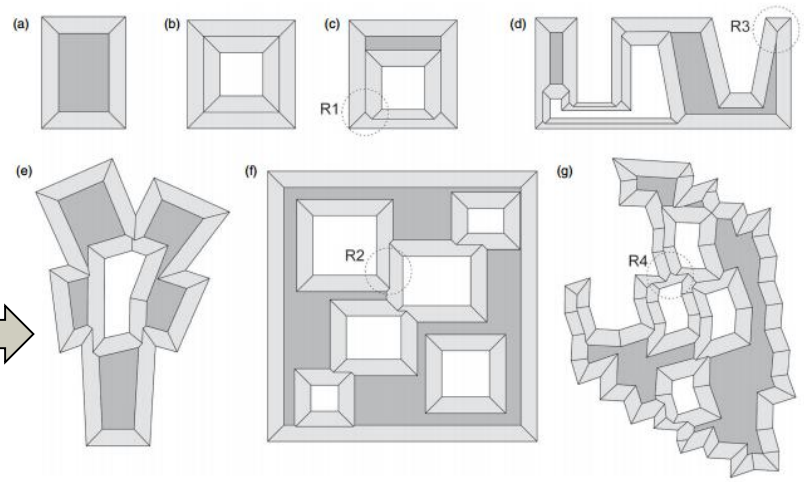


Figure 11. Automatic zoning results.

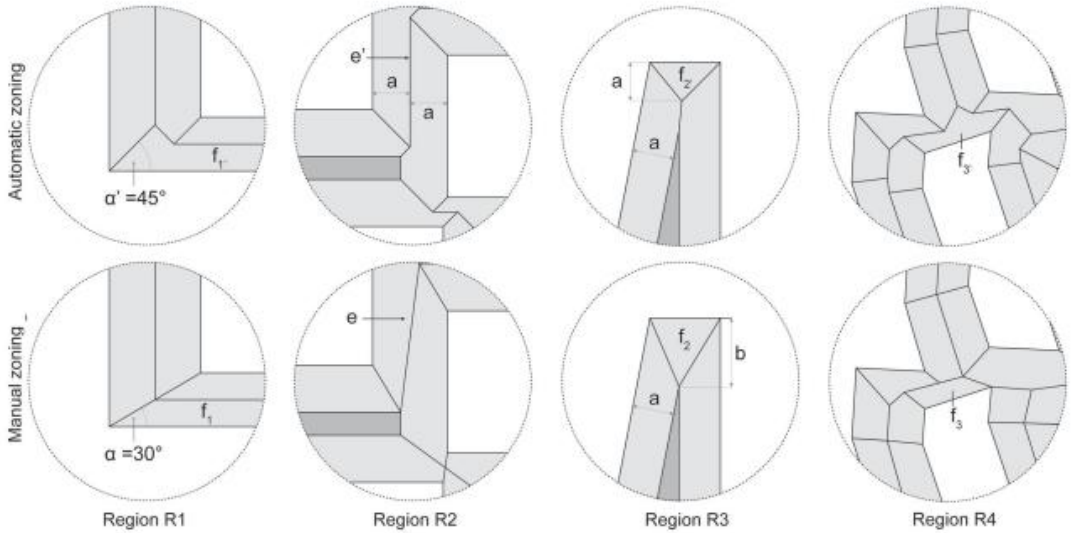
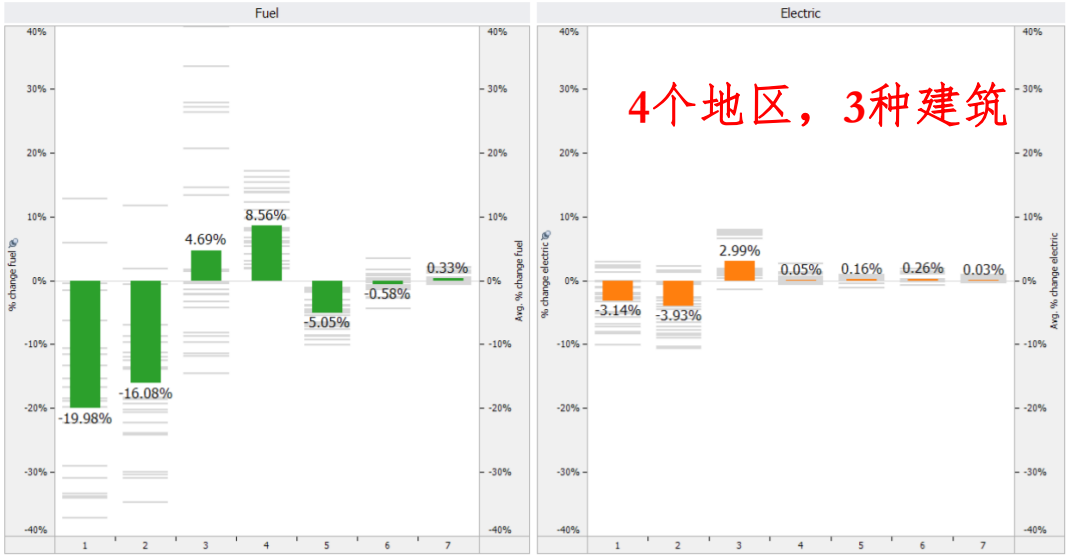


Figure 12. Complex massing: input, floor subdivision, inner subdivision and facade.

- 概念设计阶段

  基于ASHRAE 90.1 Appendix G对能耗模拟的建议，对体量模型自动划分内外区，取得较准确的结果



若干不同划分模式相对于ASHRAE标准的能耗模拟结果偏差

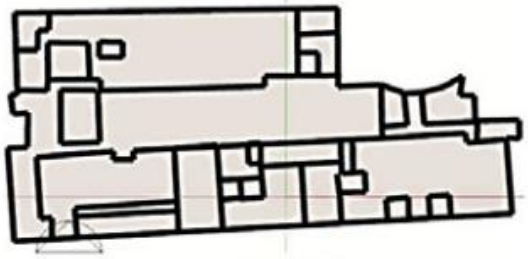
- 完备IFC阶段

  基于生成的能耗模型，考虑建筑热工特性、房间功能负荷特性、系统架设合理性，划分合理的空调系统分区，简化能耗模型

Lillian Smith, et al. "Beyond the Shoebox: Thermal Zoning Approaches for Complex Building Shapes"

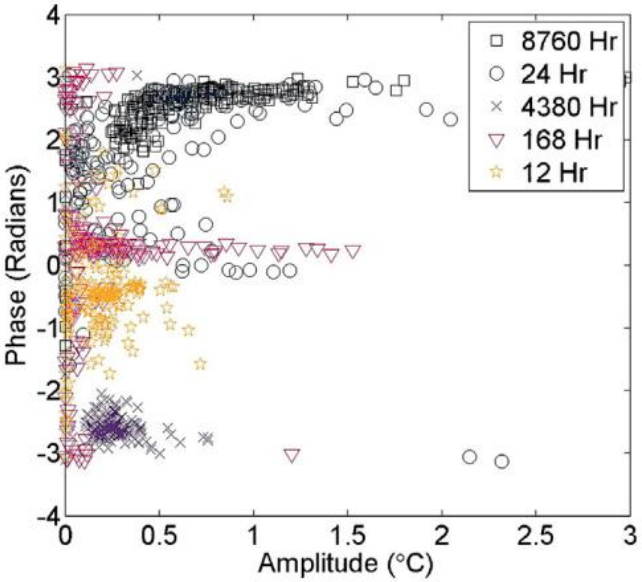
建筑体热惰性

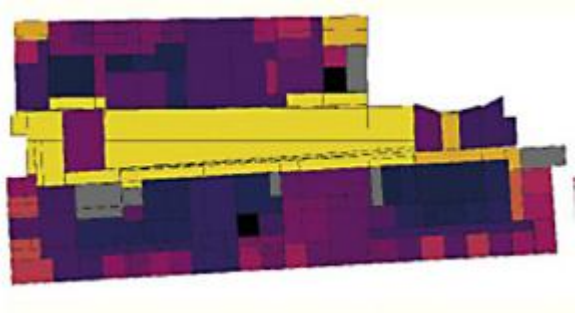
215 zones



103 zones

57 zones





4380 hours Koopman mode amplitude

Amplitude and phase of zones for the five modes considered. Adjacent zones with similar amplitudes and phases are grouped together when creating zoning approximations

Michael Georgescu, et al. "Building energy modeling: A systematic approach to zoning and model reduction using Koopman Mode Analysis"

建筑负荷特性

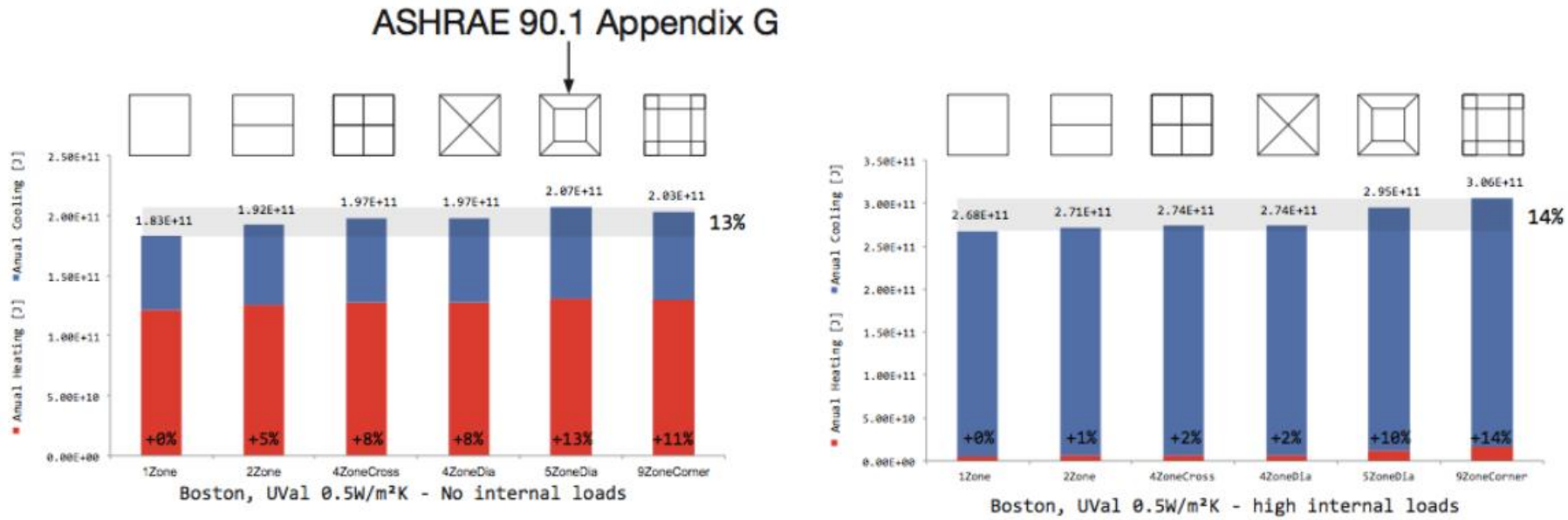


Figure 2: Comparison of subdivision schemata for two extreme internal load scenarios.

- 区域负荷分析在建筑各功能区域的启示
- 能源网络与建筑内HVAC系统设计的相似性

Timur Dogan, et al. "Automated multi-zone building energy model generation for schematic design and urban massing studies"

GBXML是什么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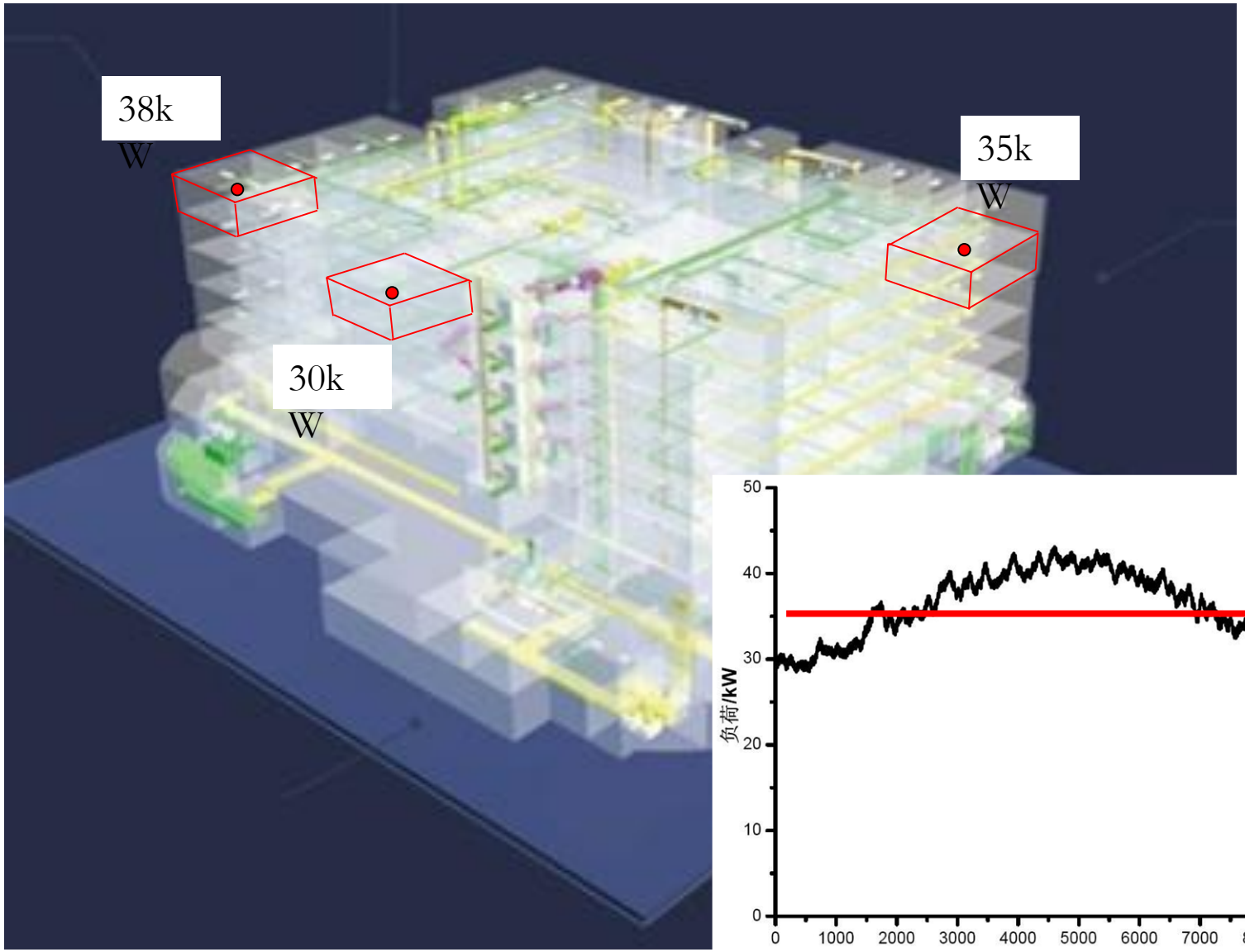
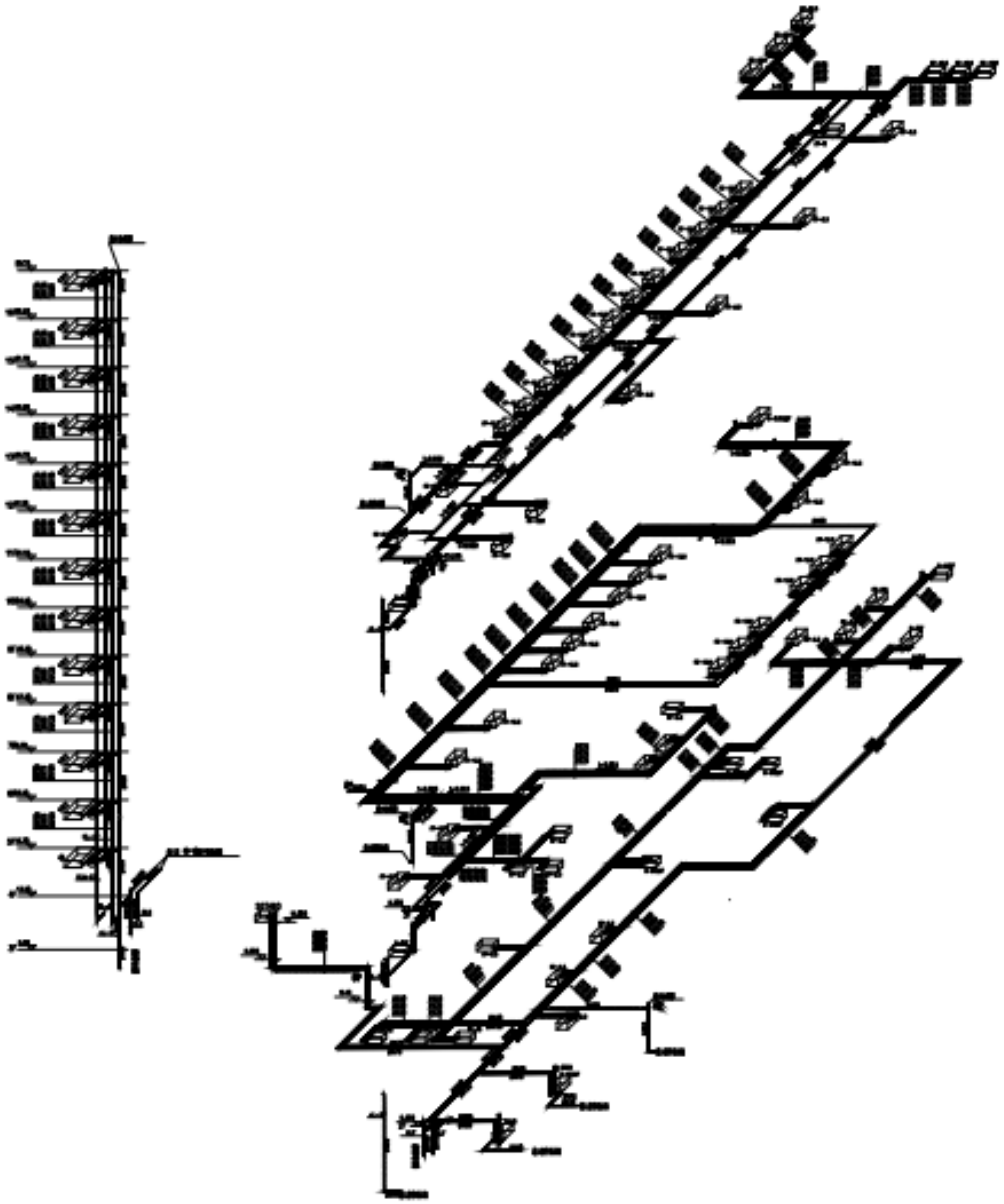
位于波士顿容纳25人的办公楼

“绿色建筑扩展性标记语言”

- 一种xml文件
- 超过500种的元素和属性
- 描述一个建筑的所有方面
- 开发了方便的存储在基于CAD的建筑信息模型的建立信息的传递
- 互操作性
- 消除了设计可持续和节能建筑的重大成本障碍。使建筑设计团队能够真正协作
- ArchiCAD、SketchUp、Open Studio……

IFC 模型简化 自动分区 GBxml 负荷计算 拓扑





图示：某楼供回水干管系统图

设备编号：

采用《GB50114-2010T 暖通空调制图标准》中对于空调系统的制图图示的相关标准进行的编号处理

向量表达

向量编写的基本规则：

基本形式：

（**XXX**XXXXXXXX） （XXXXXXXXXXX） （**XXX**XXXX）

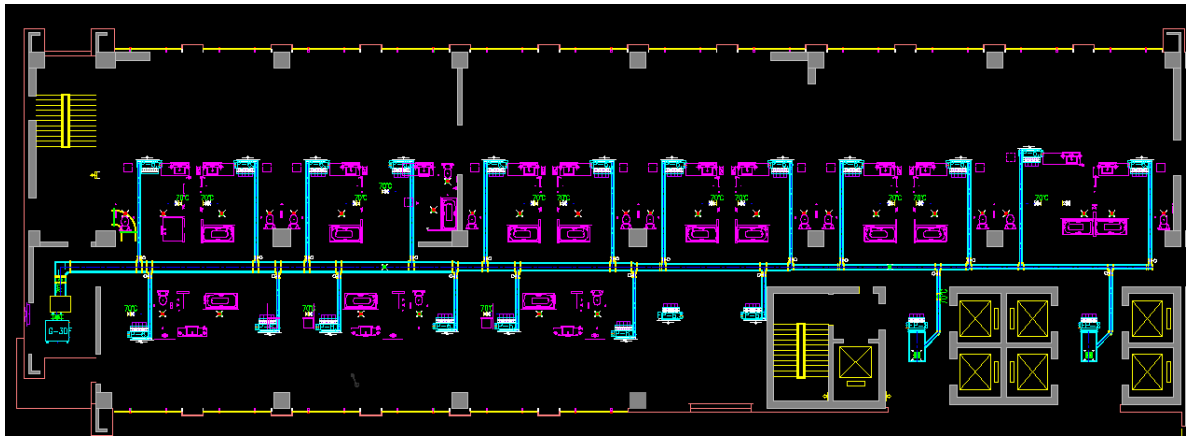
起始地址 管内流动介质的参数 结束地址

前设备的出口 后设备的入口

1、(LDJF-001) (LRG, DN150, 7℃, W) (GJD001)
2、(GJD001) (LRG, DN80, 7℃, W) (YG2.5-001)
3、(GJD001) (LRG, DN70, 7℃, W) (G-4+2DF-001)
4、(GJD002) (LRG, DN125, 7℃, W) (GJD003)
5、(GJD002) (LRG, DN125, 7℃, W) (GJD003)
6、(GJD003) (LRG, DN70, 7℃, W) (SGT460-001)
7、(GJD003) (LRG, DN100, 7℃, W) (GJD004)
8、(GJD004) (LRG, DN100, 7℃, W) (FP-6.3-001)
9、(GJD004) (LRG, DN100, 7℃, W) (GJD005)
10、(GJD005) (LRG, DN100, 7℃, W) (FP-6.3-002)
11、(GJD005) (LRG, DN80, 7℃, W) (GJD006)
12、(GJD006) (LRG, DN80, 7℃, W) (FP-6.3-003)
13、(GJD006) (LRG, DN100, 7℃, W) (GJD007)
14、(GJD007) (LRG, DN100, 7℃, W) (G-3+2DF-001)
15、(GJD007) (LRG, DN80, 7℃, W) (GJD008)
16、(GJD008) (LRG, DN80, 7℃, W) (G-3DF-001)
17、(GJD008) (LRG, DN80, 7℃, W) (GJD009)
18、(GJD009) (LRG, DN80, 7℃, W) (FP-6.3-004)
19、(GJD009) (LRG, DN40, 7℃, W) (GJD010)
20、(GJD010) (LRG, DN40, 7℃, W) (FP-3.5-001)
21、(GJD010) (LRG, DN40, 7℃, W) (GJD011)
22、(GJD011) (LRG, DN40, 7℃, W) (FP-3.5-002)
23、(GJD011) (LRG, DN40, 7℃, W) (FP-1.5-001)
24、(GJD009) (LRG, DN80, 7℃, W) (GJD012)
25、(GJD012) (LRG, DN80, 7℃, W) (G-3+2DF-002)
26、(GJD012) (LRG, DN70, 7℃, W) (GJD013)
27、(GJD013) (LRG, DN70, 7℃, W) (G-3+2DF-003)
28、(GJD013) (LRG, DN50, 7℃, W) (GJD014)
29、(GJD014) (LRG, DN50, 7℃, W) (G-3+2DF-004)
30、(GJD014) (LRG, DN40, 7℃, W) (GJD015)
31、(GJD015) (LRG, DN40, 7℃, W) (G-3+2DF-005)
32、(GJD015) (LRG, DN40, 7℃, W) (GJD016)
33、(GJD016) (LRG, DN40, 7℃, W) (FP-10-001)
34、(GJD016) (LRG, DN32, 7℃, W) (GJD017)
35、(GJD017) (LRG, DN32, 7℃, W) (FP-10-002)
36、(GJD017) (LRG, DN32, 7℃, W) (FP-10-002)

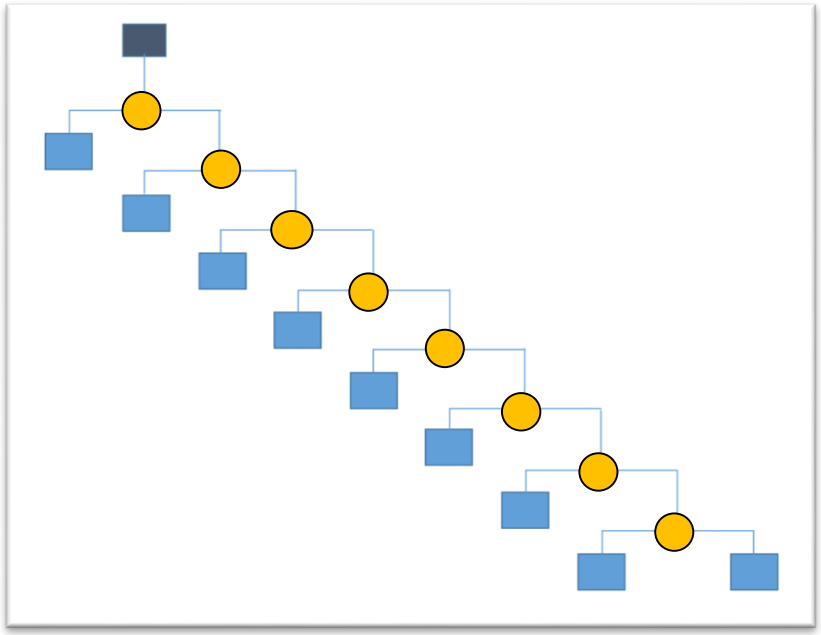
1、(G-1.5DF-001) (NP, DN32, 13℃, W) (PJD001)
2、(FP-3.5-002) (NP, DN32, 13℃, W) (PJD001)
3、(PJD001) (NP, DN32, 13℃, W) (PJD002)
4、(FP-3.5-001) (NP, DN32, 13℃, W) (PJD002)
5、(PJD002) (NP, DN32, 13℃, W) (PJD003)
6、(FP-6.3-004) (NP, DN20, 13℃, W) (PJD003)
7、(G-3DF-001) (NP, DN32, 13℃, W) (PJD003)
8、(PJD003) (NP, DN32, 13℃, W) (PJD004)
9、(G-3+2DF-002) (NP, DN32, 13℃, W) (PJD004)
10、(PJD004) (NP, DN32, 13℃, W) (PJD005)
11、(G-3+2DF-003) (NP, DN32, 13℃, W) (PJD005)
12、(PJD005) (NP, DN40, 13℃, W) (PJD006)
13、(G-3+2DF-004) (NP, DN40, 13℃, W) (PJD006)
14、(PJD006) (NP, DN40, 13℃, W) (PJD007)
15、(FP-6.3-005) (NP, DN40, 13℃, W) (PJD007)
16、(PJD007) (NP, DN40, 13℃, W) (PJD008)
17、(FP-10-003) (NP, DN25, 13℃, W) (PJD009)
18、(FP-10-002) (NP, DN25, 13℃, W) (PJD009)
19、(PJD009) (NP, DN32, 13℃, W) (PJD008)
20、(FP-10-001) (NP, DN32, 13℃, W) (PJD008)
21、(PJD008) (NP, DN40, 13℃, W) (PJD010)
22、(FP-6.3-001) (NP, DN40, 13℃, W) (PJD010)
23、(PJD010) (NP, DN40, 13℃, W) (PJD011)
24、(G-3+2DF-001) (NP, DN32, 13℃, W) (PJD013)
25、(FP-6.3-003) (NP, DN32, 13℃, W) (PJD013)
26、(PJD013) (NP, DN32, 13℃, W) (PJD012)
27、(FP-6.3-002) (NP, DN32, 13℃, W) (PJD012)
28、(PJD012) (NP, DN32, 13℃, W) (PJD011)
29、(PJD011) (NP, DN150, 13℃, W) (SWYSG-001)
30、(G-4+2DF-001) (NP, DN32, 13℃, W) (SWYSG-002)
31、(YG2.5-001) (NP, DN50, 13℃, W) (SWYSG-003)

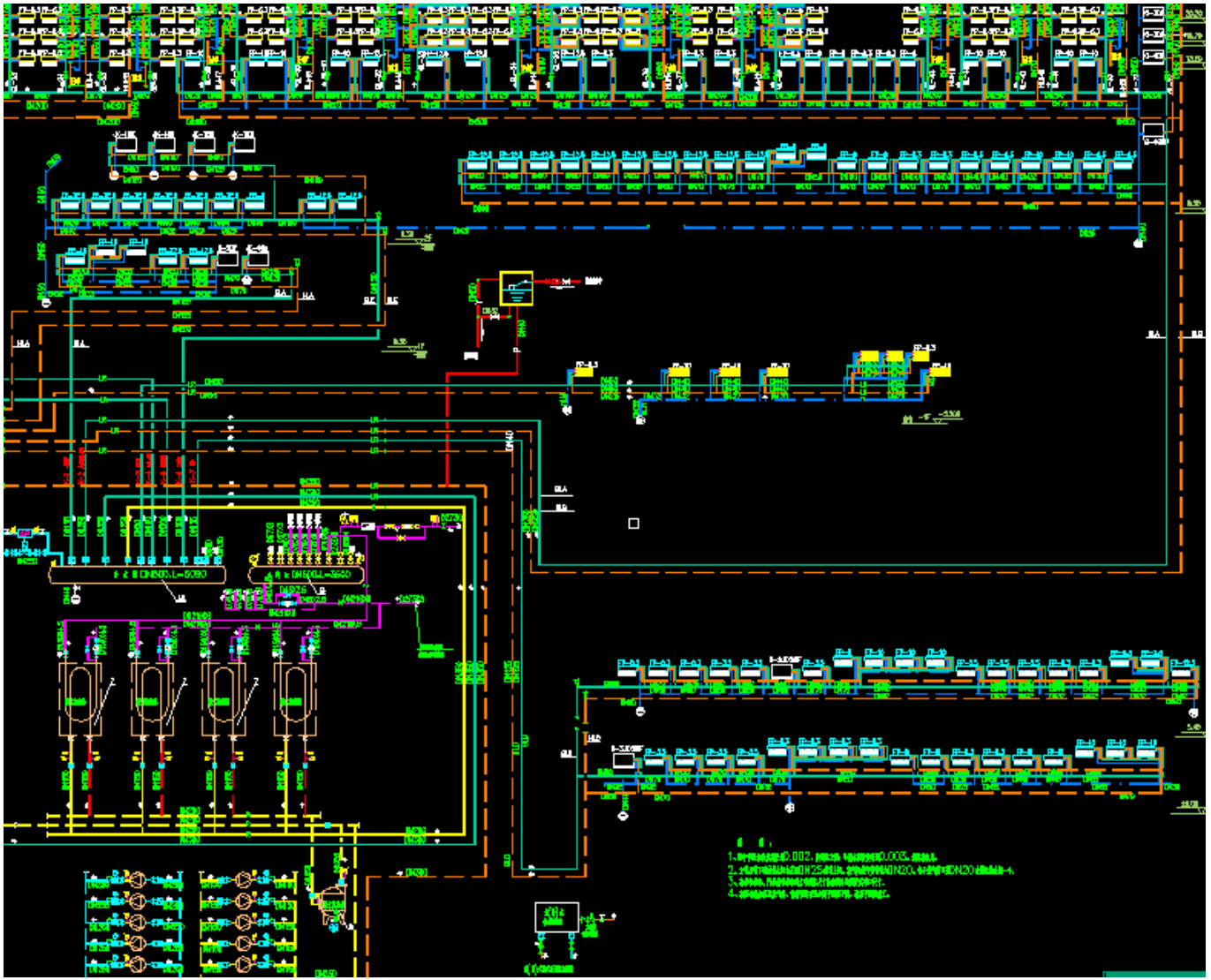
左图：部分供水管范例
右图：部分排水管范例



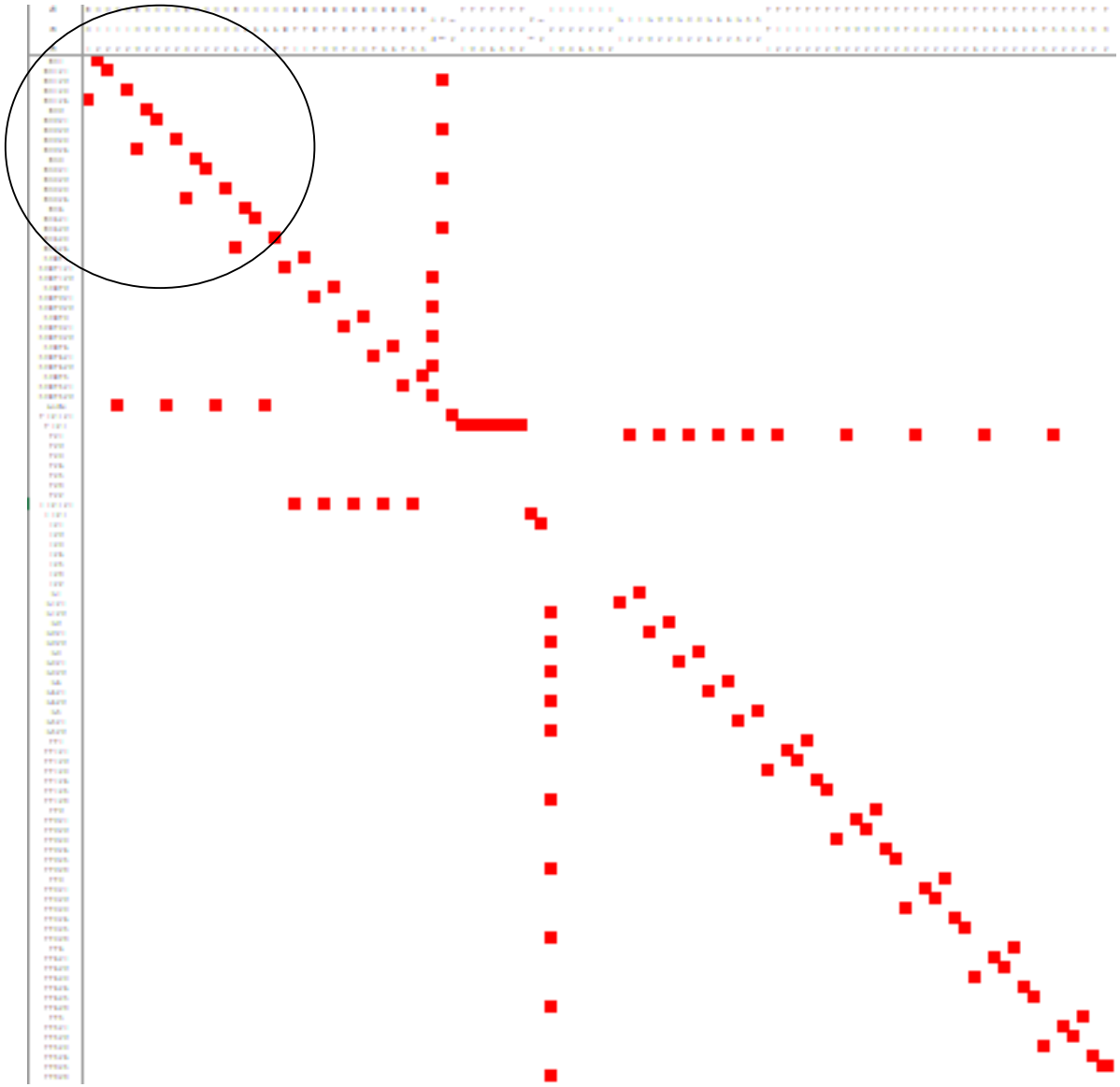
	A	PAU+Chamber+FD
	B	MD+FCU
	C	TVP

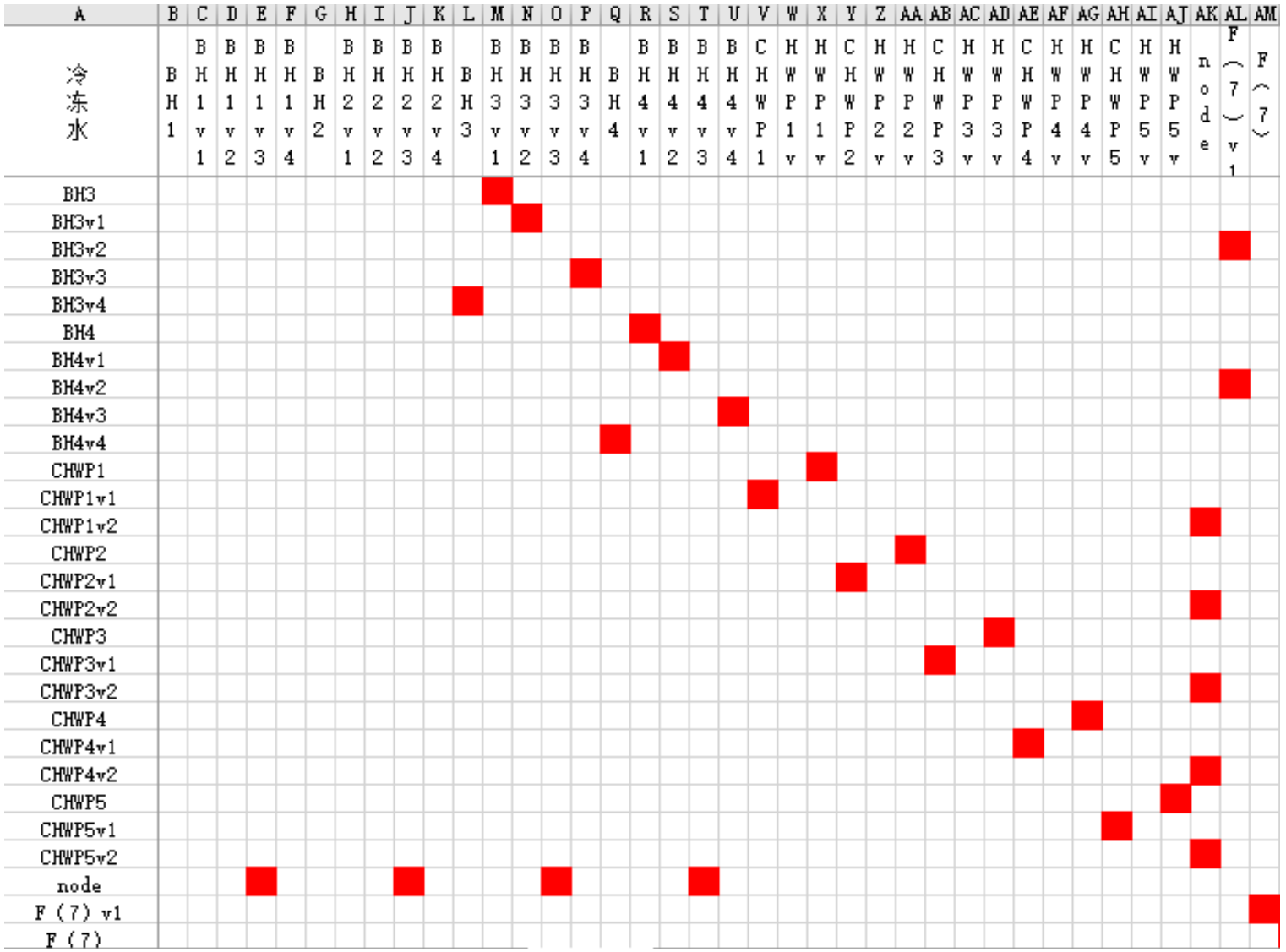
	A	B1	B2	B3	B4	B5	B6	B7	B8	B9	C1	C2	C3	C4	C5	C6	C7	C8
A	0										1							
B1		0																
B2			0															
B3				0														
B4					0													
B5						0												
B6							0											
B7								0										
B8									0									
B9										0								
C1		1									0	1						
C2			1									0	1					
C3				1									0	1				
C4					1									0	1			
C5						1									0	1		
C6							1									0	1	
C7								1									0	1
C8									1									0





水系统流程图（局部）




A
B C D E F G H I J K L M N O P Q R S T U V W X Y Z AA AB AC AD AE AF AG AH AI AJ AK AL AM
冷冻水
BH1 BH1v1 BH1v2 BH1v3 BH1v4 BH2 BH2v1 BH2v2 BH2v3 BH2v4 BH3 BH3v1 BH3v2 BH3v3 BH3v4 BH4 BH4v1 BH4v2 BH4v3 BH4v4 CHWP1 CHWP1v HWP1v HWP1v CHWP2 HWP2v HWP2v HWP3v HWP3v CHWP4 HWP4v HWP4v CHWP5 HWP5v HWP5v node F(7)v1 F(7)
BH3
BH3v1
BH3v2
BH3v3
BH3v4
BH4
BH4v1
BH4v2
BH4v3
BH4v4
CHWP1
CHWP1v1
CHWP1v2
CHWP2
CHWP2v1
CHWP2v2
CHWP3
CHWP3v1
CHWP3v2
CHWP4
CHWP4v1
CHWP4v2
CHWP5
CHWP5v1
CHWP5v2
node
F(7)v1
F(7)

自动选型　设备匹配　空间定位　系统（IFC）

Energyplus中
用户设置

全尺寸因子
特定区域的调整因子

Table 22. Details of Autosizable Objects/Fields　（部分）

Component / Object Name	Autosizable Fields
AirConditioner:VariableRefrigerantFlow	
	Gross Rated Total Cooling Capacity
	Gross Rated Heating Capacity
	Resistive Defrost Heater Capacity
	Water Condenser Volume Flow Rate
	Evaporative Condenser Air Flow Rate
	Evaporative Condenser Pump Rated Power Consumption
AirLoopHVAC	
	Design Supply Air Flow Rate
AirLoopHVAC:Unitary:Furnace:HeatCool	
	Maximum Supply Air Temperature
	Cooling Supply Air Flow Rate
	Heating Supply Air Flow Rate
	No Load Supply Air Flow Rate
AirLoopHVAC:Unitary:Furnace:HeatOnly	
	Maximum Supply Air Temperature
	Supply Air Flow Rate
AirLoopHVAC:UnitaryHeatCool	
	Maximum Supply Air Temperature
	Cooling Supply Air Flow Rate
	Heating Supply Air Flow Rate
	No Load Supply Air Flow Rate

自动选型　设备匹配　空间定位　系统（IFC）

建立设备型号、参数**数据库**

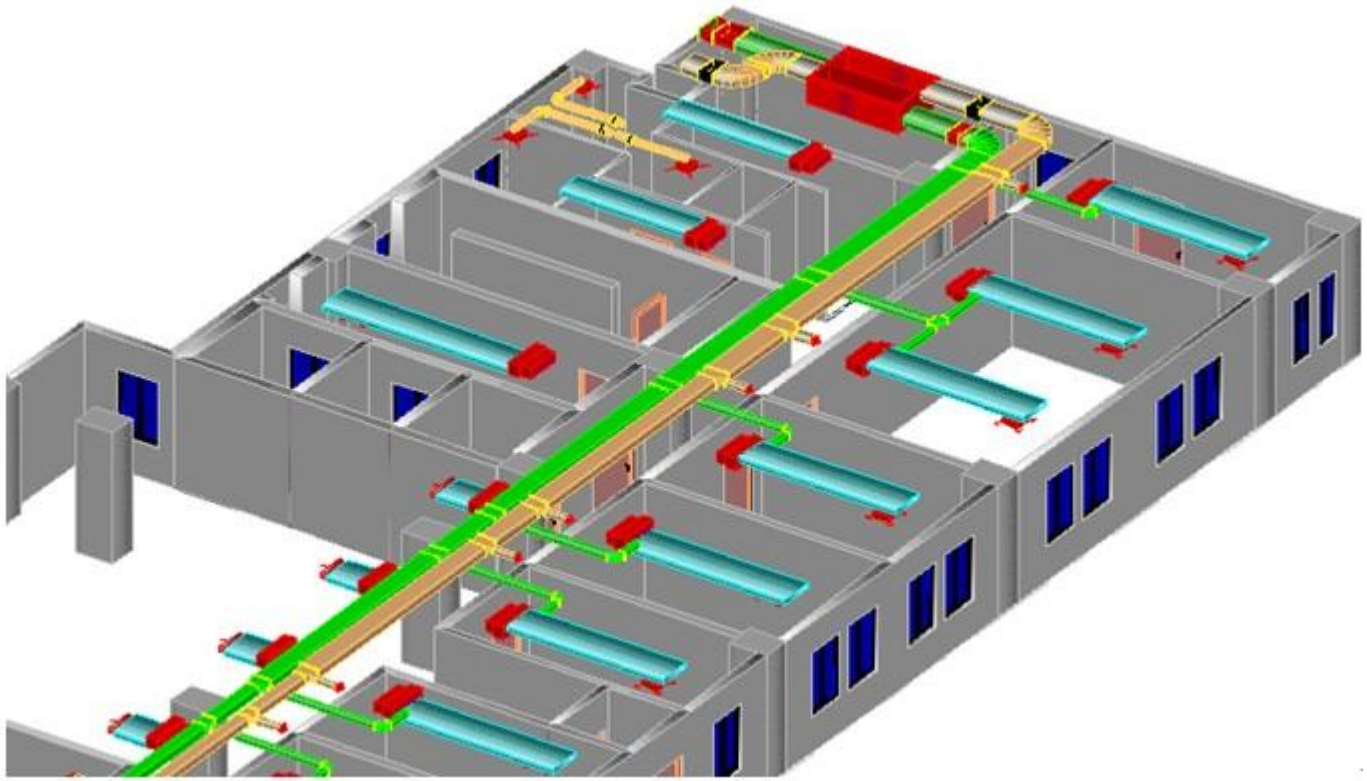
完成实际工程中设备选型匹配

编号	名　　称	型　号　规　格
1	卡式四面出风风机盘管	FP-3.5　L=350}/h，Q=2031KW
2	卧式暗装下回风循风机盘管	FP-6.3　L=630}/h，Q=3600KW
3	卧式暗装下回风循风机盘管	FP-8　L=800}/h，Q=4500KW
4	卧式暗装下回风循风机盘管	FP-10　L=1000}/h，Q=5400KW
5	卧式暗装下回风循风机盘管	FP-12.5　L=1250}/h，Q=6600KW
6	吊顶式新风空调器{6排}G-2DF	L=2000}/h，H=190Pa，N=0.32KW，　Q标 = 30.1KW
7	吊顶式新风空调器{6排}G-3.5x2DF	L=7000}/h，H=235Pa，N=0.8x2KW，　Q标 = 89.1KW
8	转轮式空气处理机组{组合类型3}	JY-8000，L=8500}/h，6排，Q=81.2KW
9	全热交换式换气机BCF-1000D-S	L=1000}/h，H=112Pa，N=0.20X2KW，
10	热回收式空气处理机组	JK-40Ⅱ，L=40000}/h，6排，Q=310KW
11	组合式空调机组	YG-2.5，L=28000，8排，Q=170KW
12	离心式风机箱DBF-Ⅰ-180	L=18000}/h，H=420Pa，N=3x1.1KW
13	70°C常开防火阀	1250X400
14	70°C常开防火阀	800X400
15	70°C常开防火阀	1250X630
16	70°C常开防火阀	2200X630
17	70°C常开防火阀	1600X800
18	70°C常开防火阀	1000X630
19	70°C常开防火阀	1250X1000
20	150°C厨房排风管道防火阀	1000X630
21	150°C厨房排风管道防火阀	630X630
22	150°C厨房排风管道防火阀	1400X800
23	150°C厨房排风管道防火阀	500X800
24	止回阀	500X800
25	止回阀	1400X800
26	止回阀	1000X630
27	止回阀	630X630
28	手动对开多叶调节阀	400X200
29	手动对开多叶调节阀	800X400
30	手动对开多叶调节阀	1000X300
31	手动对开多叶调节阀	320X250
32	手动对开多叶调节阀	250X200
33	手动对开多叶调节阀	1000X400
34	手动对开多叶调节阀	500X400
35	手动对开多叶调节阀	400X320
36	手动对开多叶调节阀	630X400
37	手动对开多叶调节阀	600X200
38	手动对开多叶调节阀	400X250
39	手动对开多叶调节阀	1000X500
40	手动对开多叶调节阀	500X320

编号	名　　称	型　号　规　格
41	手动对开多叶调节阀	500X250
42	手动对开多叶调节阀	500X200
43	手动对开多叶调节阀	250X120
44	电动蝶阀	120X120
45	电动蝶阀	250X200
46	蝶阀	160X120
47	方形散流器	160 X 160
48	手动对开多叶调节阀	630X320
49	方形散流器	300 X 300
50	方形散流器	240 X240
51	双层活动百叶风口	300 X 400
52	双层活动百叶风口	300 X 2500
53	双层活动百叶风口	4000 X 300
54	双层活动百叶风口	500 X 700
55	双层活动百叶风口	900 X 1300
56	双层活动百叶风口	400 X 700
57	双层活动百叶风口	900 X 1400
58	双层活动百叶风口	500 X 800
59	双层活动百叶风口	400 X 800
60	双层活动百叶风口	350 X 600
61	双层活动百叶风口	130 X(L+80+B)(L为风机盘管出风口宽度,B为风管宽度)
62	可开式单层带过滤网百页风口	350 X L(L为风机盘管出风口宽度)
63	单层活动百叶风口	100 X 120
64	单层活动百叶风口	150 X 300
65	单层活动百叶风口	200 X 400
66	单层活动百叶风口	500 X 600
67	单层活动百叶风口	800 X 1200
68	格栅式回风口	1000 X 500
69	静压消音箱	2200X1800X1000
70	静压消音箱	4300X1200X800
71	静压消音箱	800X1200X800
72	静压消音箱	800X800X500
73	静压消音箱	1000X1200X800
74	静压消音箱	2000X2500X1000
75	静压消音箱	2000X1800X1000
76	静压消音箱	2000X1100X900
77	静压消音箱	2200X1500X1000
78	静压消音箱	1800X1000X800
79	微孔消声弯头VKW-I	400 X1250
80	吸顶式塑料通风换气扇BPT-500	L=500}/h,H=250Pa，N=0.04KW

自动选型　设备匹配　空间定位　系统（IFC）

基于CAD的天正T-HVAC软件
智能化管线系统
采用三维管道设计，模糊操作实现管线与设备、阀门精确连接；管线交叉自动遮断



自动选型　设备匹配　空间定位　系统（IFC）

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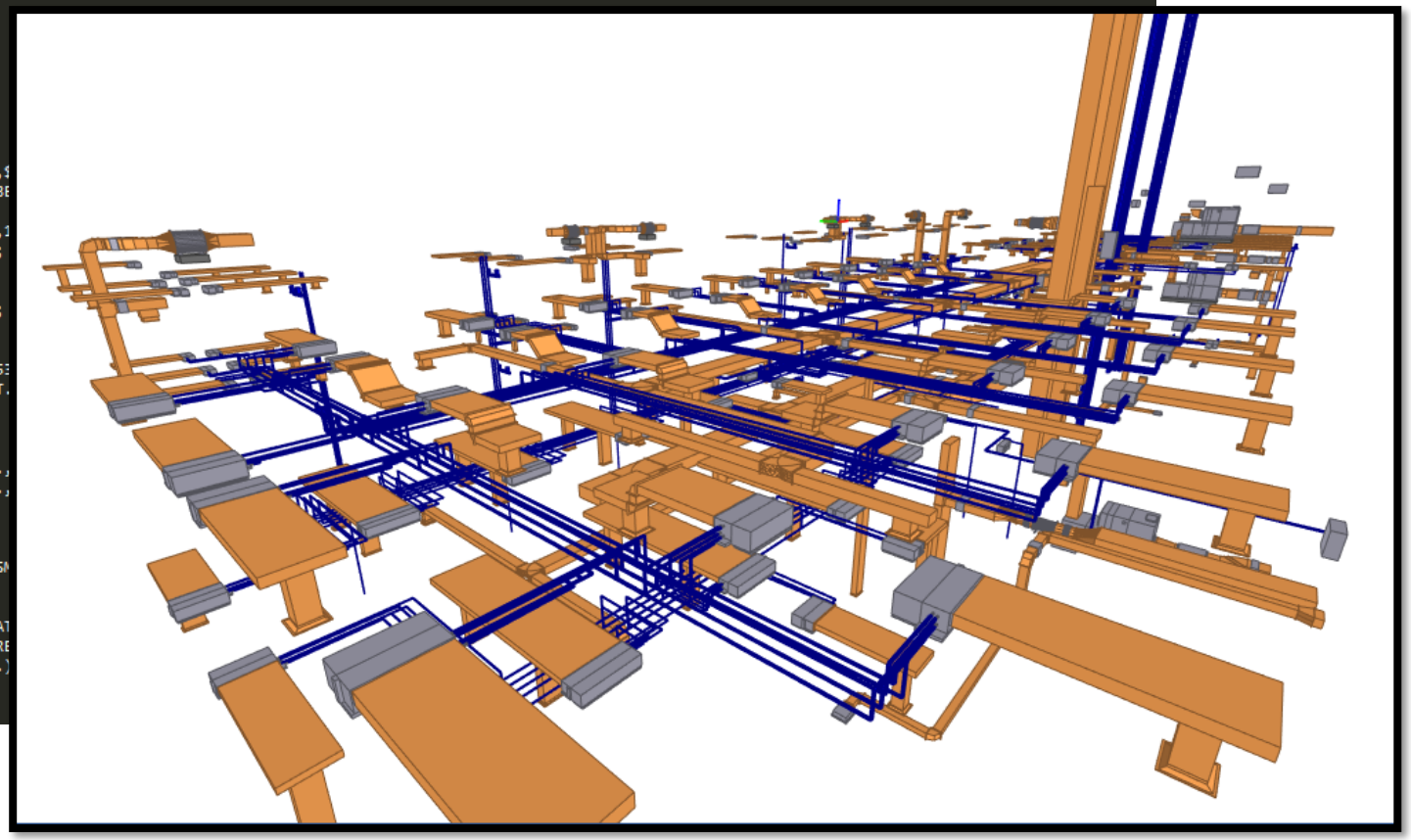

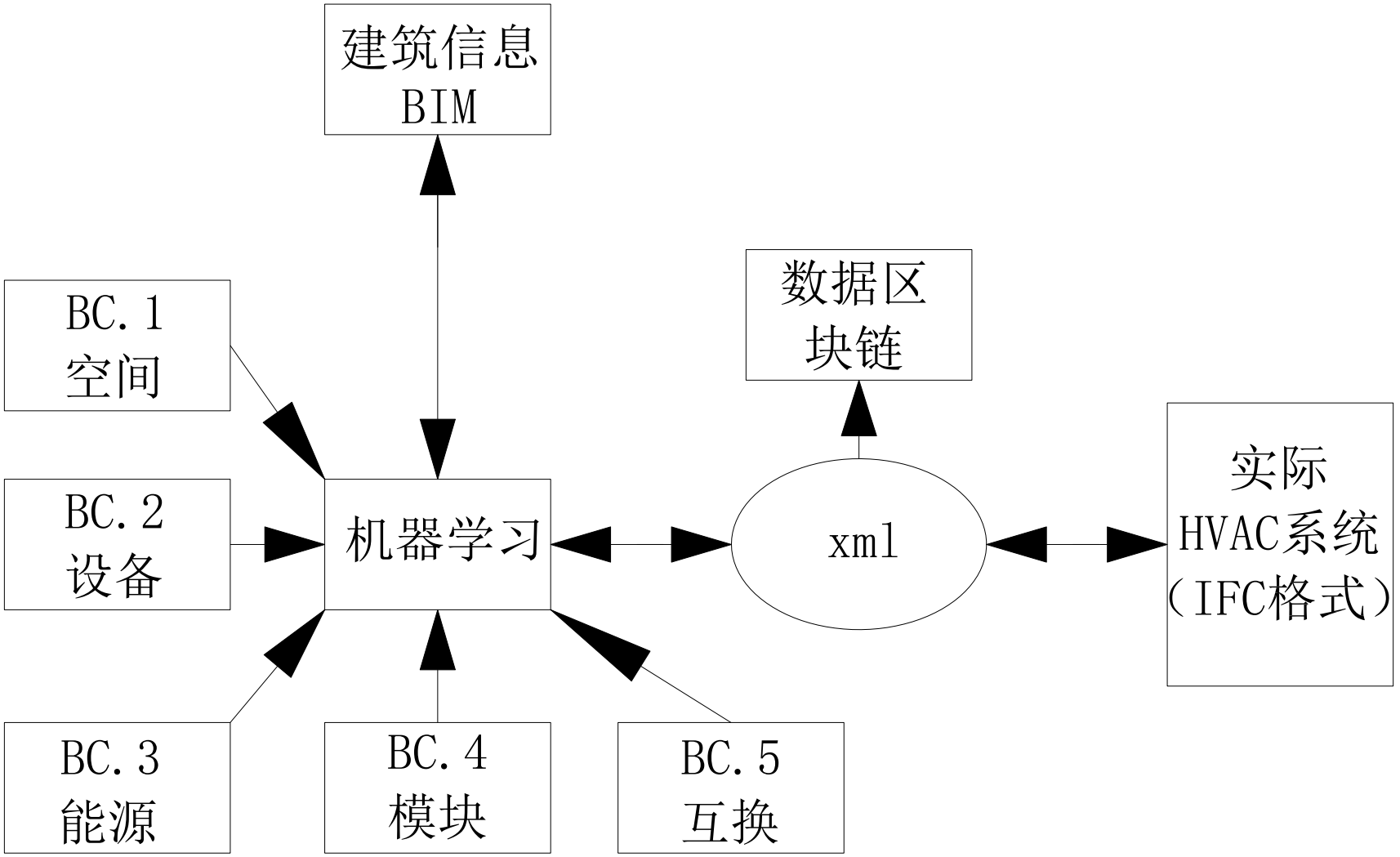
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空间
BC.2
设备
BC.3
能源
BC.4
模块
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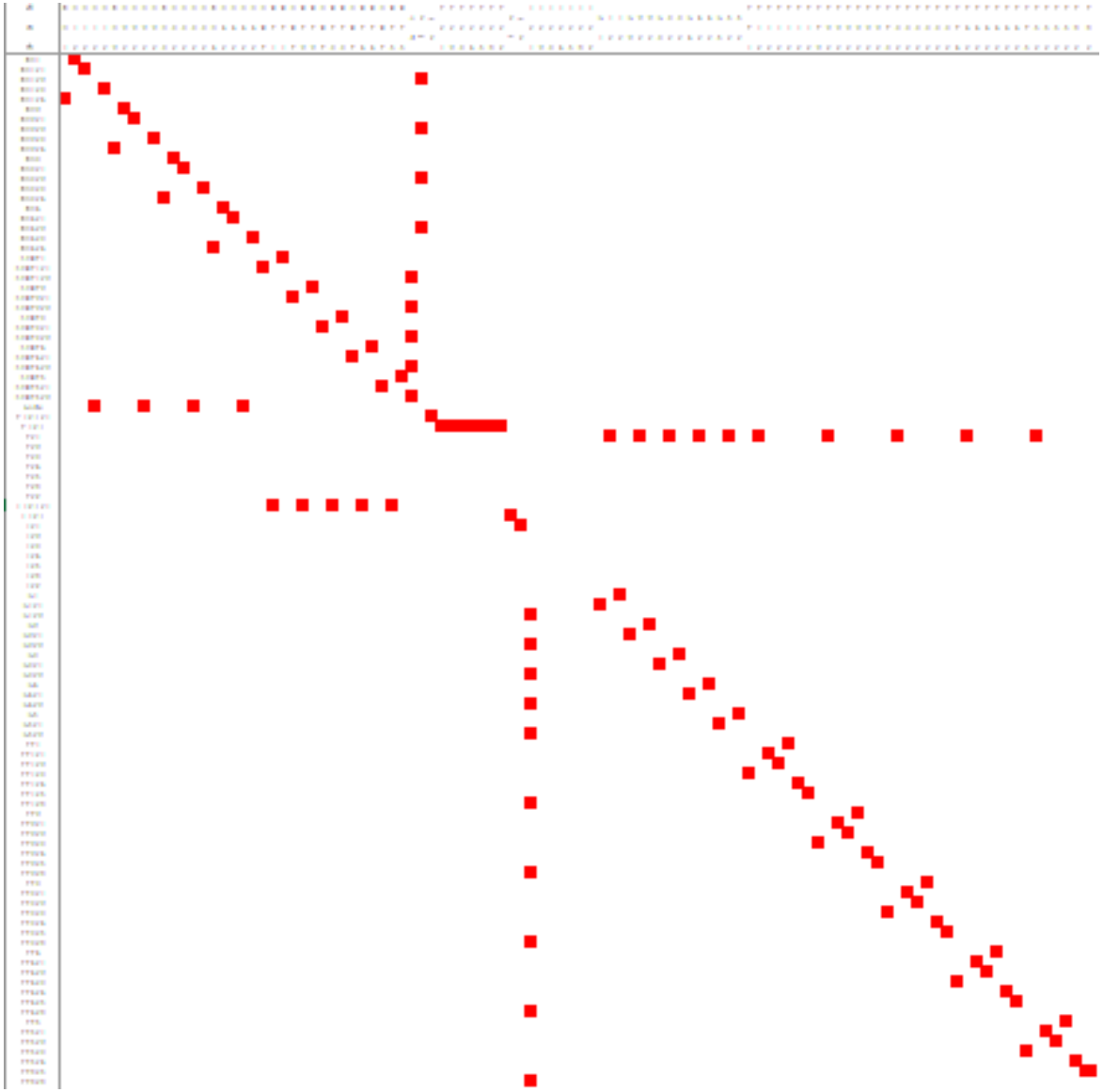
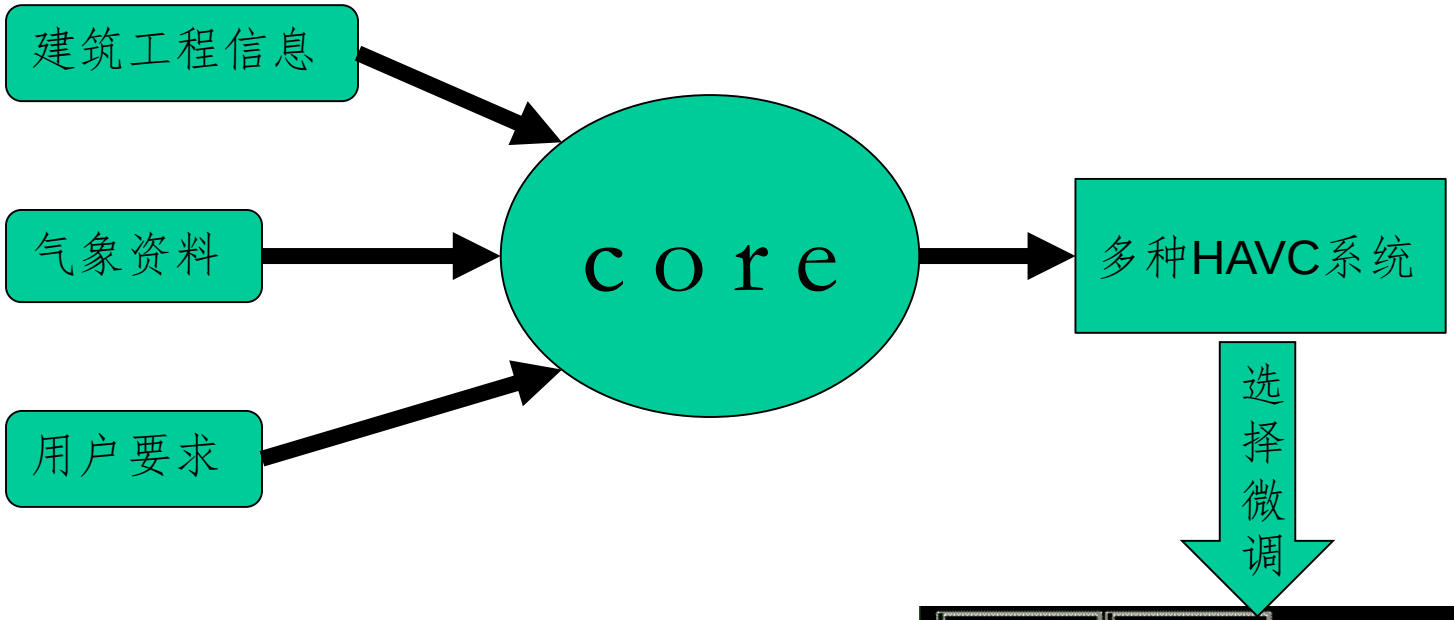
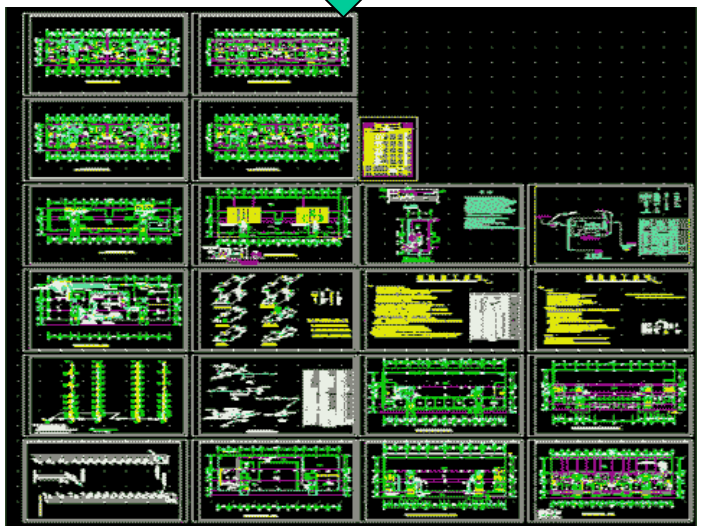
互换
机器学习
数据区
块链
xml
实际
HVAC系统
（IFC格式）



展望





便捷，快速，
参与方案设计
规避设计漏洞与浪费

展望

未来暖通工程师，更多地时间用在方案的选择中，减少重复低效的工作内容

在实际工程中，能与建筑结构设计同步进行，避免暖通设计的滞后性，减少“牵一发而动全身”的劳动负担

谢 谢