Spatially Enabled Smart Campus: Coupling GIS and Operations Research

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- 28,084 Students
- 6,254 Employees
- 10.8 Million square feet
- 200+ Major Buildings (main campus)
- 1,450 acre campus
Introduction

• Smart Campus (what is “Campus”?)

• Analytics: Descriptive, Predictive & Prescriptive (being ‘smart’ through optimization of operations and use of existing resources).

• What are prerequisites for bringing OR methods to support ‘smart’ decisions

• Approaching optimization of campus-wide space assignment

Campus Environment
Campus is a complex system (decomposition)

3.1 Buildings
3.2 Open Space
3.3 Transportation/Transit
3.4 Utilities
3.5 Infrastructure

Processes
- Academic/Teaching
- Research
- Operations
- Residential Life

“Divide & Conquer”
“No buffer space”
“Changes all the time”
3.4 Utilities

- 3.4.1 Steam
- 3.4.2 Water
- 3.4.3 Sewer and Drainage
- 3.4.4 Electrical

CAD, GIS in Dev

3.5 Infrastructure

- 3.5.1 Lightpoles
- 3.5.2 Utility poles
- 3.5.3 Street Furniture
- 3.5.4 Signs/Signage
- 3.5.5 Emergency Phones
- 3.5.6 Other

CAD/GIS/Hardcopy Maps
3. Campus is a Complex System

- Specialization (to cope with complexity)
- Multiple databases
- “Silos”
- Living organization/changes!

Location/Space & Time as KEY to join and relate entities/features in the DBs.

How can we create & maintain ‘comprehensive’ spatial model/db of Campus efficiently.

Spatial Data: CAD, GIS, BIM, NavisWorks
Non-Spatial Data: MS SQL Server, SharePoint, Excel, Other DBs, Text files

4. Data & Analytical Workflows (WF)

Spatial Data Warehouse
Set of ETL workflows
“PULL” system vs “PUSH System”
LEAN approach
Principles of such integration (CAD&GIS)

2.2 Principles

2.2.1 "Reproducible"

2.2.2 Maintainable

2.2.3 Data Driven Models

2.2.4 Workflow Driven

2.2.5 Comprehensive

2.2.6 Interoperability

2.2.7 "Federated" system

... given the fact that majority of the existing buildings data are in CAD/BIM systems/formats.
2.2 3D Modeling: Tools: FME

ETL = Extract – Transform - Load

~300 formats in
~250 formats out
Ability to embed
Python sci libraries
Easy to express ideas

4. Data & Analytical Workflows (WF)

"BRAIN"
Client Applications & Systems
Desktop Mobile Web

"HEART"
ArcGIS Server WebServices Geo-Database

"LUNGS"
GIS File GeoDB Personal GeoDB ShapeFiles
CAD Georefl. CAD Floor Plans CAD TRIRIGA (Space)
BIM SQL Server XML Other IT Systems Legacy Data
“Backfill” Space Assignment Problem

GIS & Buildings

BUILDINGS are “BLACK BOXES”
“OBSTACLES” :: “ORIGIN/DESTINATIONS”
SYSTEM ANALYSIS?

1860
http://www.bostonfirehistory.org/nuonebucketengine04a.html

1880
GIS & Buildings vs. CAD & Buildings

NOLLI MAP of ROME (1748) [http://nolli.uoregon.edu]

Giambattista Nolli (1701-1756) - Architect & Surveyor

Why do we need model buildings as a part of the system:

They are important …

In the US:

- 70% of Electricity
- 40% of overall waste produced
- 50% of lifetime of an average American vs 13% of time spent OUTDOORS

http://www.smarterbettercities.ch/3dgis-hospital/
Buildings/Urban Environment are critical for Human Race

![Map of cities](http://www.192021.org)

19.20.21 PROJECT:

- 1800 – 3% of population
- 1900 – 150 million
- 2000 – ~50% (3 Billion)
- 2050 – 75% of population

will be living in CITIES/BUILDINGS

“Backfill” Space Assignment

New building is built on campus
Researchers/Groups are moved to the new building, vacating their offices and labs.

What would be an optimal policy to assign the vacant space to other groups/users?

Demand - Supply - Assignment

What parameters and constraints? Performance metrics?

Everything has a SPATIAL component
“Backfill” Space Assignment

Demand

Supply

Demand

Supply
"Backfill" Space Assignment

Demand

Supply

\[ C_{ij} \]

\[ X_{ij} = \{0, 1\} \]

Assigning Person A from office i to office j

- Distance to teaching space
- Office area is adequate
- Distance to department HQ
- Distance to Grad Student Labs
- Distance to a collaboration space
Creating room/space inventory

3.1 Spatial DB of Space Inventory

3 step process: (3 feature classes)

Input:
- CAD Floor Plans
- CAFM
- GIS Layers with BLDG footprints
- Elevation profiles
### 3.1 Unique Campus Space ID & 3D representation of rooms

Spatial database is a collection of **rooms(spaces)**, which are registered in physical space and have unique “global” campus ID.

Connection to the enterprise DB

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**STEP 1: CAD to GIS (Architectural Space)**

From CAD Space to ARCH Space
Origin (0,0) is shifted to specific tile/cell
Every SPACE has PRIMARY KEY
BLGD_FLOOR_ROOM
ETL: CAD to Arch Space

2D (2.5D) Inner Space Modeling: “Architectural Space”
2D (2.5D) Inner Space Modeling

Step 2: Getting Shift, Scale and Rotation for Buildings
Step 2: Getting Shift, Scale and Rotation for Buildings

Step 3: GIS “Arch” to GIS “Real World”

Every SPACE has PRIMARY KEY BLGD_FLOOR_ROOM

Ability to JOIN External datasets
ETL: Arch to GIS Space

2D (2.5D) Inner Space Modeling: 2-Way process

2-way translation: ETL to add/update data in CAD via GIS (“Breadcrumbs”)

UMassAmherst
Each space/room has LOCATION_ID to join with DBs
UMassAmherst

Room/Space Spatial Database

3 Feature classes:

- Floors (~1,800)
- Rooms (~32,000)
- Arch Details (windows, doors, stairs) ~ 8 million

Every feature has LOCATION_ID
Buildings Networks I
(“Pine branches”)
Example 3: Indoor Routing & Navigation

A building is more than just set of Rooms/spaces.
- From inventory/reporting to optimization and analysis

Vertical & Horizontal Conveyors

Getting ideas for modeling building networks

Network/Graph $G(N,E)$

edges $E$:
- $E_h$ - horizontal edges (room $\rightarrow$ floor centroid)
- $E_v$ - vertical connections b/w floors

nodes $N$:
- $N_r$ - room centroids
- $N_f$ - floor centroids

$G(V,E)$ should be connected to pedestrian networks.

IBM (Supply Chain Optimization)
Testing our ideas for modeling building networks
Workflow to build the network/graph $G(V,E)$

Input:
- FC - Rooms (~32K)
- FC - Floors (~1,8K)

Output:
- FC - Nodes (Pnts)
- FC - Edges (Lines)

Network/Graph $G(V,E)$

- $|E|$ ~ 32,000 (horizontal) + 1,800 (vertical)
- $|V|$ ~ 32,000

Full set of attributes for rooms/floors

Processing time: ~ 2 min.

Connectivity to pedestrian/transportation networks

Bridging the “scale” divide (geo-design)
Building/Floor topology defines the performance metrics ("Pine branch" networks are not enough)

IBM (Supply Chain Optimization)  ESRI (Travel Time along actual road network)
Modeling paths between rooms

Building Indoor Networks

- Space Assignment
- Location/Allocation
- User/Space Interaction
- 2D/3D Routing
- Evacuation Planning
- Accessibility

Example 3

Source: J. MacGregor Smith (MIE, UMass Amherst)

Developing networks to model crucial building functions
Example 3: Indoor Routing & Navigation

Rectilinear Steiner Minimal Trees (RSMT) with Obstacles

- Rooms
- Doors
- Corridors (Circulation)
- Walls (Obstacles)

CAD/DB

Example 3 RSMT: IMPLEMENTING MST with Custom Transformer

Rectilinear Steiner Minimal Trees is a graph connecting all rooms/corridors with edges and ensures min. total length

Prof. J. MacGregor Smith (jmsmith@ecs.umass.edu)

Network Representation (Floor/Building)
Example 3 RSMT: IMPLEMENTING MST with Custom Transformer

```python
import pynms
import networkx as nx

class MetPythonFactory(object):
    def __init__(self):
        self.edge_counter = 0
        self.logger = pynms.PMLogFile()
        self.logger.log("MST Factory was initialized ...", 2)
        self.G = nx.Graph()
        self.logger.log("NX Graph was initialized", 1)

    def input(self, feature):
        self.edge_counter += 1
        self.logger.log(" Processing feature ' + str(self.edge_counter) + "
        self.edgeID = feature.getAttribute('metEdgeID')
        self.startNodeID = feature.getAttribute('metStartNodeID')
        self.endNodeID = feature.getAttribute('metEndNodeID')
        self.edgeLength = feature.getAttribute('metEdgeLength')
        self.edgeNodes = str(self.startNodeID) + '_' + str(self.endNodeID) + '
        self.G.add_edge(self.startNodeID, self.endNodeID, weight = self.edgeLength, id
        self.logger.log( 'Close method for MetPythonFactory ->
        self.met = nx.kruskal_met( self.G)
```

21 rows of code to implement MST transformer
4 rows to solve Minimum Spanning Tree sub-problem using NetworkX (LANL) (http://networkx.lanl.gov/)

Buildings as system: GIS as Decision Support System

UNIQUE ANALYTICAL ABILITIES TO DECISION MAKERS

- Energy Use Optimization
- Facilities Management
- Asset Management (Equipment)
- Location/Allocation of Resources
- Public Safety and Security
- Maintenance
- Space and Group Management (NIH, the largest research organization)
- Optimization of Space Utilization
- Improve Collaboration
- Indoor Navigation and Routing
- Event Scheduling (‘time table for College’)
- Urban Planning
- Landscape Architecture and Design

- Sea Ports, Airports, Shopping Centers …
Conclusion

• GIS is an **enabling technology** for prescriptive analytics (Operations Research).

• GIS facilitates research collaboration among **multi-disciplinary** teams

• Geospatial approach **dissolves silos** within organization and stimulates organization-wide awareness.

• Spatial DB/ETL coupling allows to bring existing analytical tools and libraries to transform/analyze data.

• (Format agnostic, data centric)

• GIS approach may encourage collaboration among academic, research, operations and industry.

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