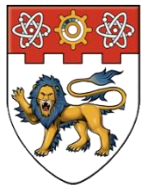# Thrust 6: Cyber-Physical Testbeds

K.M. Mosalam, UC-Berkeley
& S.P. Chiew, NTU
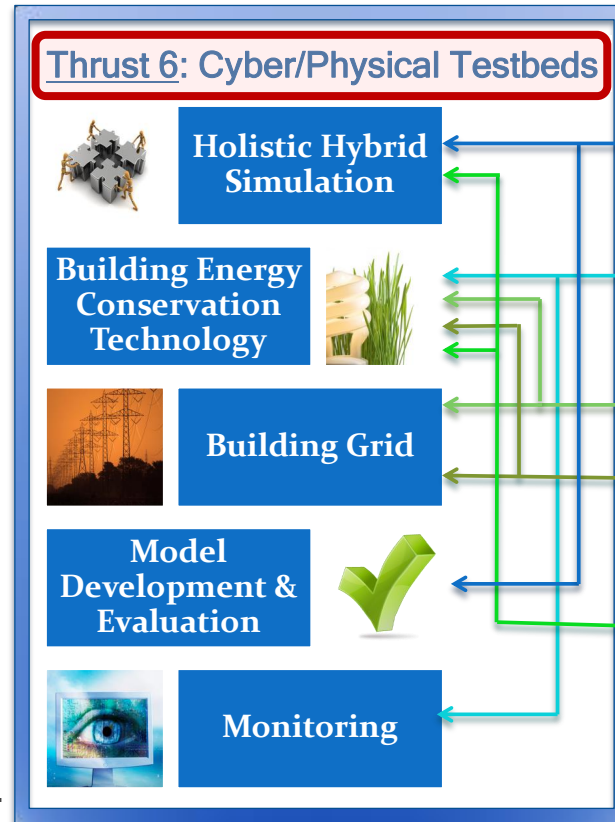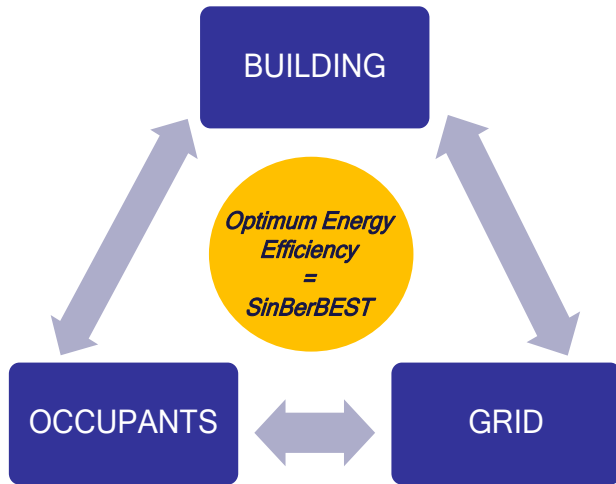
9 January 2013

BEARS | SinBerBEST

NATIONAL
RESEARCH
FOUNDATION

# Dynamic Interaction for Optimum Energy Efficiency within SinBerBEST



BUILDING

Optimum Energy Efficiency = SinBerBEST

OCCUPANTS

GRID

Consumed energy in building construction and operation can be reduced by intelligent interaction between the grid, the building and its occupants/appliances. This requires a transformational paradigm-shift in designing, commissioning, & retrofitting.

**Thrust 6**: Cyber/Physical Testbeds

Holistic Hybrid Simulation

Building Energy Conservation Technology

Building Grid

Model Development & Evaluation

Monitoring

**Thrust 1**: Sensing, Data Mining and Modeling

**Thrust 2**: Multi-Level Optimal Control

**Thrust 3**: High Confidence Building Operating System

**Thrust 4**: Human-Building Interaction & the Environment

**Thrust 5**: Material, Design and Lifecycle

# Thrust 6: Mission Statement and Plan

## Cyber-Physical Testbeds

Verify the actual performance, efficiency and effectiveness of all developed technologies ***in other thrusts*** as an ***integrated*** system.

1) Survey existing testbeds in Singapore and UC-Berkeley

2) Close communication with other thrusts to understand needs for future testing and soliciting cross-thrusts proposals:

❑ Middleware services for testbed integration

❑ Cyber-infrastructure for data management

3) Develop a decision-making assessment framework

# Thrust 6: PI's



Khalid Mosalam[1]    Sing-Ping Chiew[2]    Costas Spanos[3]    King Jet Tseng[4]    Hock Beng Lim[5]    Stefano Schiavon[6]

1) Khalid Mosalam (Professor, Structural Engineering, Mechanics, and Materials, CEE, **UC-Berkeley**, Thrust Co-Leader)
2) Sing-Ping Chiew (Associate Professor, Structures and Mechanics, CEE, **NTU**, Thrust Co-Leader)
3) Costas Spanos (Professor, Electrical Engineering and Computer Science, **UC-Berkeley**, Co-PI)
4) King Jet Tseng (Associate Professor, Power Engineering, Electrical and Electronic Engineering, **NTU**, Co-PI)
5) Hock Beng Lim (Director, R&D, Intelligent Systems Center, **NTU**, Collaborator)
6) Stefano Schiavon (Assistant Professor, Center for the Built Environment, Architecture, **UC-Berkeley**, Collaborator)
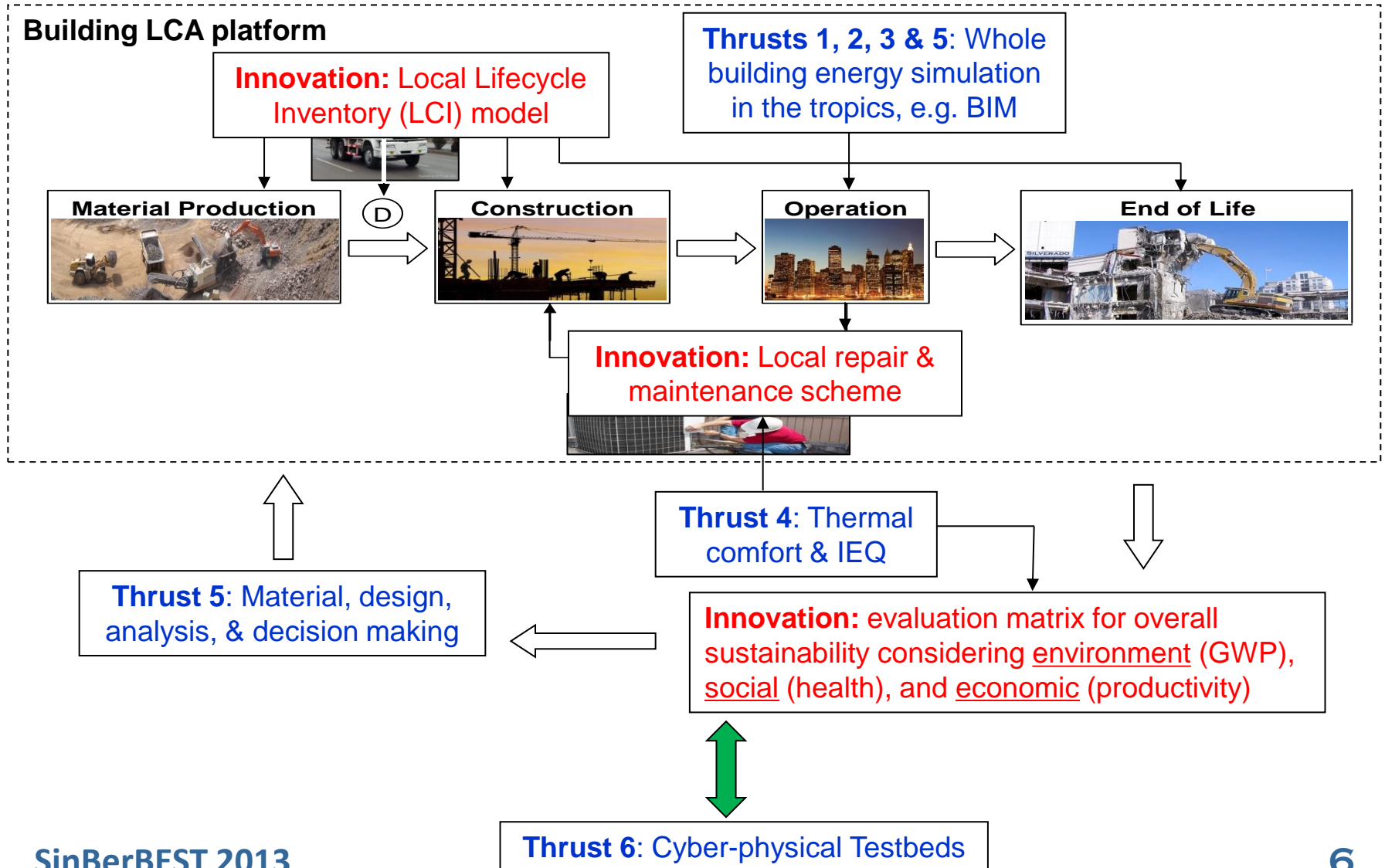
# Unveiling the Built Environment
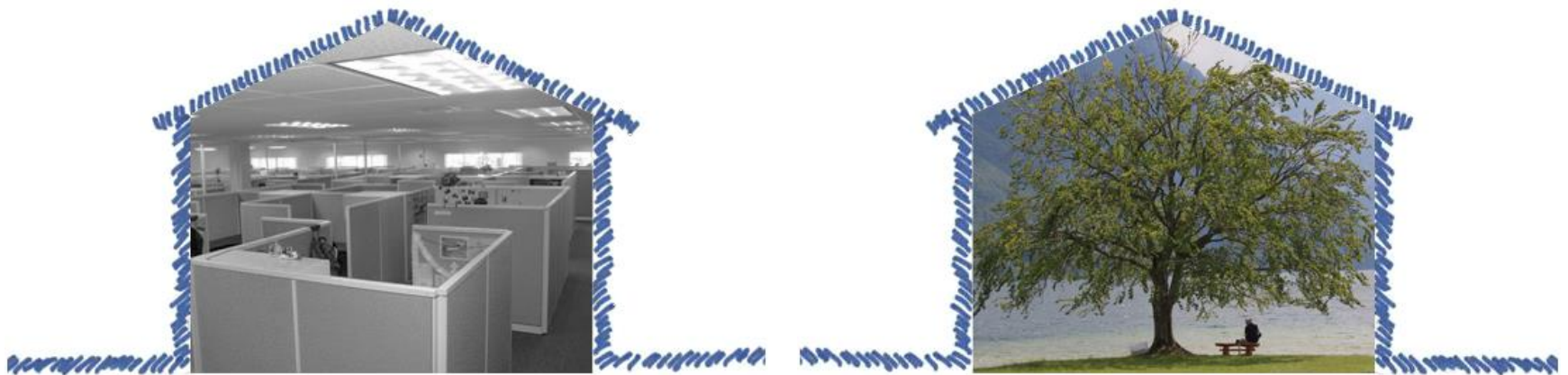


Design by S Schiavon

*We should design indoor environments that are better than the best environment found in nature*
— Ole Fanger

# Building Lifecycle Assessment and SinBerBEST Innovations

**Building LCA platform**

**Innovation:** Local Lifecycle Inventory (LCI) model

**Thrusts 1, 2, 3 & 5:** Whole building energy simulation in the tropics, e.g. BIM

**Material Production**

D

**Construction**

**Operation**

**End of Life**

**Innovation:** Local repair & maintenance scheme

**Thrust 4:** Thermal comfort & IEQ

**Thrust 5:** Material, design, analysis, & decision making

**Innovation:** evaluation matrix for overall sustainability considering environment (GWP), social (health), and economic (productivity)

**Thrust 6:** Cyber-physical Testbeds

# Displacement Ventilation & Chilled Ceilings



Manitoba Hydro Building, Canada, by KPMB



David Brower Center, US, by Solomon/WRT

# Displacement Ventilation & Chilled Ceilings

Laboratory experiments for typical U.S. interior zone office to investigate how:

1. Ratio of cooling load removed by CC over the total cooling load

2. Percentage of active ceiling area (radiant surface temperature) affect:

   i. Air stratification
   ii. Air change effectiveness

*Schiavon S, Bauman F, Tully B, and Rimmer J. 2012. Room air stratification in combined chilled ceiling and displacement ventilation systems. HVAC&R Research, Vol. 18(1).*
*http://escholarship.org/uc/item/980931rf*



Center for the Built Environment

# A Testbed for Increasing the Heat Load

Center for the Built Environment
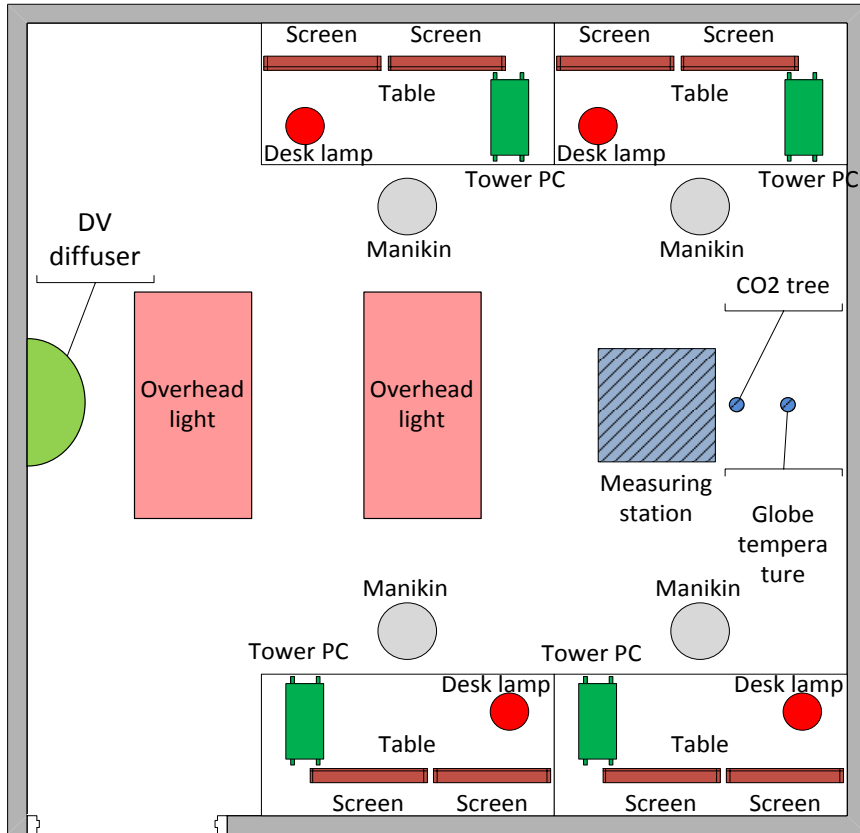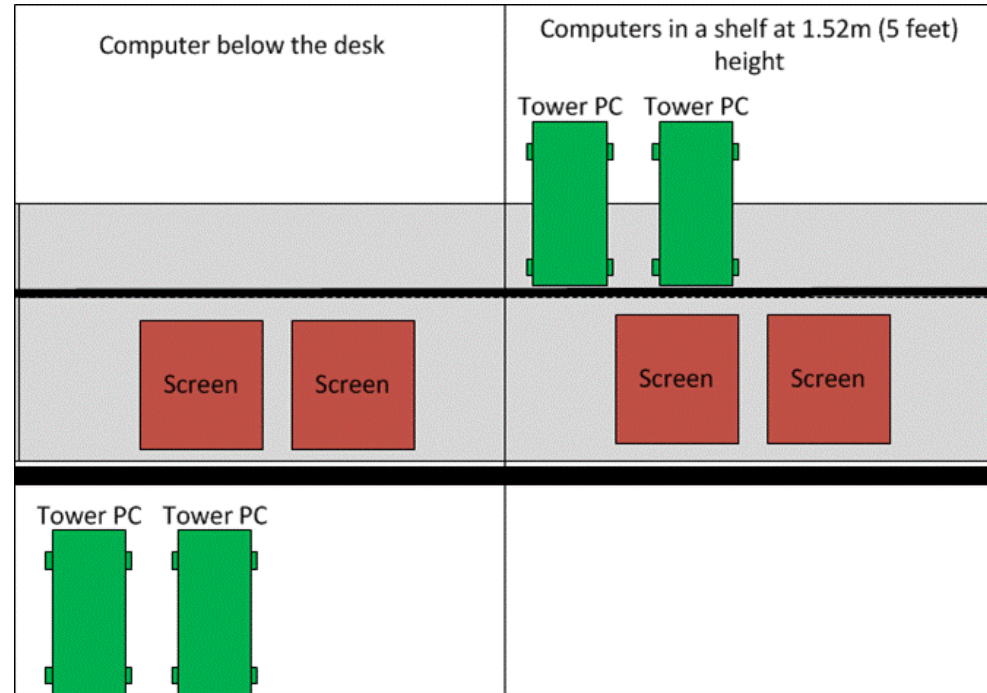


## Case C1    Case C2



**Tower PCs (50% of total load) moved from under the desk (C1) to a shelve above the screens at 5 ft (C2)**

*Schiavon S, Bauman F, Tully B, and Rimmer J. 2013. Temperature stratification and air change effectiveness in a high cooling load office with two heat source heights in a combined chilled ceiling and displacement ventilation system. Submitted to Energy and Buildings.* http://escholarship.org/uc/item/58m8302p

# SinBerBEST Testbed Initiative in Collaboration with Thrust 3

- **Thrust 3: High Confidence Building Operating System** focus on reducing energy consumption in interior lighting by developing efficient and intelligent lighting grids using solid-state devices and natural light.

- A project between SinBerBEST & Energy Research Institute (ERI@N) started to use SinBerBEST space as a testbed for assessing visual performance metrics.
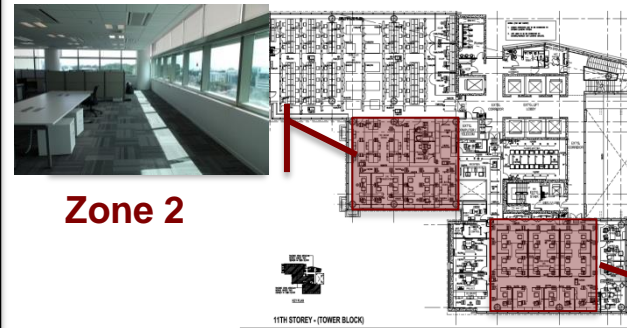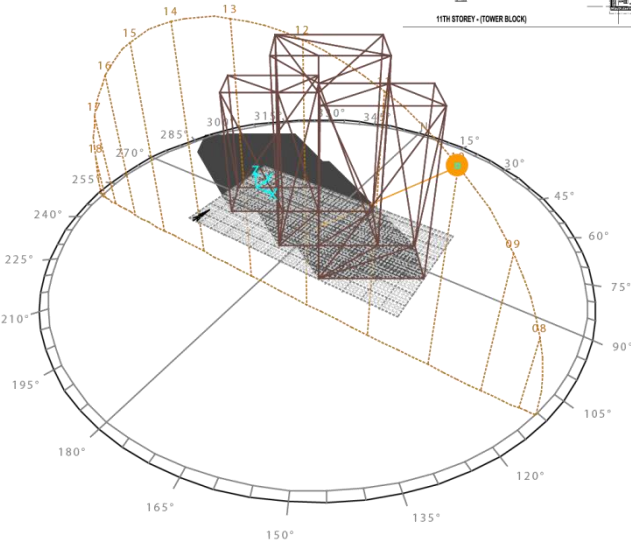
SinBerBEST, Level 11, CREATE Tower

U Town

# SinBerBEST Testbed – Office Environment



Zone 2

Zone 1

N

KEY PLAN

11TH STOREY - (TOWER BLOCK)
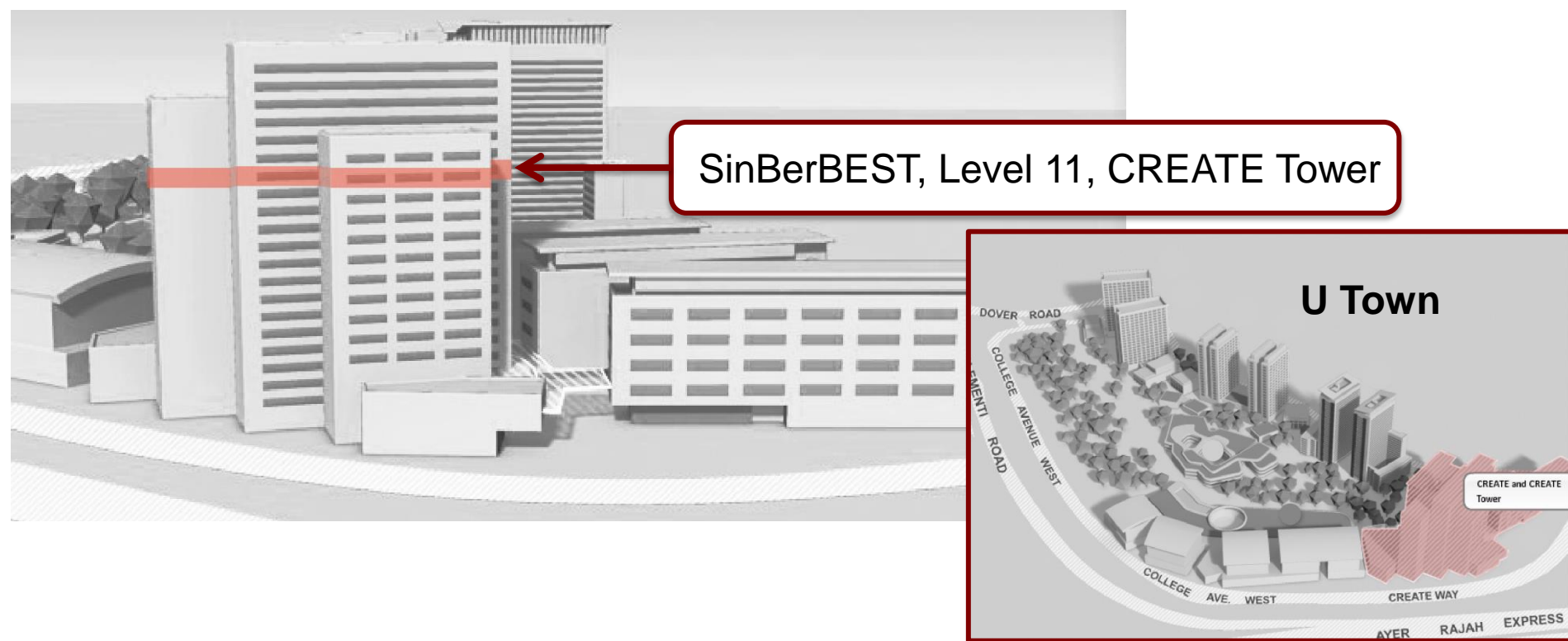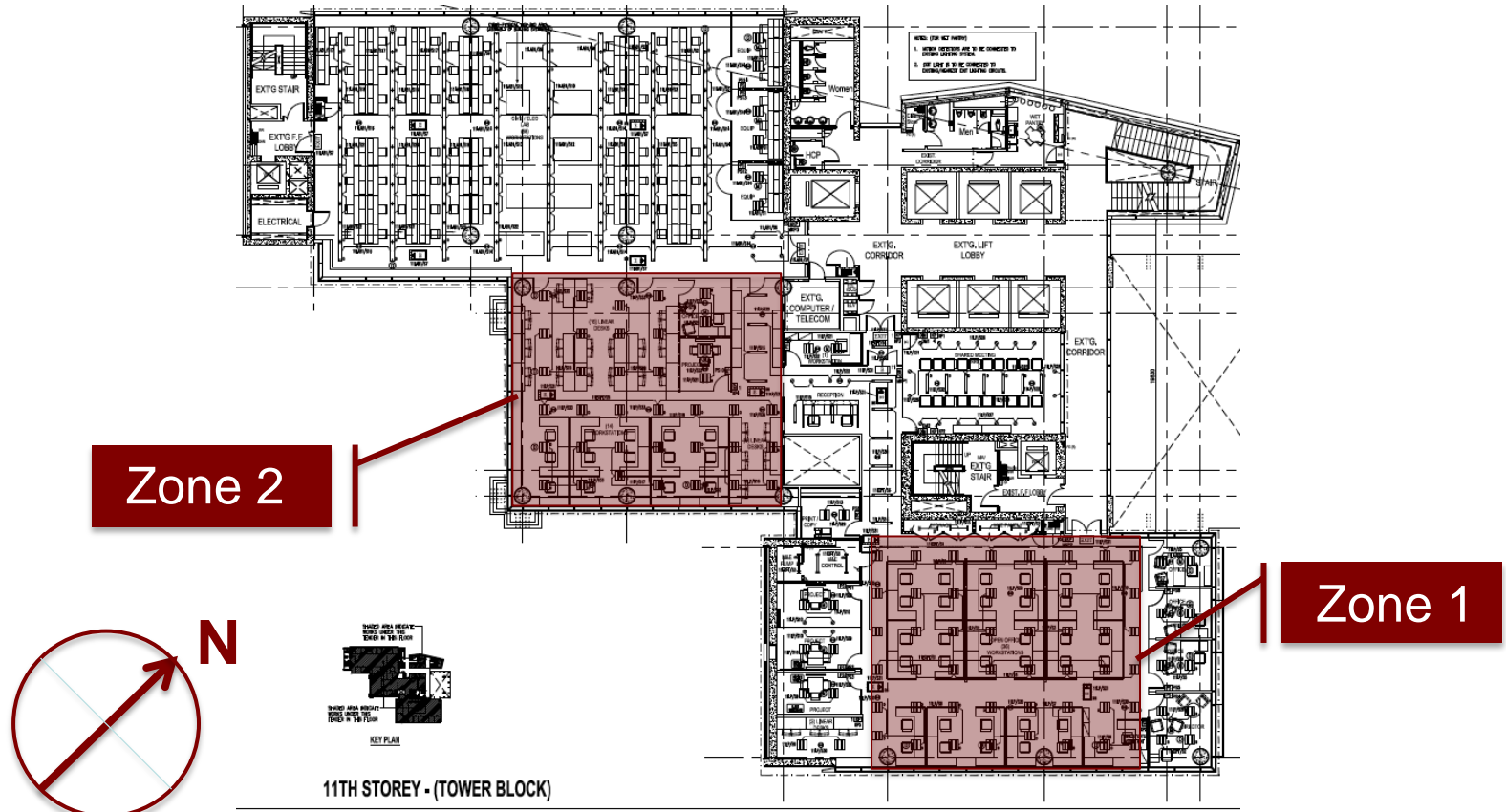
# SinBerBEST Testbed – Office Environment

## Daily sun path



10:00 am, Dec 21, 2012

Zone 2

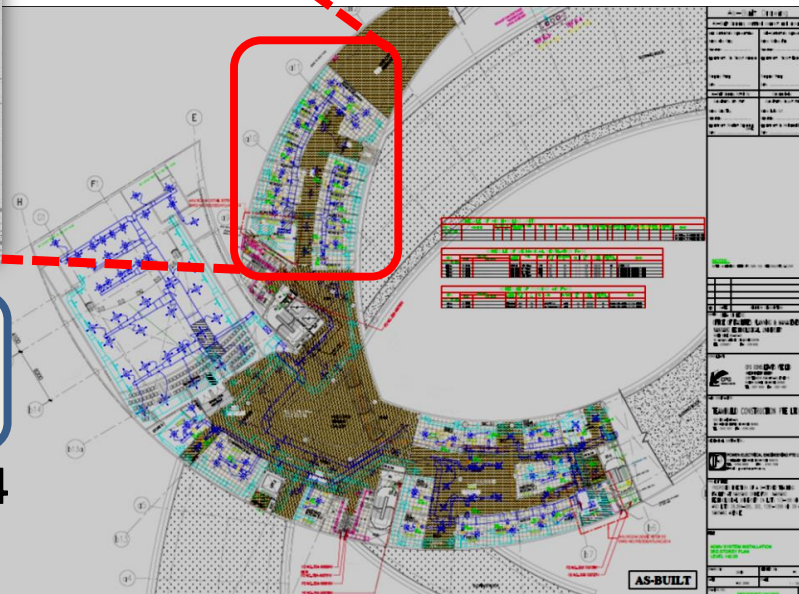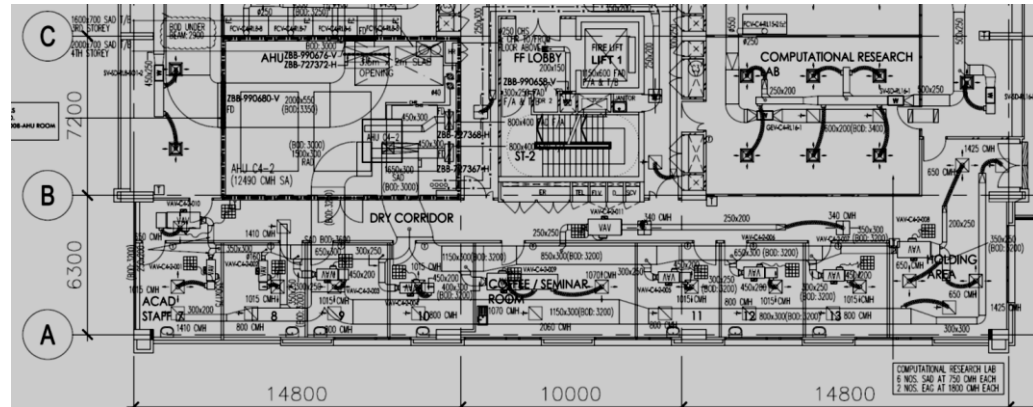Zone 1

N

December 21th Singapore

Zone 2

4:00 pm, Dec 21, 2012

Zone 1
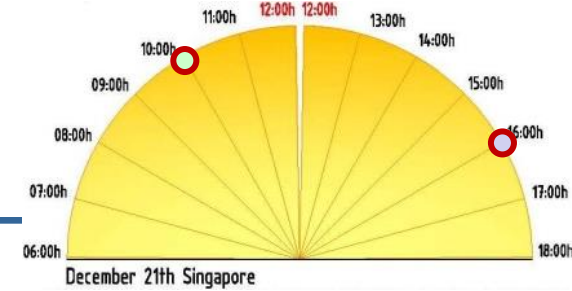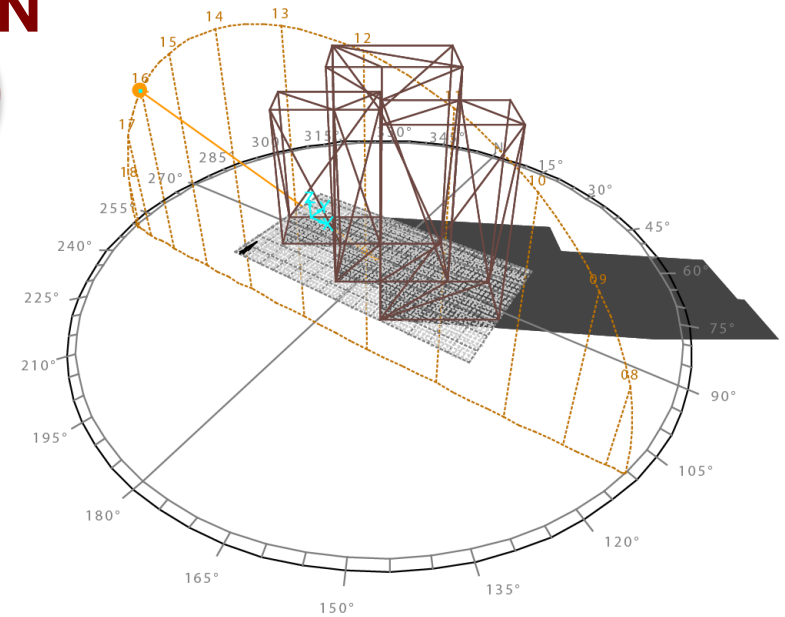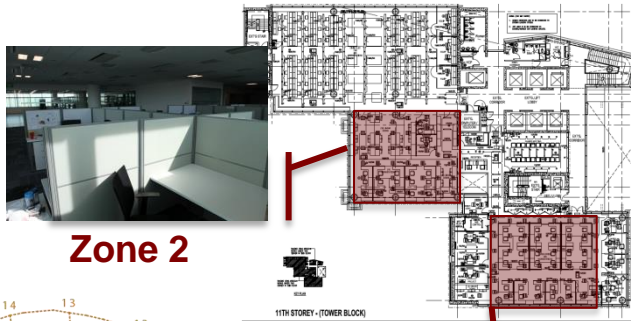
# Other Testbeds (UC-Berkeley + ERI@N)

## Sensor Selection and Placement for $CO_2$ and Temperature Fields

- Data collected includes Temp., RH, <u>$CO_2$ concentration</u>, Occupancy, & Supply airflow rate in the defined spaces.

- **Idea:** Use sparse sensor array, occupancy info., models → $CO_2$ & Temp fields in a networked rooms.

- 7 office spaces
- 1 discussion room
- 1 holding area + hallway
- Served by same AHU
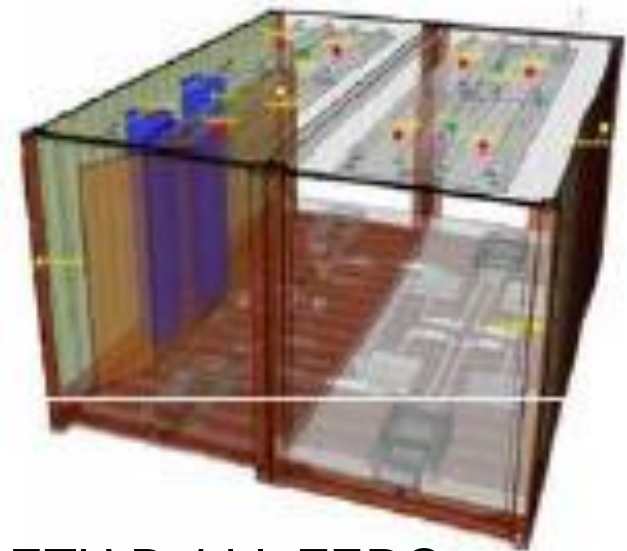
SMPS Building, Level 4

- 12 office spaces
- 1 hallway
- Served by same AHU
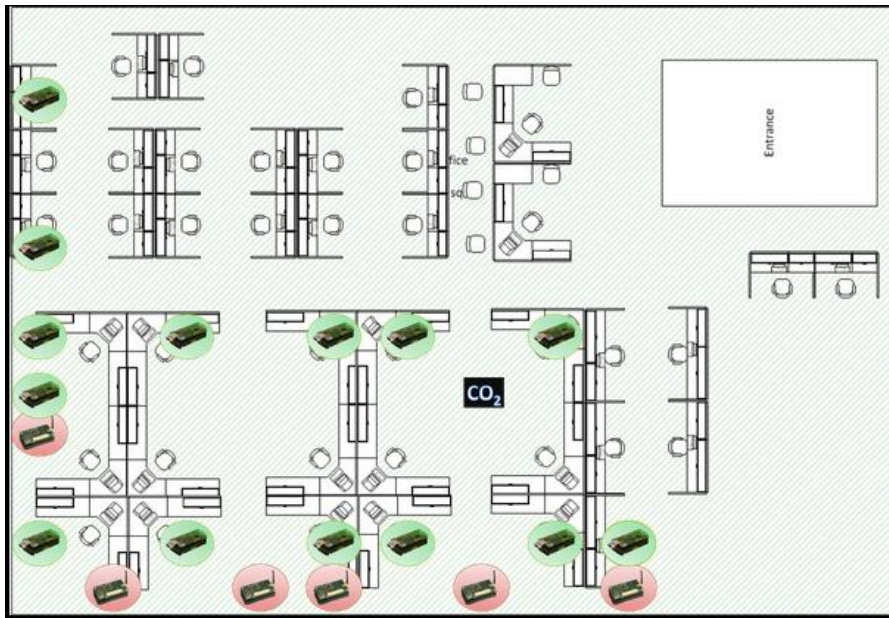
SADM Building, level 4

# Sensor Network Testbeds



SinBerBEST sensor network testbeds deployed at:
- ❖ SinBerBEST office space
- ❖ BCA test chambers
- ❖ ETH BubbleZERO
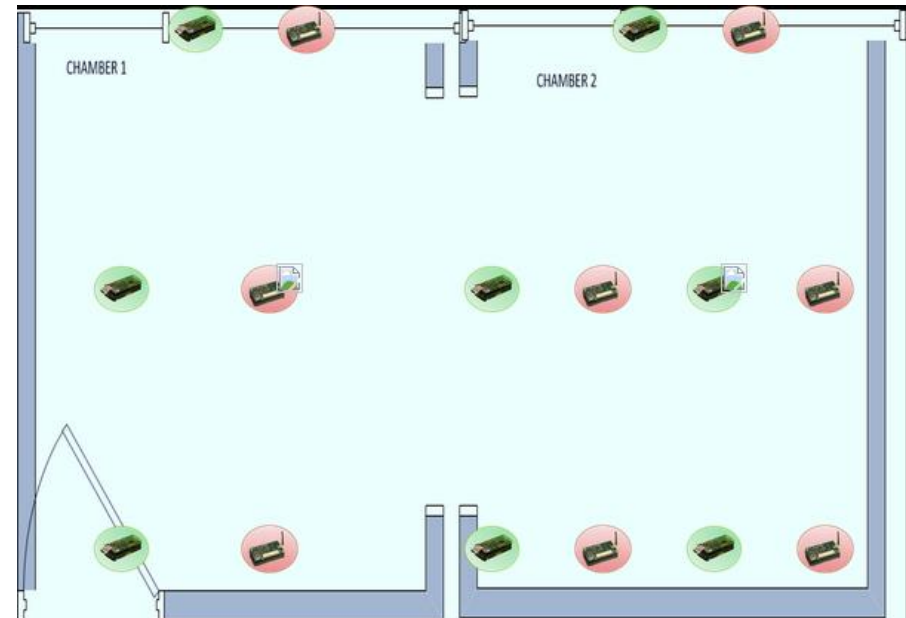
ETH BubbleZERO Testbed



SinBerBEST Testbed



BCA Testbed

# BCA Press Release

*"… of interest is the SinBerBEST's wireless sensing system … meant to connect test labs from various sites in Singapore to a central monitoring server so that building technology researchers could share data and align research activities on facades or indoor environment quality going forward."*

# Deployment Status

Deployed heterogeneous sensor networks:

❖ MicaZ with TinyOS
❖ TelosB with Contiki OS
❖ iMotes, IRIS

Sensing functionality:

❖ Temperature, light, humidity, **$CO_2$ levels**
❖ **Example**: humidity readings from TelosB

Data Stream

❖ Sensor data streaming from SinBerBEST testbed to Berkeley's Sensezilla

# Demo Prototype



**Dashboard Interface**:
- ❑ Heat map
- ❑ Network topology
- ❑ Real time sensor data

# Future Extension: Data Management and Analytics Framework for Smart Buildings
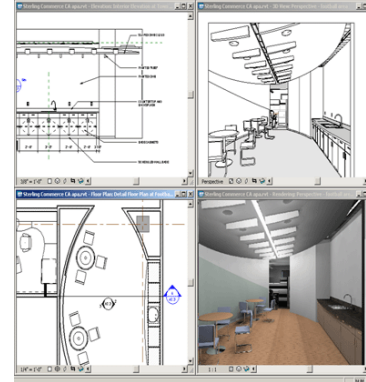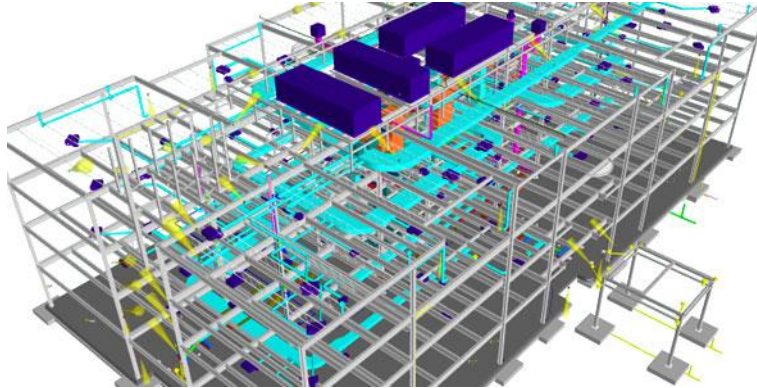


**Motivation:**

- Building Information Model (<span style="color:red">BIM</span>) are required for all building design submissions

- Current <span style="color:red">BIM</span> provides building information that is mainly architectural & physical in nature without sensing and information of energy consumption.

- <span style="color:red">BIM</span> has the potential to be a universal data aggregation platform.

**Objective:**
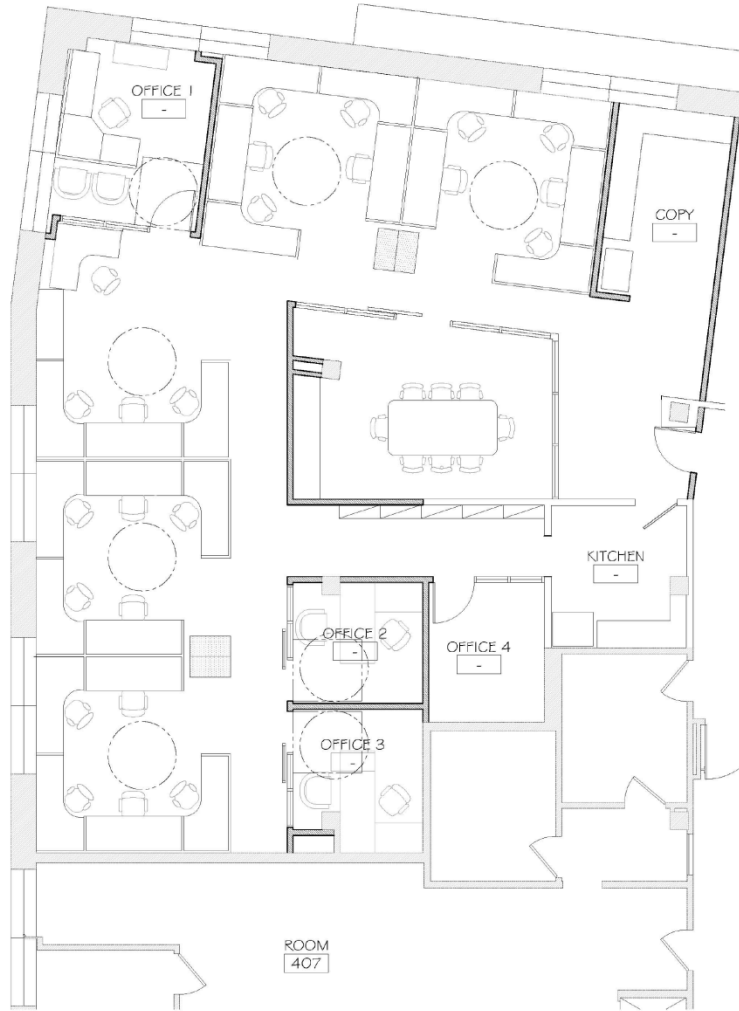
Develop a data management and analytics framework to share data from different building testbeds and to integrate with <span style="color:red">BIM</span>.

# CREST† 406 Bubble:
# A Testbed in Cory Hall, UC-Berkeley

†Center for Research in Energy
Systems Transformation
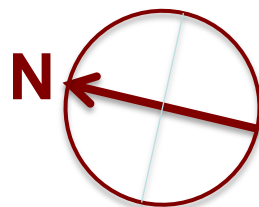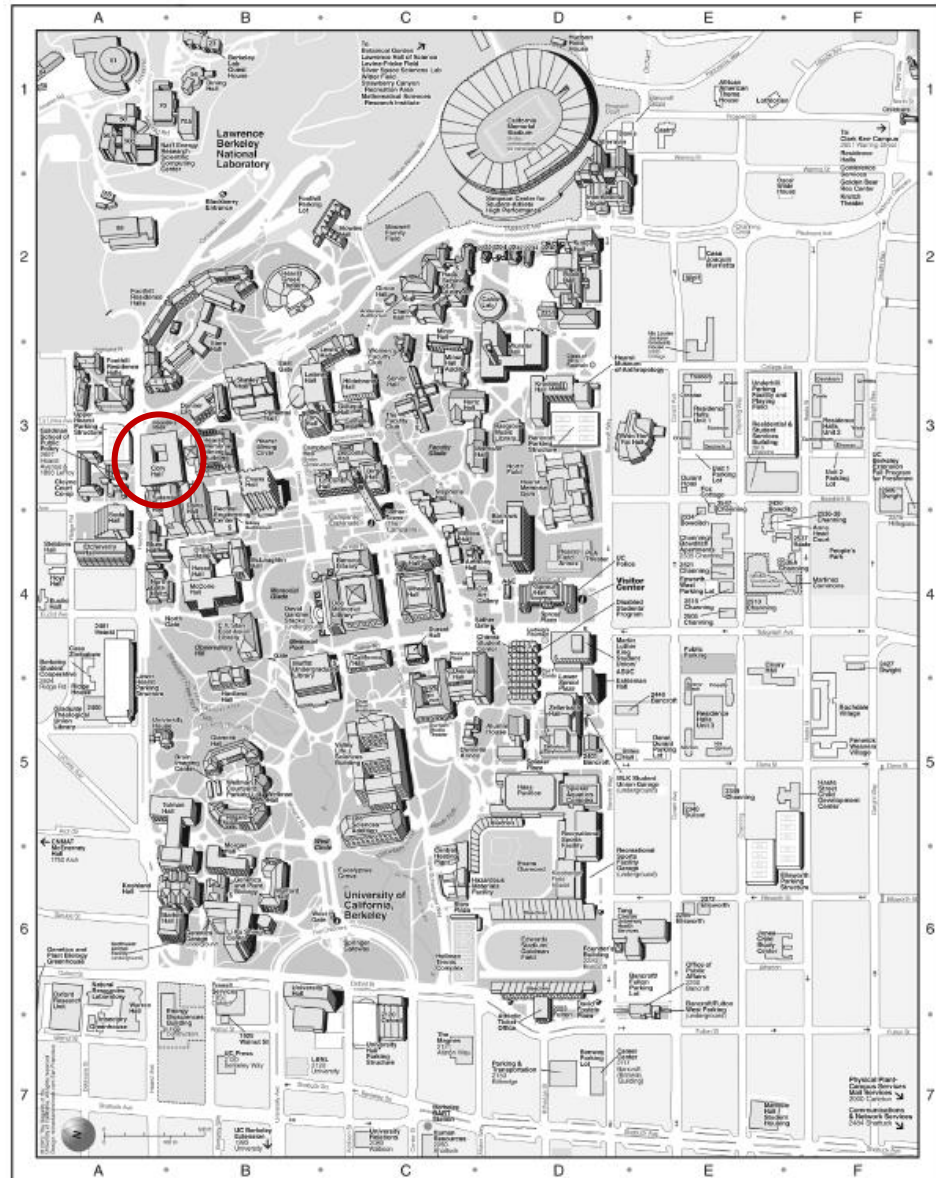
# CREST 406 Bubble



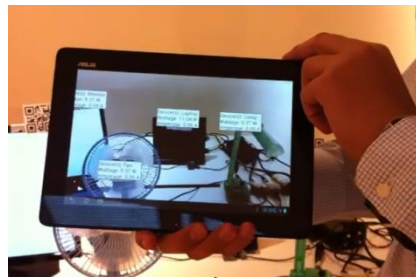A — SUITE 406 CONCEPTUAL LAYOUT
SCALE: 3/16" = 1'-0"

SHAFFER ARCHITECTS
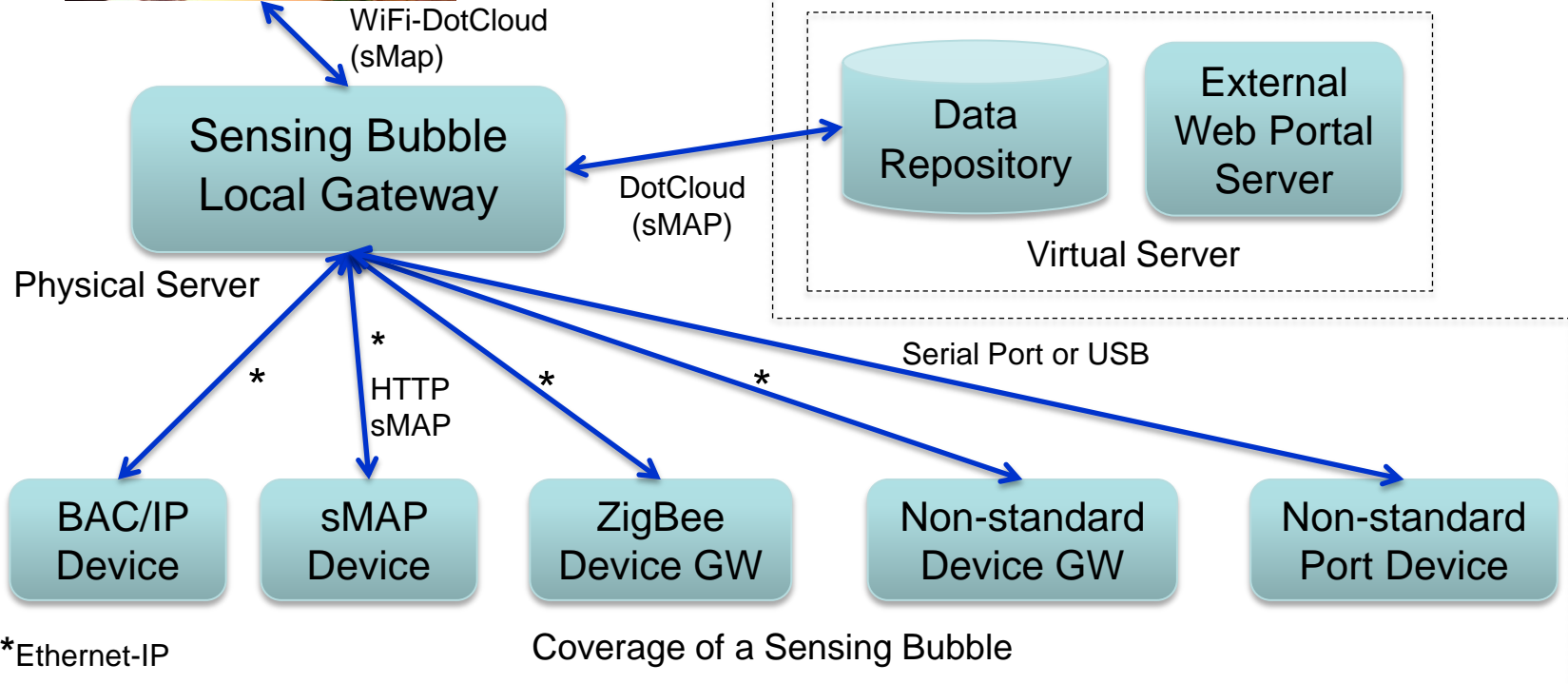5.3.12

# Data Connectivity in a Sensing Bubble

**EnergyEyes** app uses QR codes & real-time data flow from devices to an end-user to find energy waster



WiFi-DotCloud
(sMap)

Sensing Bubble
Local Gateway

Physical Server

DotCloud
(sMAP)

## Objectives:

– Build a local bubble gateway
– Interface with *all types* of sensors/actuators in 406
– Provide Augmented Reality (AR) view/control on Android Pad
– Preliminarily implement the data-centric infrastructure with space-time and semantic searching interface

Data Repository

External Web Portal Server

Virtual Server

Serial Port or USB

*

*
HTTP
sMAP

*

*

| BAC/IP Device | sMAP Device | ZigBee Device GW | Non-standard Device GW | Non-standard Port Device |

*Ethernet-IP

Coverage of a Sensing Bubble

# Performance-based Engineering (PBE) for "Best" Decision of Energy-efficient & Sustainable Building Design

## Objective:

Develop a framework to make the best decision for building design satisfying:
- ✓ Energy-efficiency
- ✓ Sustainability
- ✓ Safety
- ✓ Economical constraints, etc.

considering interests of stakeholders & sources of uncertainties during lifecycle.
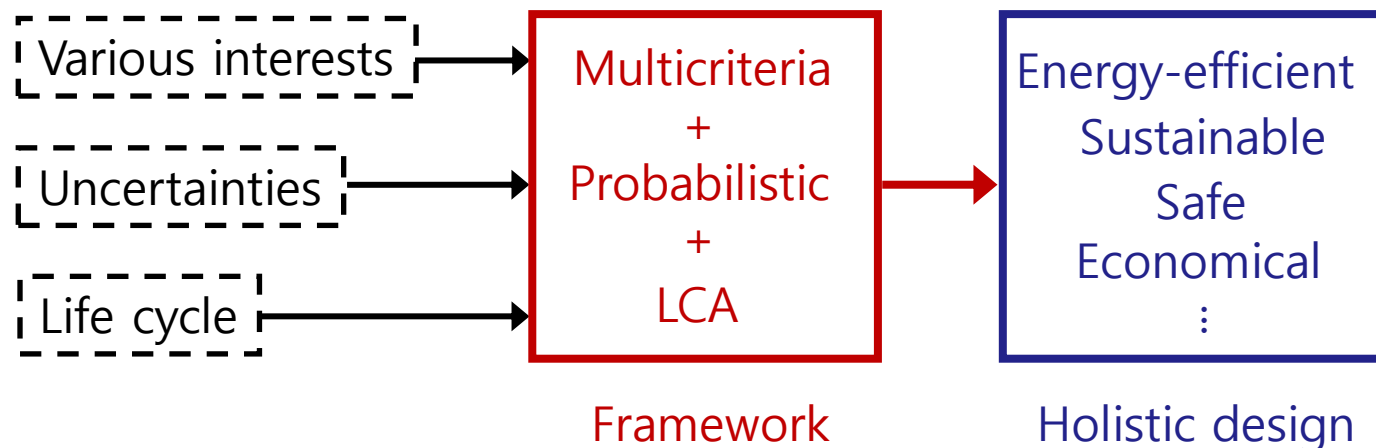
# PBE-Approach to the Holistic Best Design Decision

**Decision-Making Process:**

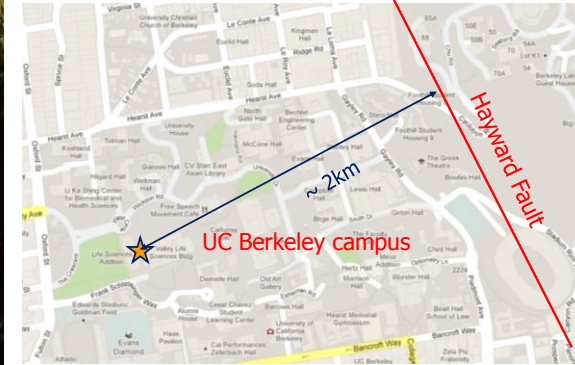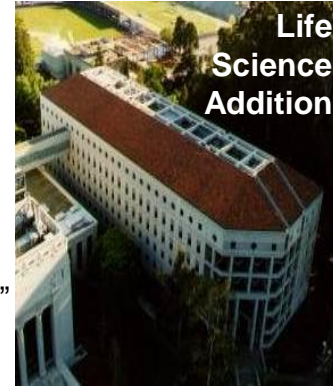**MIVES** (Model for Integration of Values for Evaluation of Sustainability)

**4 steps:**
– Tree Construction
– Value Function
– Weight Assignment
– Selection Amongst Alternatives

# Testbed for PBE-MIVES Approach

**Example building**: UCS building at UCB

**Details are presented tomorrow by Dr. Hyerin Lee**

Mosalam K.M., Armengou J., Lee H., Günay S., and Chiew S.P., "**Performance-based Engineering Approach to the Best Decision for Energy-efficient and Sustainable Building Design**," Invited Paper, 1st International Conference on Performance-based and Life-cycle Structural Engineering (PLSE 2012), 5-7 December 2012, Hong Kong, China.



Life Science Addition



~ 2km

UC Berkeley campus

Hayward Fault
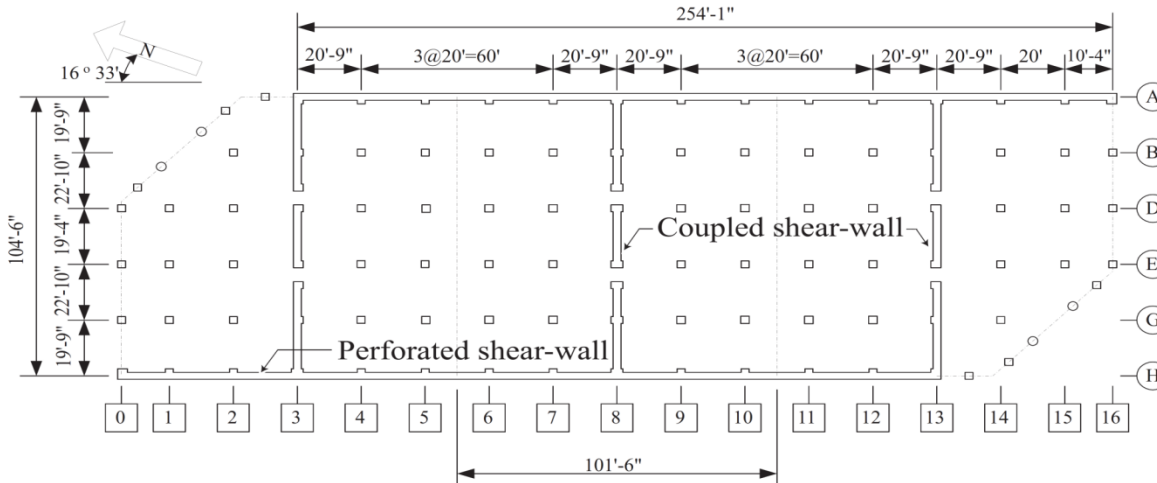


**Plan view of the UCS building located at UC-Berkeley campus**
Lee & Mosalam, 2006
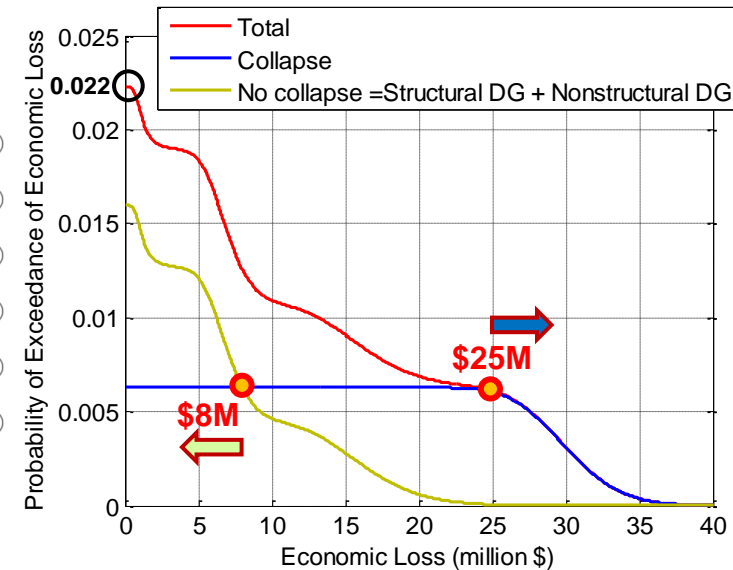


**Loss Curve**
Mosalam & Günay, 2011

# Future Extension: PBE-MIVES

- ✓ Selecting major indicators (including those for safety and health in construction activities) and corresponding weights in office building design

- ✓ Collecting data/defining probability distributions & correlations for office buildings in the tropics

- ✓ Accounting for results obtained from various testbeds, e.g. on newly developed façade systems

- ✓ Evaluating the efficiency of a newly developed technologies, e.g. novel façade systems

*Thank You!*
*Questions? Comments?*