An Indoor Contaminant Sensor Placement Toolbox for Critical Infrastructure Buildings

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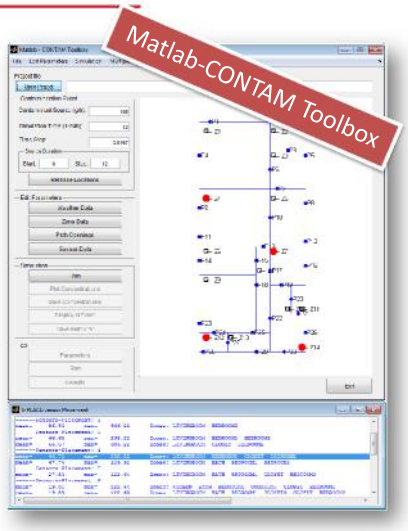
CRITIS 2013, Amsterdam, The Netherlands

Acknowledgement

This research work has been funded by the European Research Council (ERC) under the project ERC-2011-ADG-291508 ``Fault-Adaptive Monitoring and Control of Complex Distributed Dynamical Systems''(FAULT-ADAPTIVE).

Summary of Work

- Address the airborne contaminant sensor placement in Critical Infrastructure buildings
- Present a new open-source software for assisting in simulating contamination scenarios in buildings
- Propose a solution for the sensor placement problem in buildings
- Demonstrate its usage on a case-study using a realistic benchmark



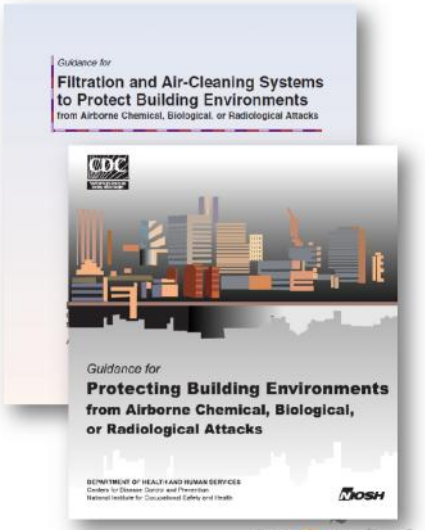
Attacks in Critical Infrastructures

- Critical Infrastructure Protection
- Cyber-physical attacks
- Focus on building infrastructures
  - Essential part of all Critical Infrastructures
  - Typically are large-scale (Power Stations, Water Treatment Plants, Water Distribution Networks, Governmental offices, Ministries, Utilities, Airports, Hospitals etc)
- Smart buildings need to have smart protection!

An attack in a critical infrastructure could involve affecting the overall operation in some building, through some airborne contaminat

Airborne Contamination Attacks

- Release airborne CBRN agent within a building
- Affect the health and safety of the occupants in the different building zones dramatically
- Hart Senate Office Building Anthrax attack in 2001
- Guidelines by US CDC/NIOSH for physical security, ventilation, filtration and maintenance
  - Use of CBRN sensors



What happens during a contamination event

- A released substance **spreads through the different zones** of the building as a result of the air-flows between the different zones.
- It is important that the contaminant is **promptly detected and localized** so that appropriate **control actions** are taken to **mitigate the damage** and ensure the safety of the people and the operation of the infrastructure
- **Air quality sensor** information can be utilized to alert the occupants and operators to take the appropriate measures
- CBRN sensors are **specialized and expensive**, and in practice they **cannot be installed everywhere within building**
  - Consider building topology
  - Importance of zones (Closet vs Control Room)

The Sensor Placement Problem

- Operational Research, Control Systems, Water Distribution Systems
  - Formulate a mathematical (multi-objective) risk-minimization problem
- CFD and multi-zone simulations to explore contaminant propagation in buildings
  - Use of CONTAM multi-zone simulator (NIST)
- Proprietary software for sensor placement (Schropp 2008)

Lack of an open, common benchmarking platform for contaminant simulation, sensor placement and contamination event detection

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In this work

- Present the new **Benchmarking Toolbox** along with a solution of the airborne contaminant sensor placement problem.
  - Based on CONTAM and Matlab
- Allows creation of **multiple contamination event scenarios** with **varying parameters**
  - wind direction, wind speed, leakage path openings, source magnitude, evolution rate and onset time
- It constructs multiple environmental and contamination scenarios based on sampling of the different **probability distributions**,
- Takes into account **building utilization** and **people distribution**, for minimizing **multiple impact-risk objectives**.

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Problem Formulation

$$\dot{x} = A(p_x)x + \phi(p_x, p_\phi)$$ Contaminant propagation dynamics

$$\dot{z}_k = f_z(x_k; p_z)$$ Impact damage dynamics

$$\Omega = \begin{bmatrix} \Omega_{1,1} & \cdots & \Omega_{1,N} \\ \vdots & \ddots & \vdots \\ \Omega_{N_p,1} & \cdots & \Omega_{N_p,N} \end{bmatrix}$$ Overall impact matrix

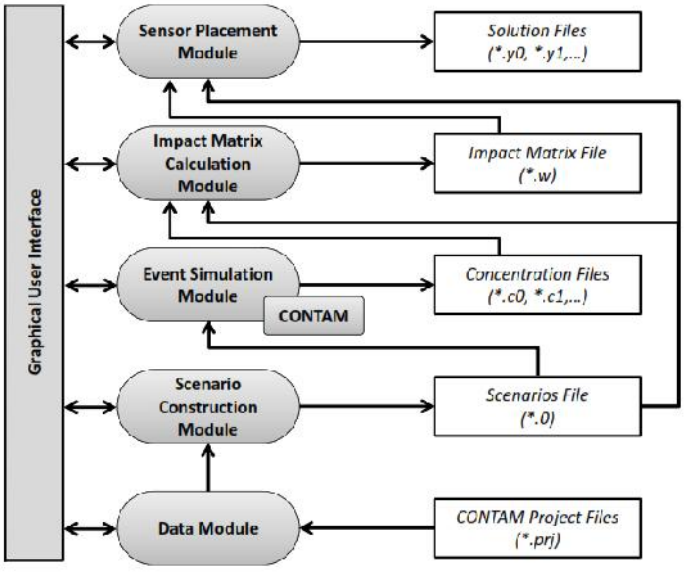
p_x: *environ. related*
p_φ: *contaminant related*
p_z: *impact related*

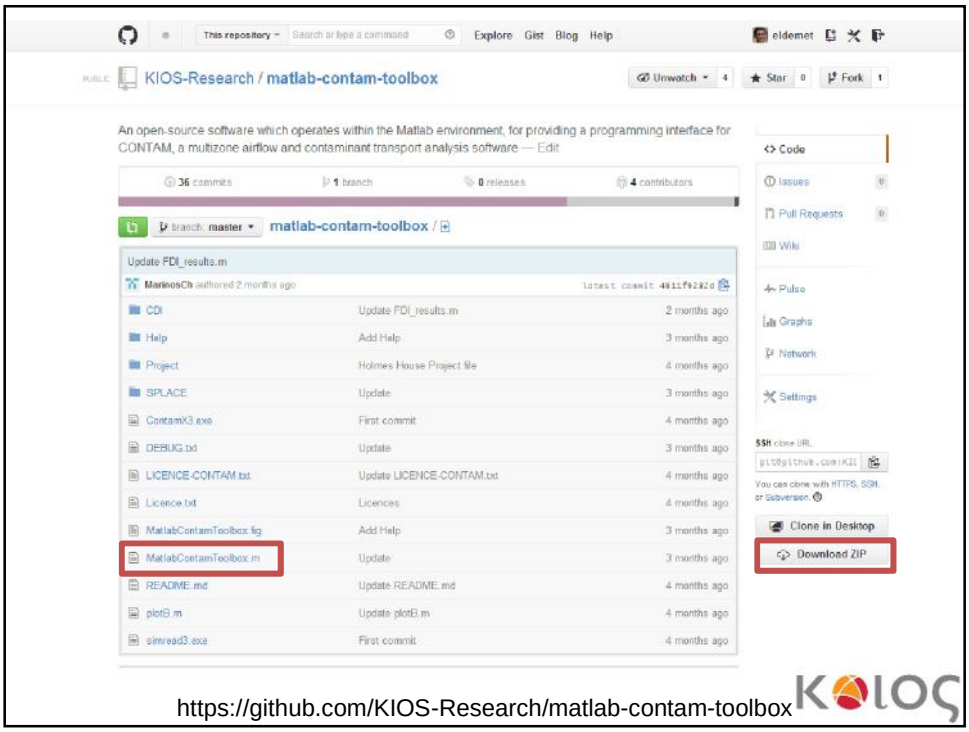
F_0: *cost*
F_1: *average*
F_2: *worst-case*

$$Y = \underset{\chi \in \{1,0\}^N}{\operatorname{argmin}} \{F_0(\chi), F_1(\chi; \Omega), F_2(\chi, \Omega)\}$$ Pareto front/Multi Objective Optimization

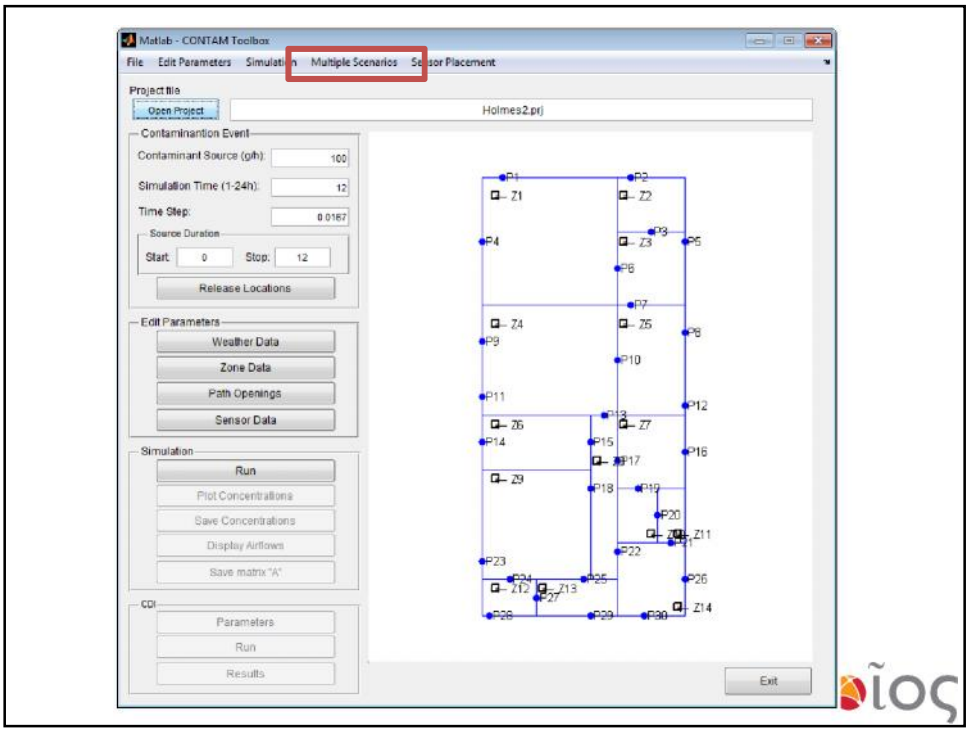
D.G. Eliades, M.P. Michaelides, C.G. Panayiotou, M.M. Polycarpou, **Security-oriented sensor placement in intelligent buildings**, *Building and Environment*, Volume 63, May 2013, Pages 114-121

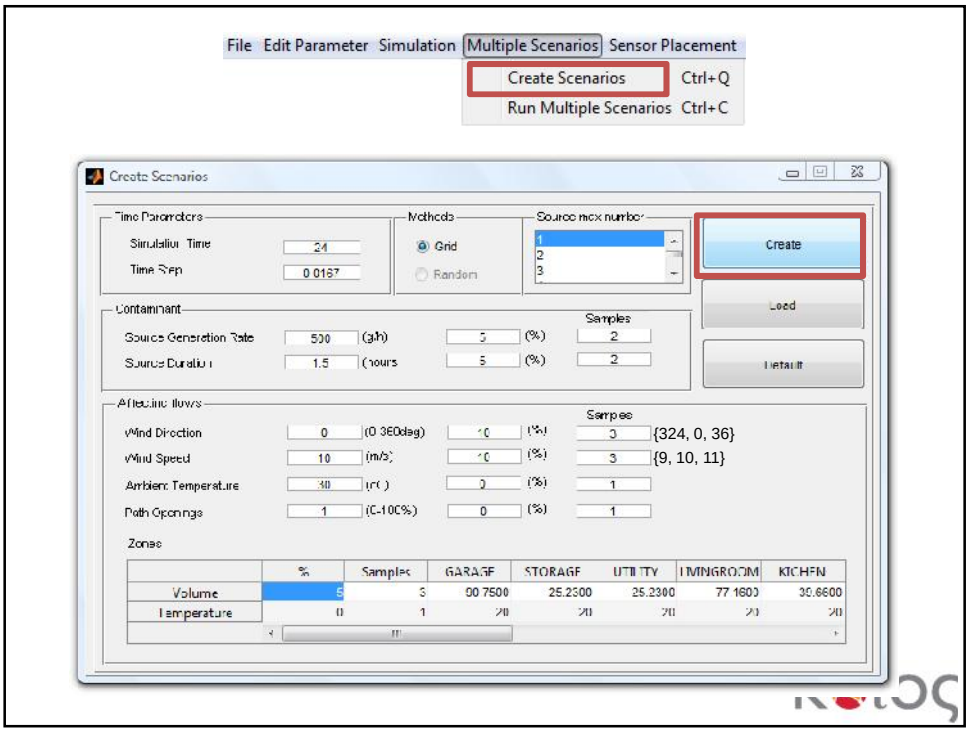
Modular Software Architecture





https://github.com/KIOS-Research/matlab-contam-toolbox

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Create Scenarios Ctrl+Q
Run Multiple Scenarios Ctrl+C
Create Scenarios
Time Parameters
Simulation Time
Time Step
Methods
Grid
Random
Source max number
Create
Load
Default
Contaminant
Source Generation Rate
Source Duration
Samples
Affecting flows
Wind Direction
Wind Speed
Ambient Temperature
Path Openings
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{9, 10, 11}
Zones
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Temperature
GARAGE
STORAGE
UTILITY
LIVINGROOM
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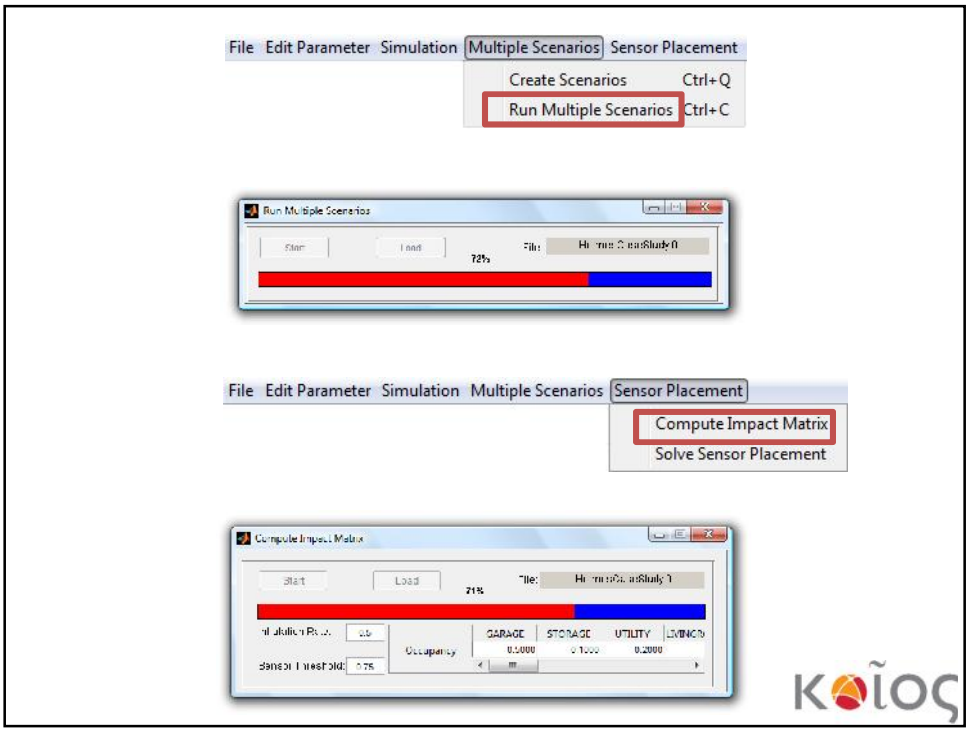
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Run Multiple Scenarios
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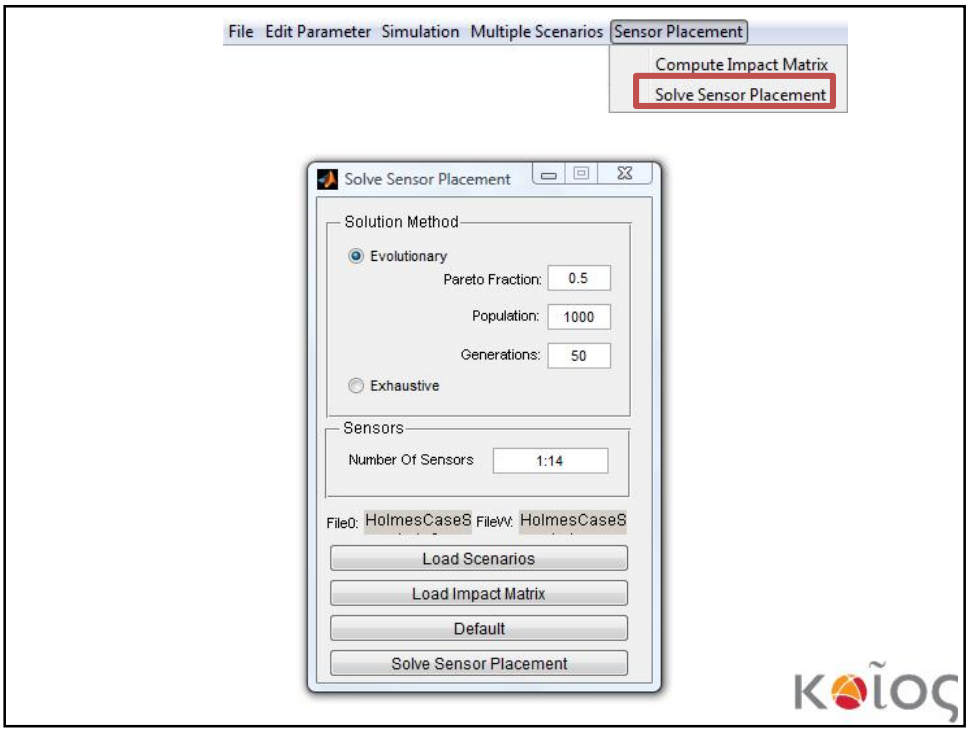
Compute Impact Matrix
Solve Sensor Placement
Compute Impact Matrix
Start
Load
File:
Occupancy
GARAGE
STORAGE
UTILITY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Compute Impact Matrix
Solve Sensor Placement
Solve Sensor Placement
Solution Method
Evolutionary
Pareto Fraction: 0.5
Population: 1000
Generations: 50
Exhaustive
Sensors
Number Of Sensors 1:14
File0: HolmesCase8 FileW: HolmesCase8
Load Scenarios
Load Impact Matrix
Default
Solve Sensor Placement
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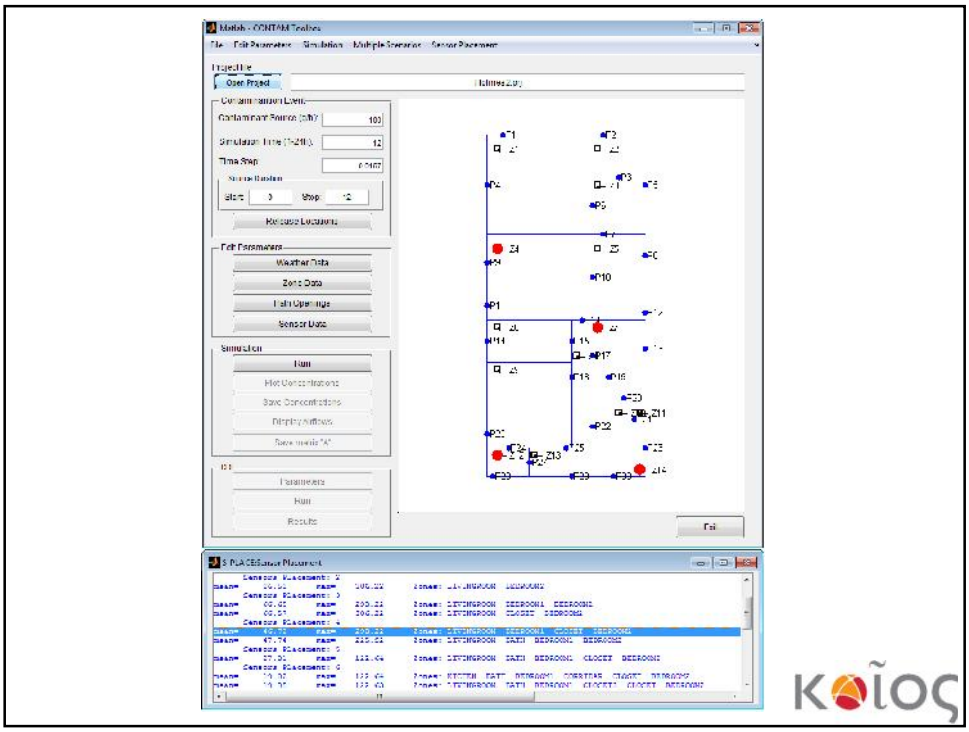
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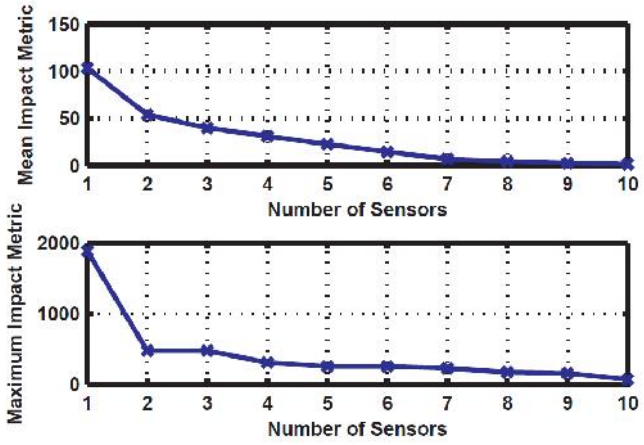

Summary

- New open-source software for benchmarking building security
- Evaluate solutions under various scenarios
- GUI provides an intuitive way of interfacing with the software
- Software architecture is modular, and each module can be accessed independently.
- The software is extendible, as it allows to add, modify or remove algorithms in accordance to the research objectives
- The software is under an open-source license
- **https://github.com/KIOS-Research/matlab-contam-toolbox**


See you in CRITIS 2014,
Cyprus!
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