Monitorowanie zachowań ludzi w budynkach

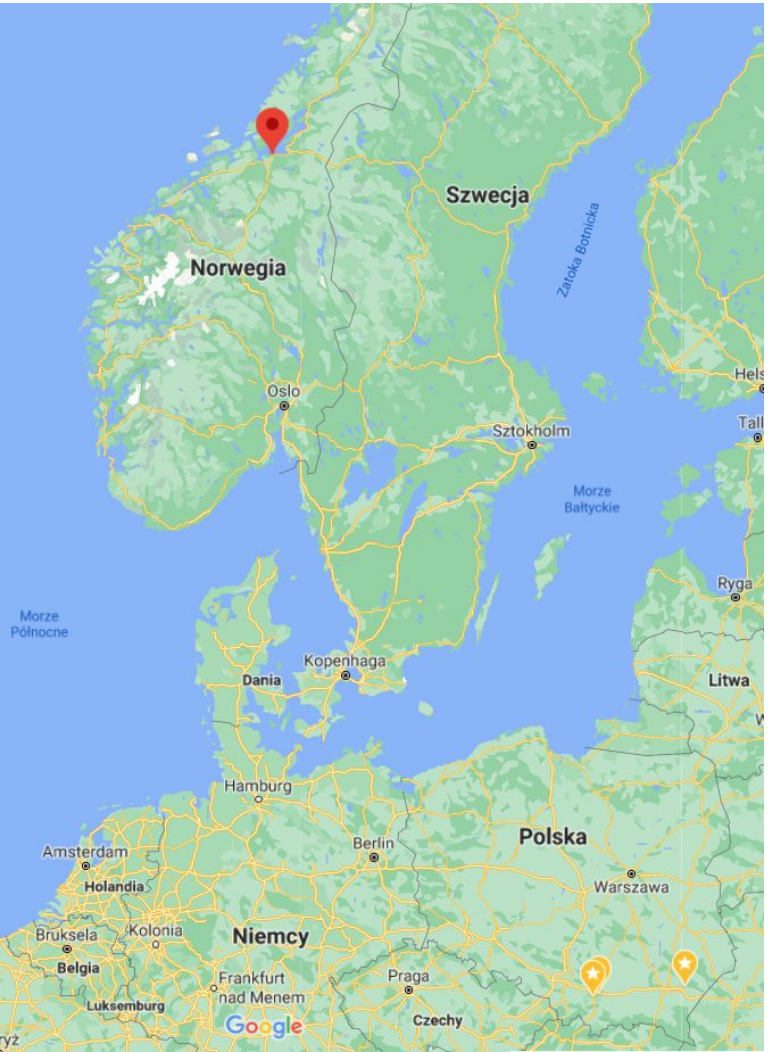
About me

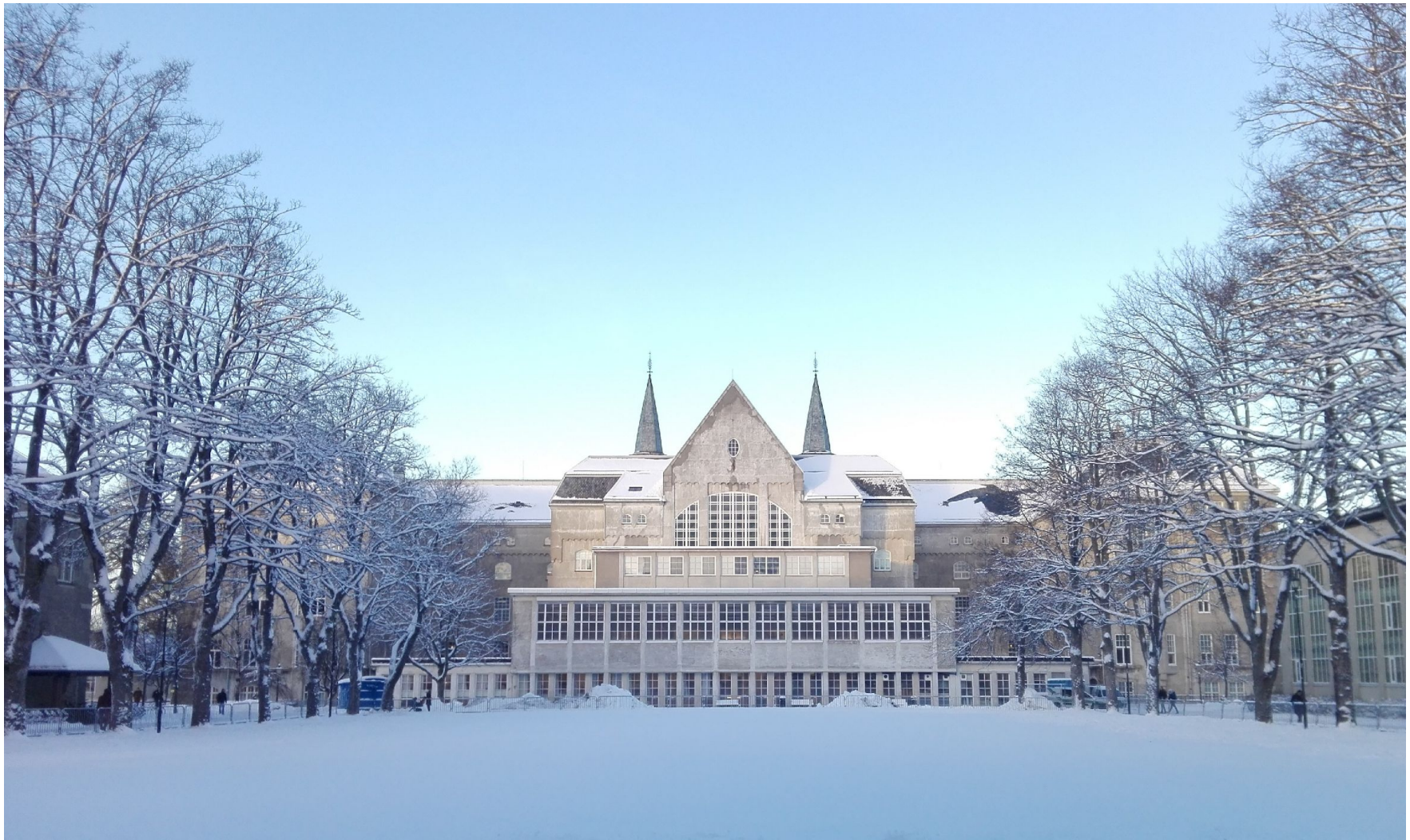
- Currently working at PICTEC from December 2020
- PhD Candidate with teaching duties at NTNU (2016-2020)
- PhD Candidate at Politechnika Krakowska (2014-2021)
- Participant in EU founded, EU-CHINA exchange project (2017)
- Member of IEA EBC ANNEX 66 (2016-2017) & IEA EBC ANNEX 79 (2018 - now)

About me

- Master’s and bachelor in **Environmental Engineering**; specialty: Thermal installations and health equipment
- Bachelor in **Transportation Engineering**; specialty: Logistics and Transportation Systems

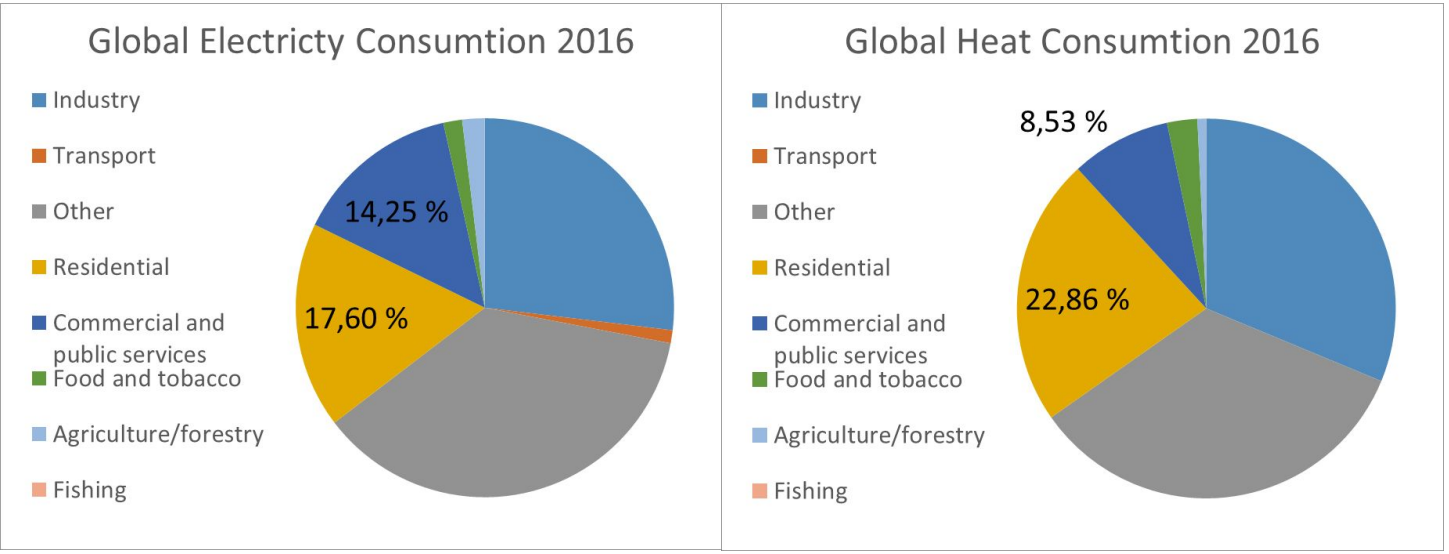
NTNU: Norwegian University of Science and Technology



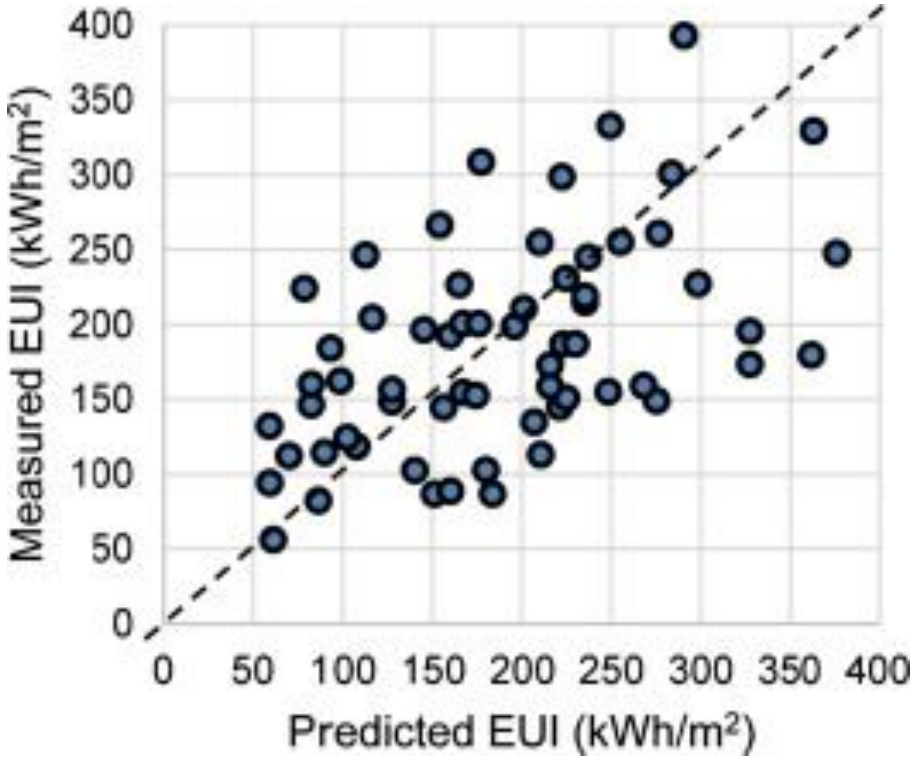


Importance of building is global scale

- **Buildings are one of the biggest energy users**
- **Prediction of the building energy performance is inaccurate**



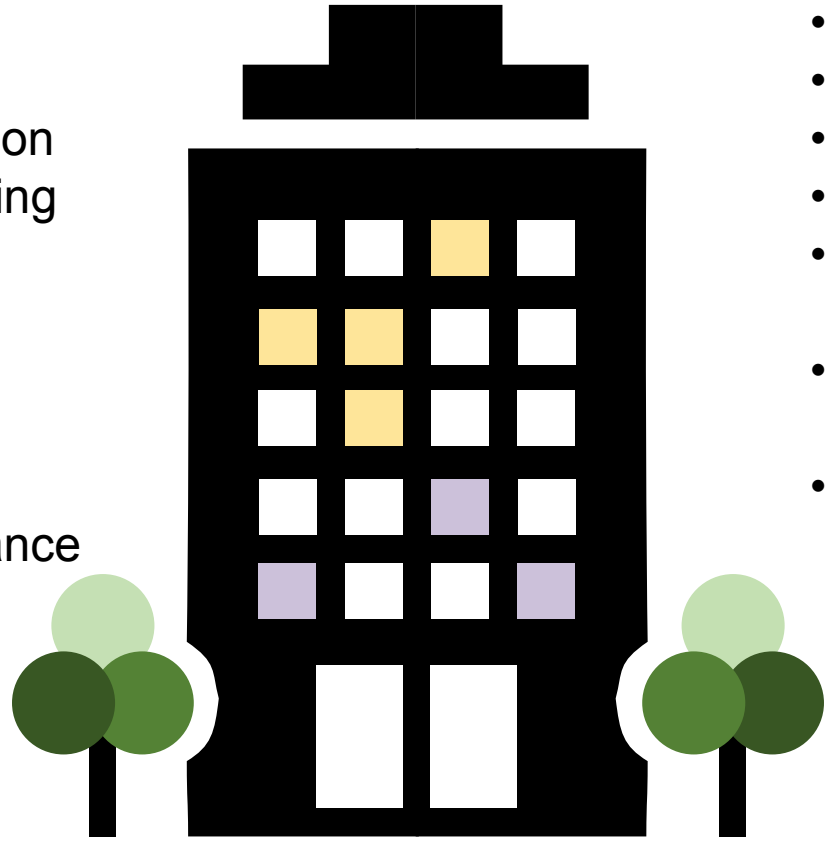
International Energy Agency, World Energy Outlook 2017



Turner, Cathy et. al. Energy performance of LEED for new construction buildings, **New Buildings Institute** 2008

Building performance simulation

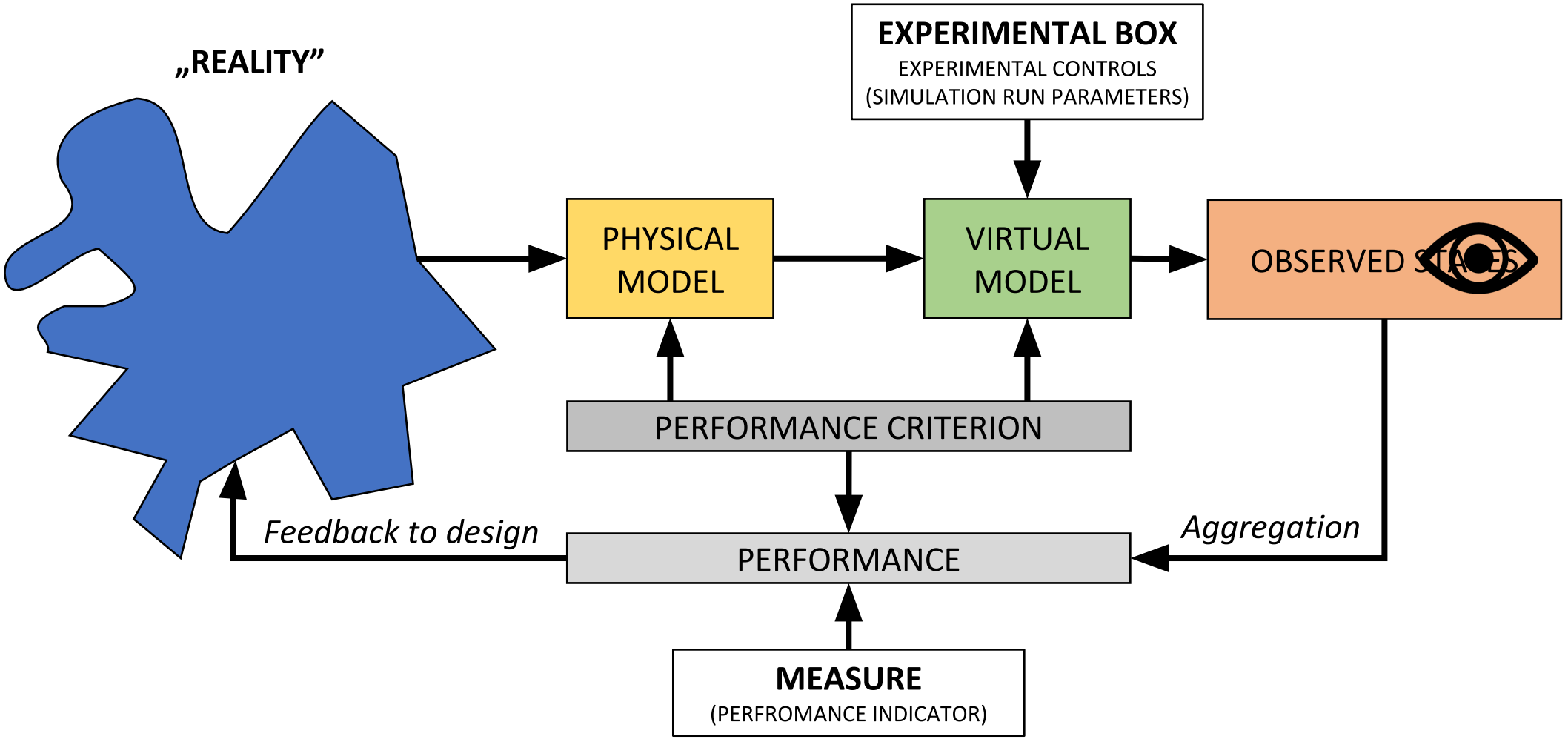
- Room acoustics performance prediction
- Daylight performance prediction
- Moisture phenomena in building performance prediction
- HVAC system performance prediction
- Micro-cogeneration system performance prediction
- Building automation performance prediction



- Weather data
- People in buildings
- Thermal load prediction
- Energy performance prediction
- Ventilation performance prediction
- Indoor thermal quality performance prediction
- Integrated resource modeling

J. L.M. Hensen, R.Lamberts, **Building Performance Simulation for Design and Operation**

Simulation as a „virtual” experiment



J. L.M. Hensen, R.Lamberts, **Building Performance Simulation for Design and Operation**

Importance of indoor climate

Human-related variables

Physical Variables	Physiological Variables	Behavioral Variables	Psychological Variables
• Safety and Security • Protection • Thermal Variation • Air Quality • Acoustic Variations • Light • Aesthetics • Controllability • Size	• Metabolism • Age • Gender • Time • Health • Medication • Acclimatization	• Clothing • Location • Activity • Posture • The use of controls	• Family or Personal relations • Relations at Work or School • Stress • Work Satisfaction • Perception of Control • Psychosis

Influences…

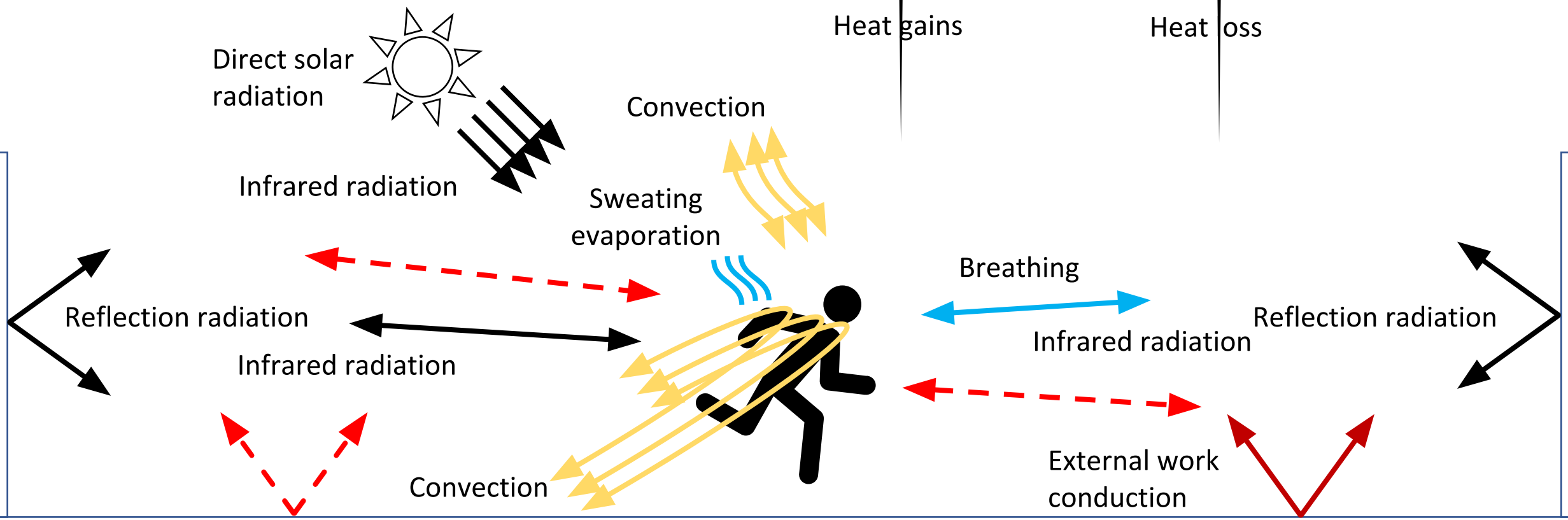
- Human Comfort
- Human Health
- Productivity

Objective

Subjective

Human Thermal Comfort

Conceptual heat balance equation: $\underbrace{M - W}_{\text{Heat gains}} = \underbrace{E + R + C + K + S}_{\text{Heat loss}}$



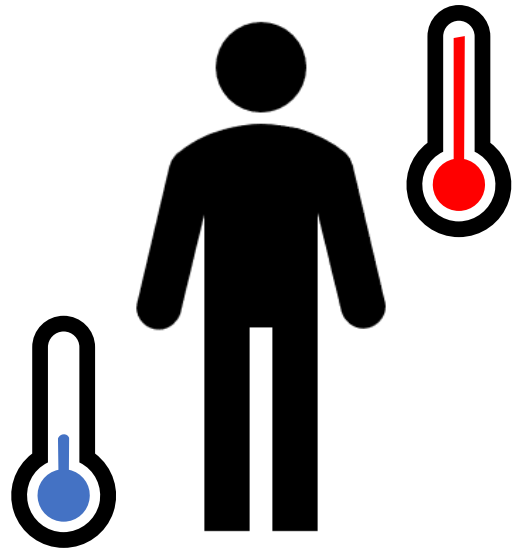
Human Thermal Comfort

Practical heat balance equation:

$$M - W = Q_{sk} + Q_{res} = (C + R + E_{sk}) + (C_{res} + E_{res})$$

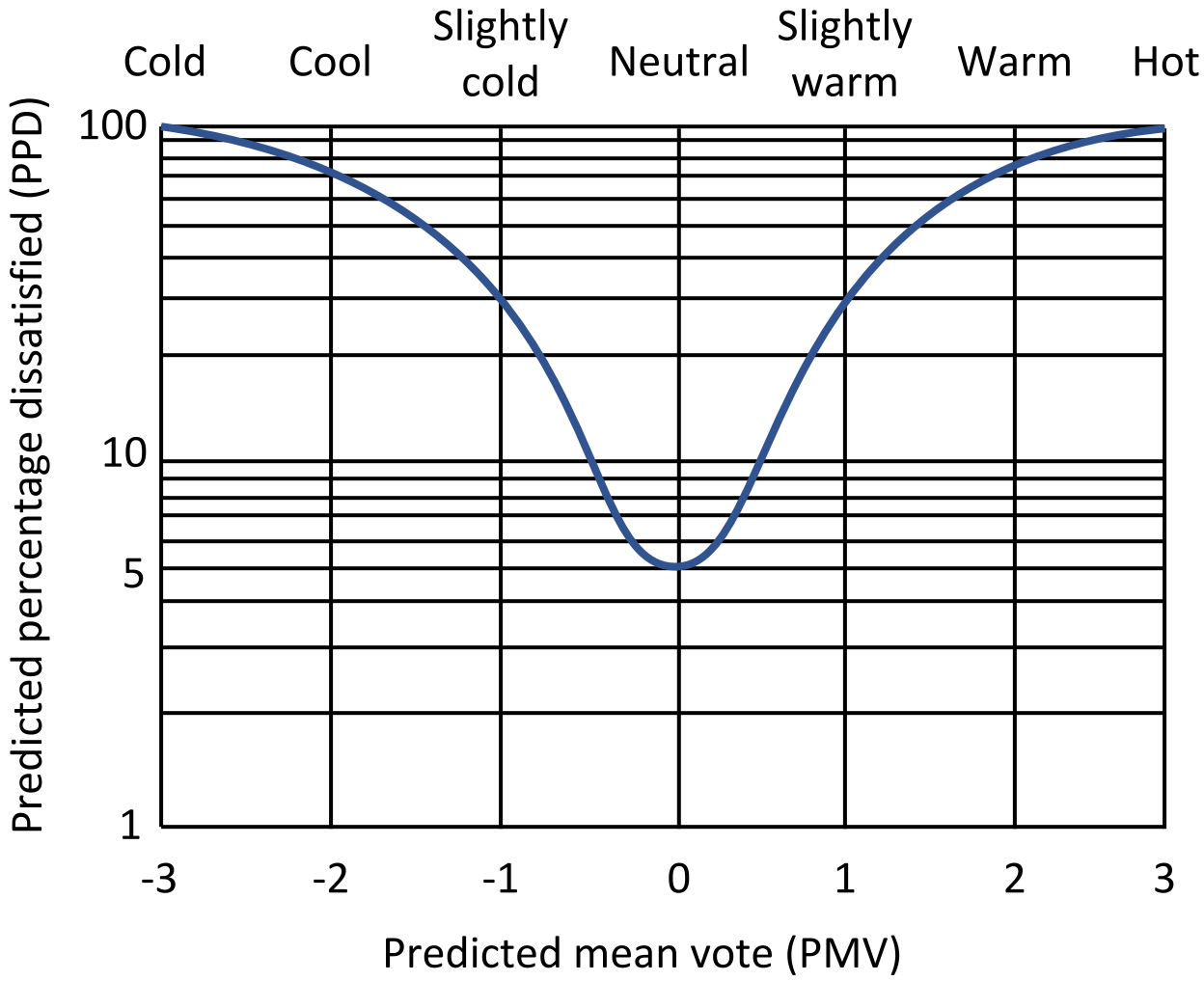
Heat production with a body	Sensible heat loss	Evaporative Heat Loss from the Skin	Heat Loss from Respiration

M = rate of metabolic Energy production
W = rate of mechanical work
Q_{sk} = total rate of heat loss from skin
Q_{res} = total rate of heat loss through respiration
C = rate of convective heat loss from skin
R = rate of radiative heat loss from skin
E_{sk} = rate of total evaporative heat loss from the skin
C_{res} = rate of convective heat loss from respiration
E_{res} = rate of evaporative heat loss from respiration



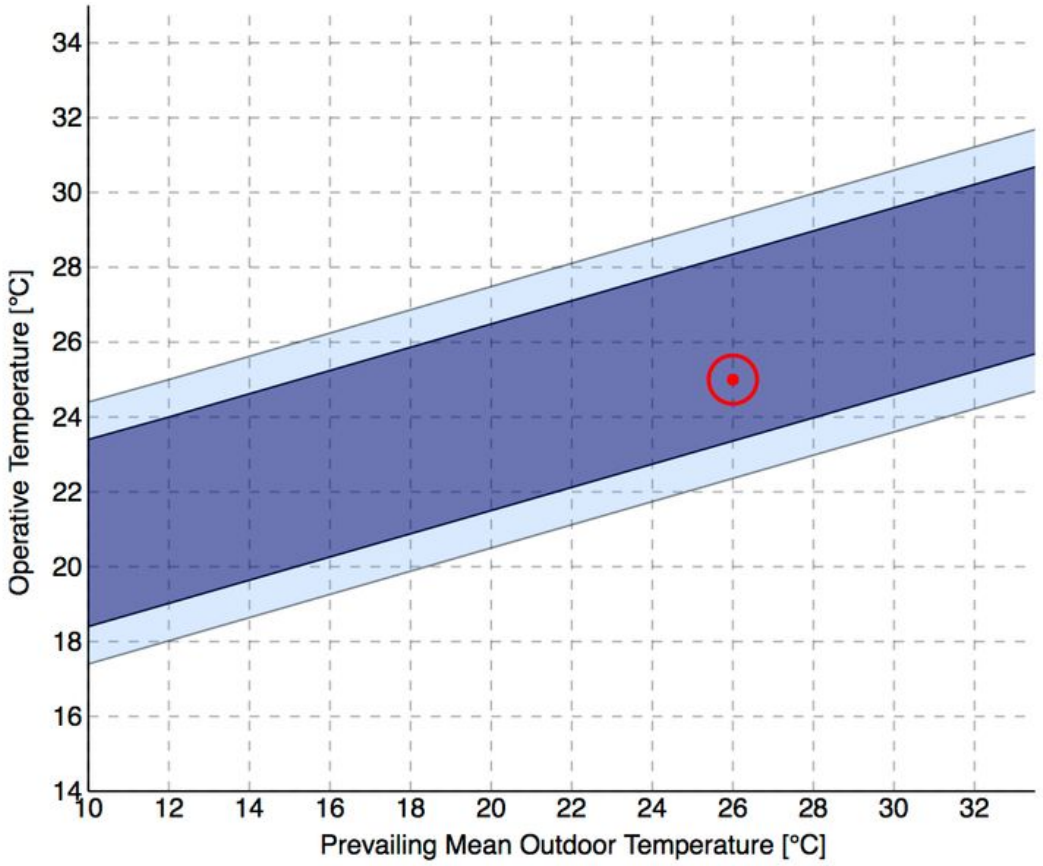
Evaluation of the thermal environment

- Proposed by P.O. Fanger in *Themral Comfort* (1970)
- It proposes that degree of discomfort depends on a thermal load
- Thermal load is a difference between internal heat production and heat losses



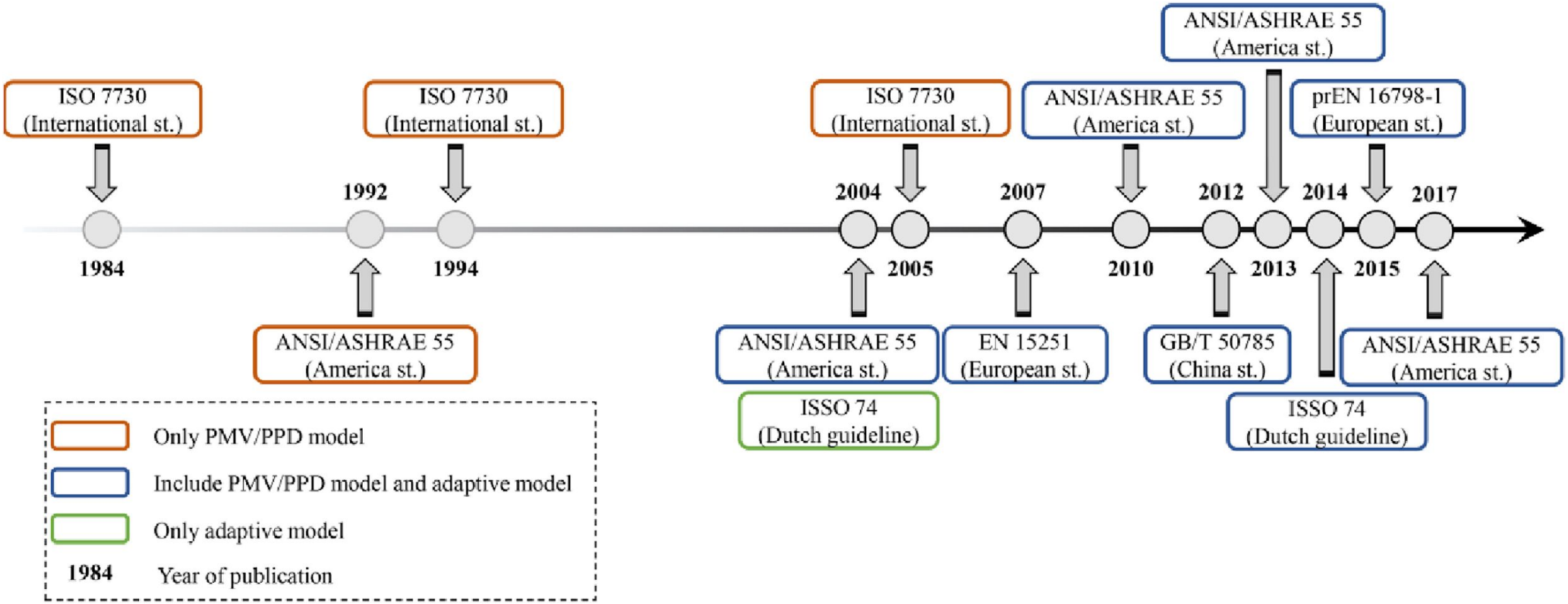
Adaptive thermal comfort model

- Proposed by R. de Dear and G. Brager in 1998
- Includes an outdoor temperature in comfort evaluation
- Numerus word-wide studies have shown its applicability



CBE Thermal Comfort Tool for ASHRAE 55

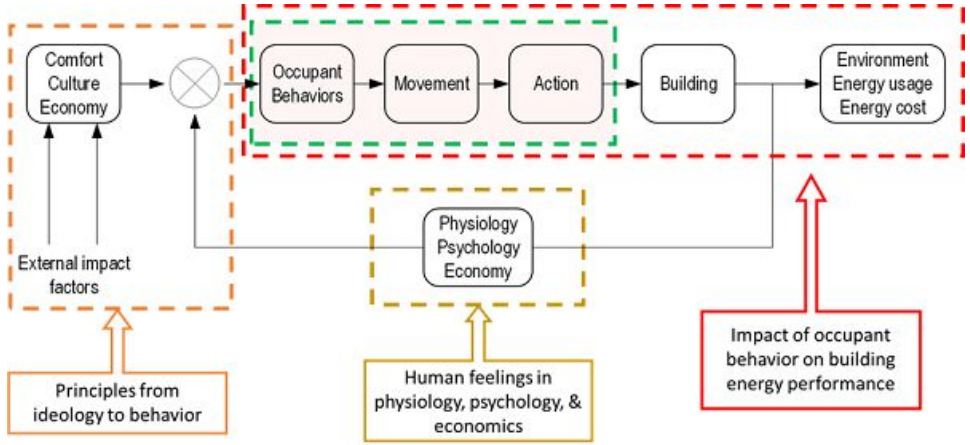
Application of models



S.Carlucci et.al, Review of adaptive thermal comfort models in built environmental regulatory documents, **Building Environment**, 2018

Investigation of occupant behavior

- IEA EBC - Annex 66: Definition and Simulation of Occupant Behavior in Buildings (2012-2017)
  - Subtask A - Occupant movement and presence models.
  - Subtask B - Occupant action models in residential buildings.
  - Subtask C - Occupant action models in commercial buildings.
  - Subtask D - Integration of occupant behavior definition and models with current building energy modeling programs.
  - Subtask E - Applications in building design and operations

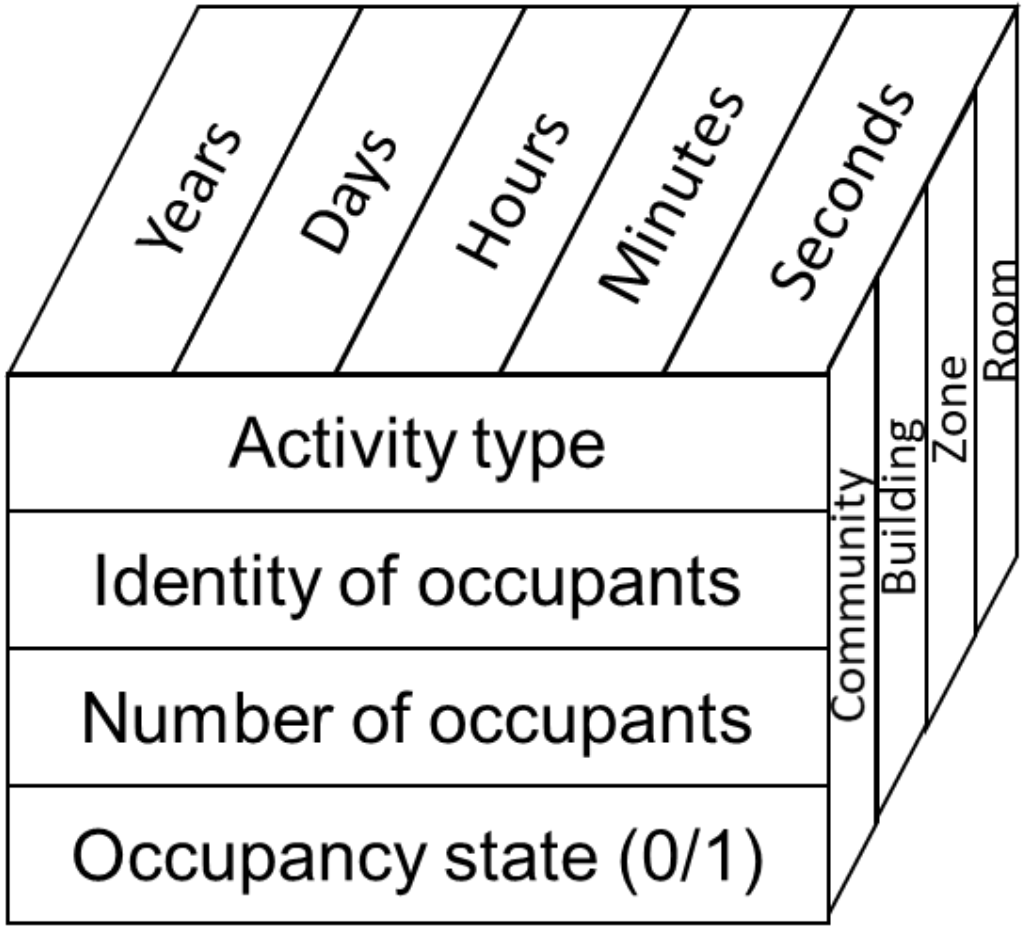


EBC
Energy in Buildings and Communities Programme

Investigation of occupant behavior

- IEA EBC - Annex 79: Occupant-Centric Building Design and Operation (2018 - 2023)
  - Subtask 1: Multi-aspect environmental exposure, building interfaces, and human behavior
  - Subtask 2: Data-driven occupant modeling strategies and digital tools
  - Subtask 3: Applying occupant behavior models in performance-based design process
  - Subtask 4: Development and demonstration of occupant-centric building controls

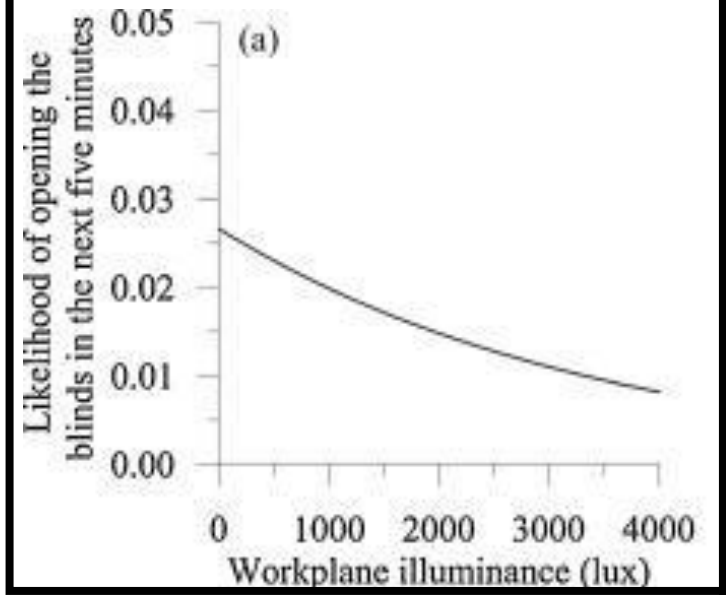
Occupant Behavior simulation targets



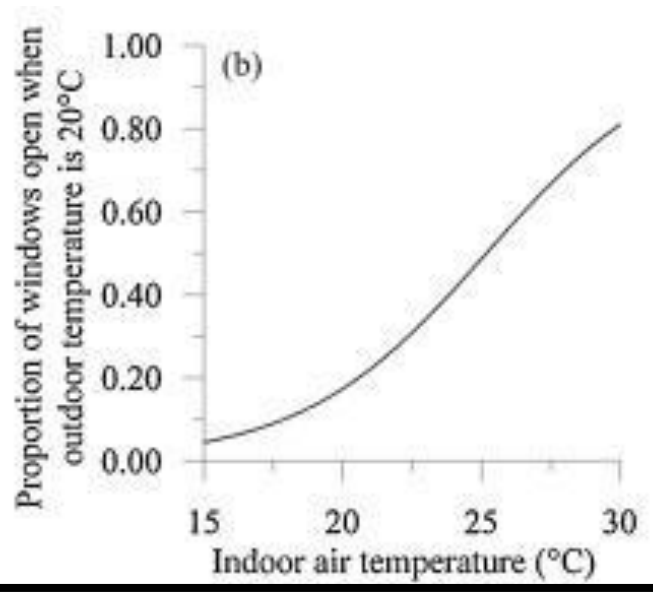
Yan, Da et.al, Occupant behavior modeling for building performance simulation: Current state and future challenges, **Energy and Build**ings, 2015

Occupant behavior simulations types

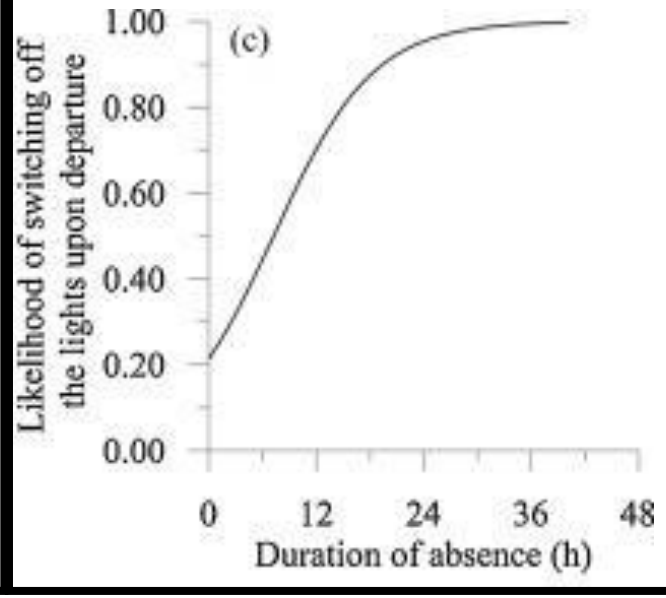
Bernoulli processes



Markov chains

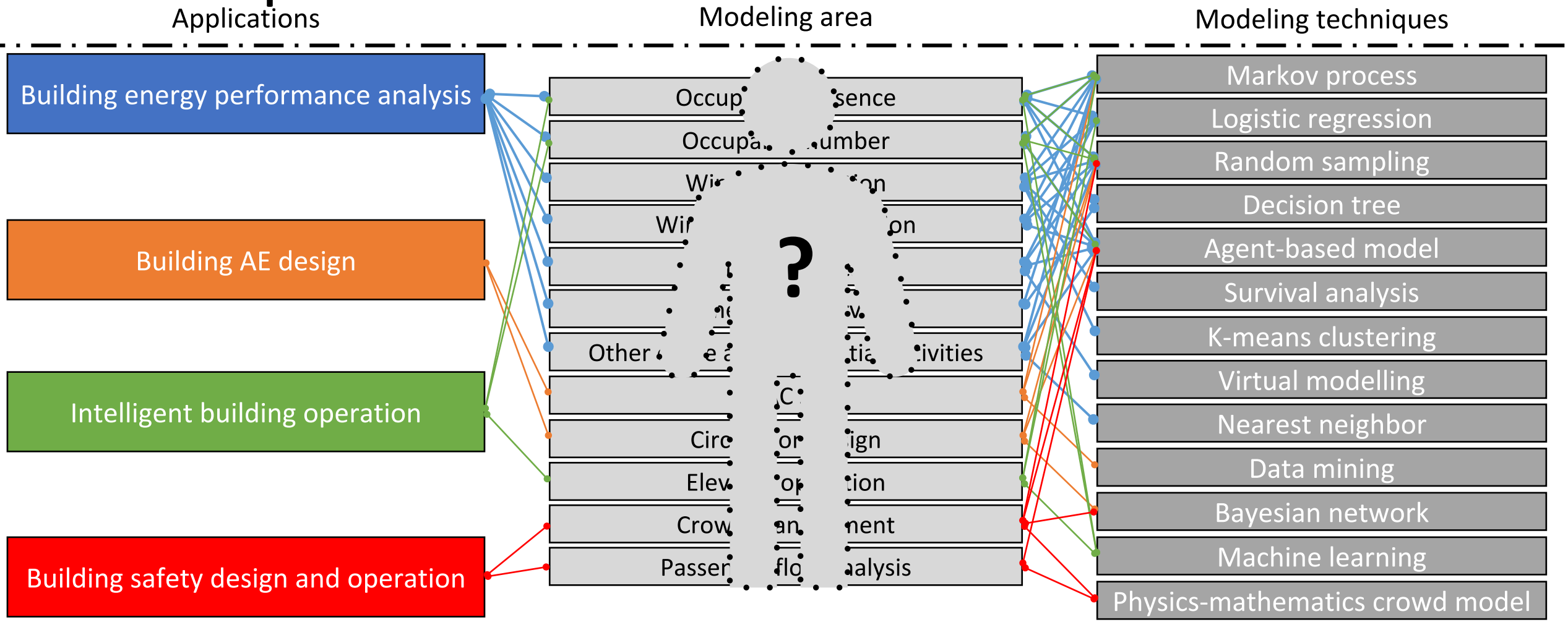


Survival analysis



Yan, Da et.al, Occupant behavior modeling for building performance simulation: Current state and future challenges, **Energy and Build**ings, 2015

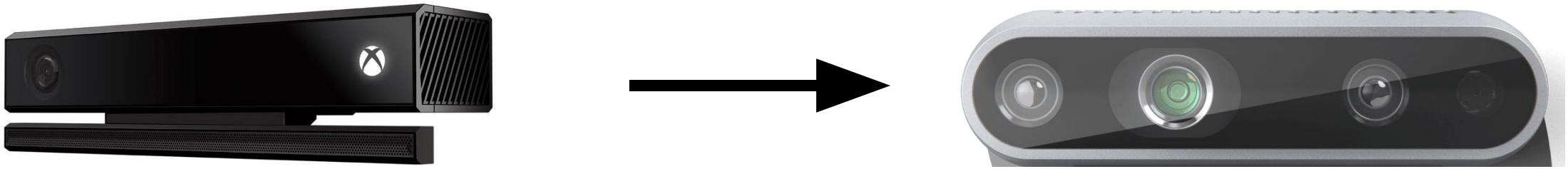
Occupant behavior simulations overview



Based on: Dong, Bing et.al, Modeling occupancy and behavior for better building design and operation---A critical review, **Building Simulation 2018**

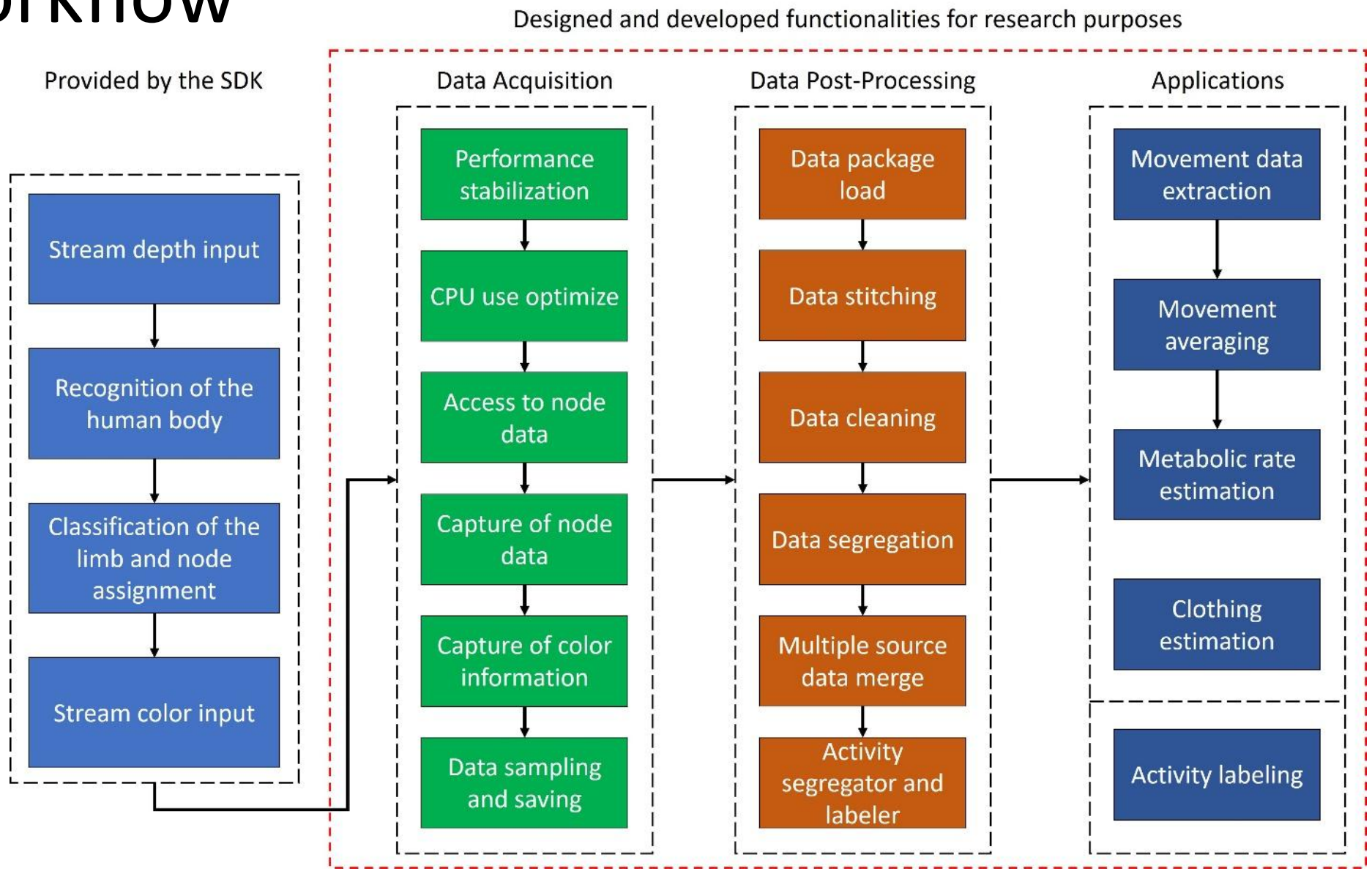
Direct observation of the occupant activities

- Microsoft device used for entertainment
- A depth registration camera able to capture human activity

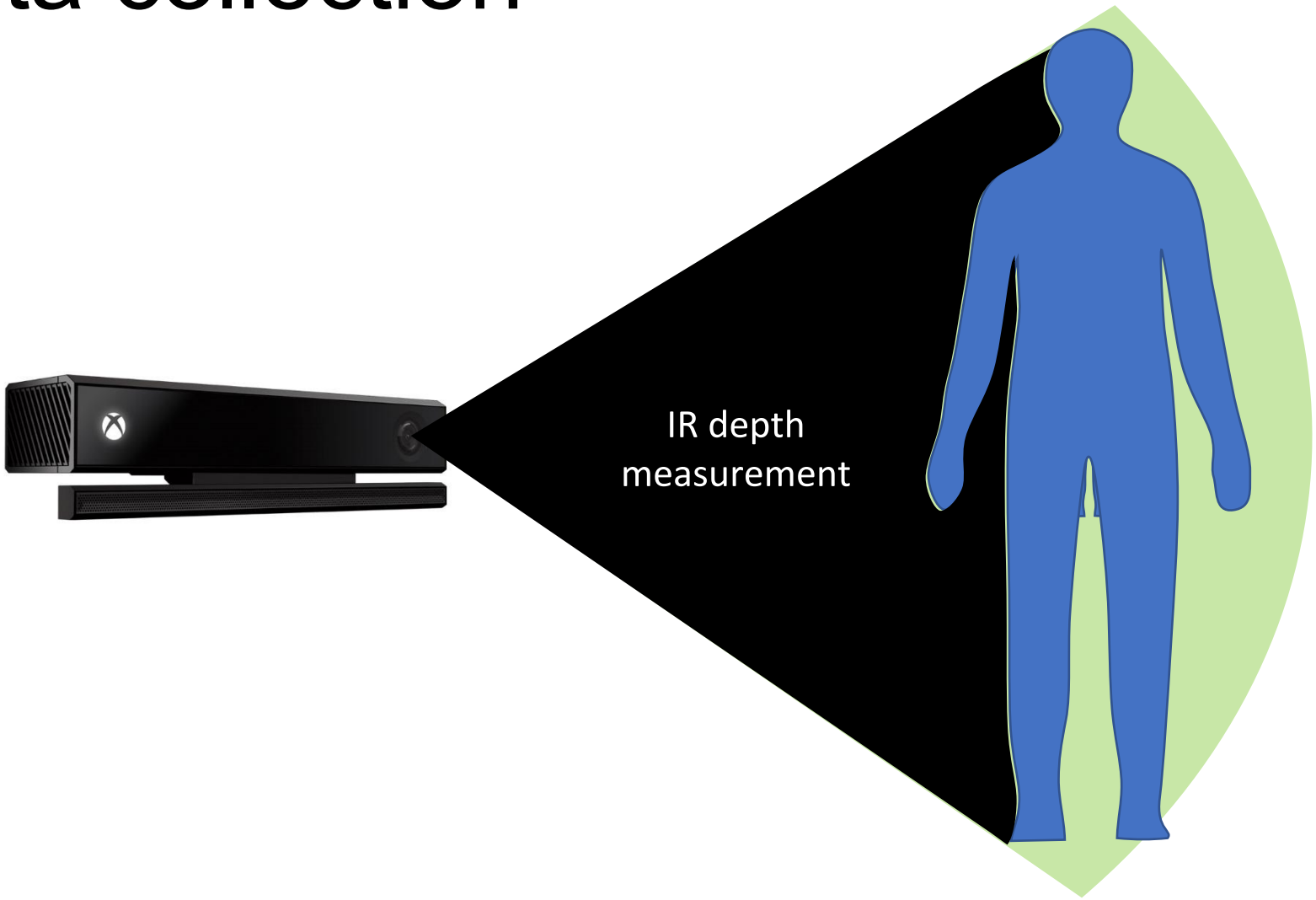


- We used these monitoring and registration of occupant activity in the ZEB Living LAB, China, Hungary and Poland
- Now we are switching towards Intel RealSense Depth Camera

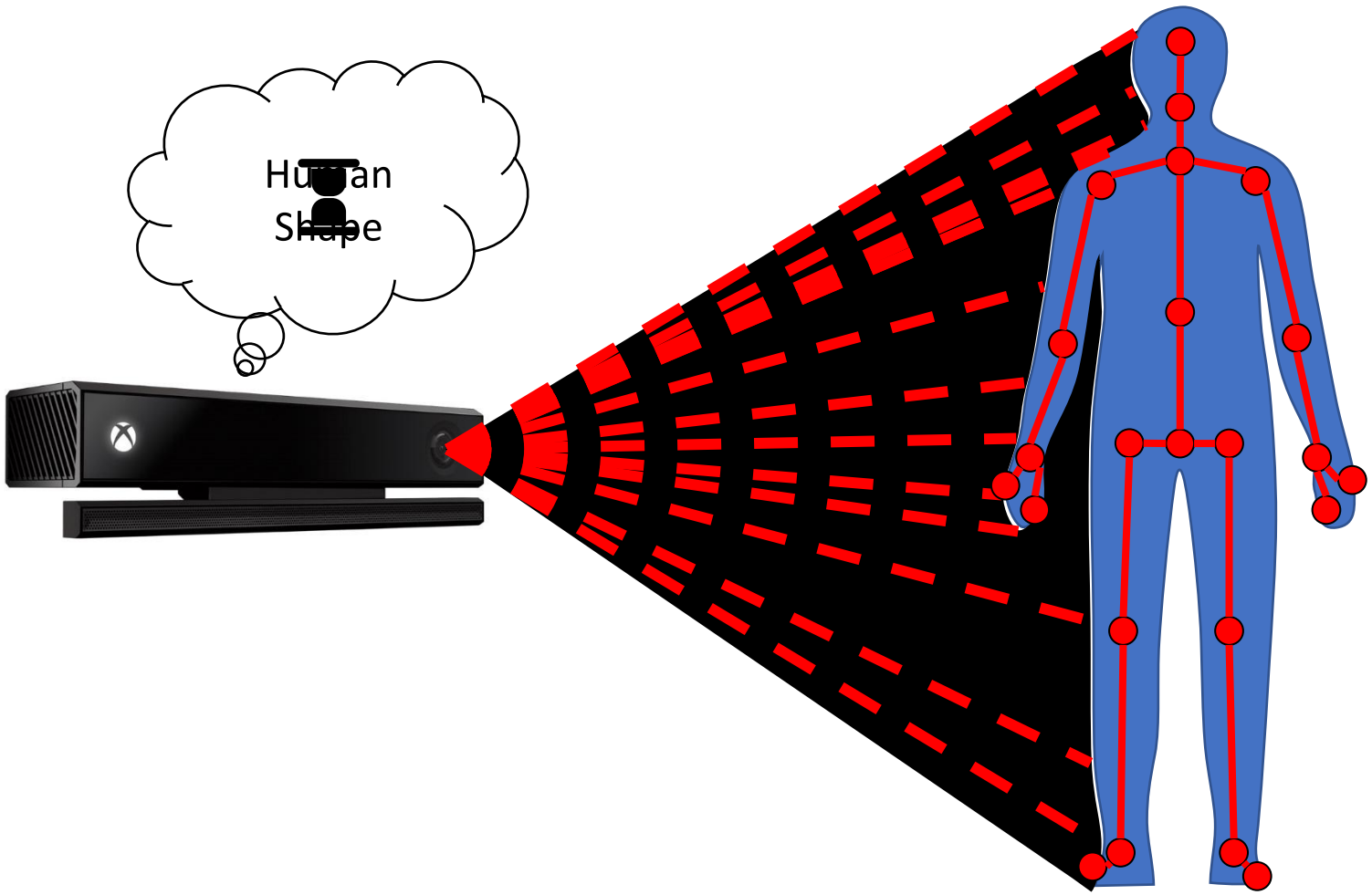
Workflow


Designed and developed functionalities for research purposes
Provided by the SDK
Stream depth input
Recognition of the human body
Classification of the limb and node assignment
Stream color input
Data Acquisition
Performance stabilization
CPU use optimize
Access to node data
Capture of node data
Capture of color information
Data sampling and saving
Data Post-Processing
Data package load
Data stitching
Data cleaning
Data segregation
Multiple source data merge
Activity segregator and labeler
Applications
Movement data extraction
Movement averaging
Metabolic rate estimation
Clothing estimation
Activity labeling

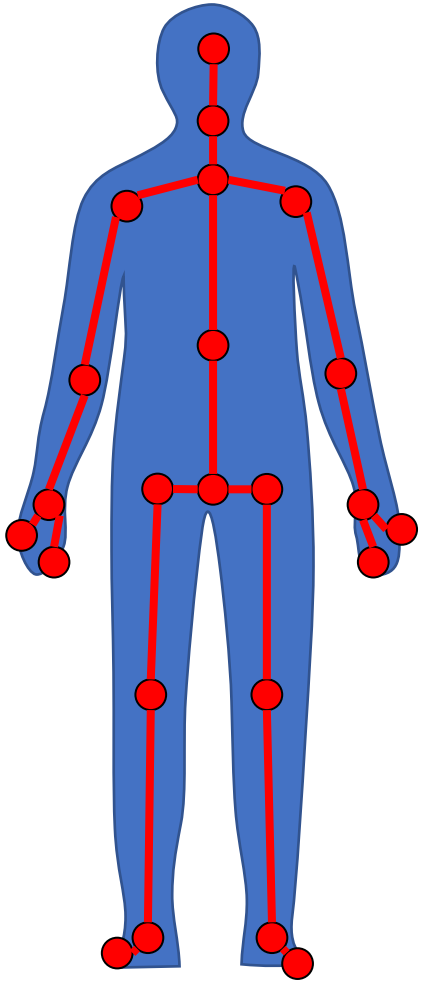
Data collection



Data collection



Data package

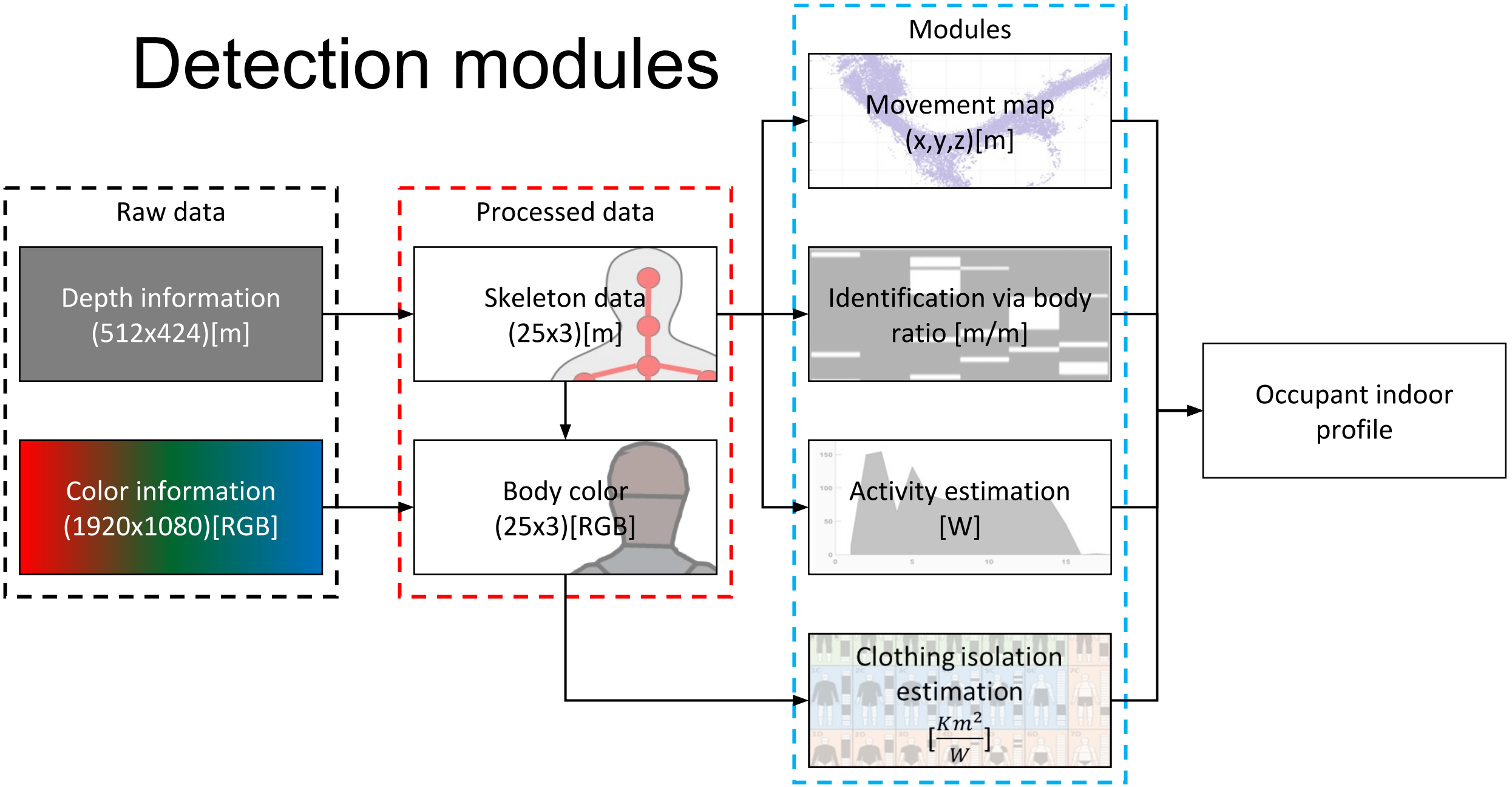


	X [m]	Y [m]	Z [m]
SpineBase = 1;	0.1066	-0.2272	2.3211
SpineMid = 2;	0.0990	0.0792	2.3576
Neck = 3;	0.0903	0.3762	2.3800
Head = 4;	0.0832	0.5278	2.3588
ShoulderLeft = 5;	-0.0939	0.2785	2.3739
ElbowLeft = 6;	-0.2182	0.0450	2.3635
WristLeft = 7;	-0.3324	-0.1487	2.3171
HandLeft = 8;	-0.3879	-0.1982	2.2953
ShoulderRight = 9;	0.2749	0.2756	2.3563
ElbowRight = 10;	0.4278	0.0628	2.3095
WristRight = 11;	0.5774	-0.0988	2.2356
HandRight = 12;	0.6207	-0.1409	2.2146
HipLeft = 13;	0.0210	-0.2271	2.2906
KneeLeft = 14;	-0.0017	-0.5919	2.2254
AnkleLeft = 15;	-0.0485	-0.8850	2.1211
FootLeft = 16;	-0.0264	-0.7374	2.1179
HipRight = 17;	0.1888	-0.2196	2.2758
KneeRight = 18;	0.2266	-0.5835	2.2297
AnkleRight = 19;	0.2552	-0.8882	2.1656
FootRight = 20;	0.2160	-0.7434	2.1606
SpineShoulder = 21;	0.0926	0.3032	2.3768
HandTipLeft = 22;	-0.4402	-0.2368	2.2771
ThumbLeft = 23;	-0.3892	-0.1488	2.2181
HandTipRight = 24;	0.6720	-0.1895	2.1962
ThumbRight = 25;	0.6357	-0.0864	2.1534

Data package

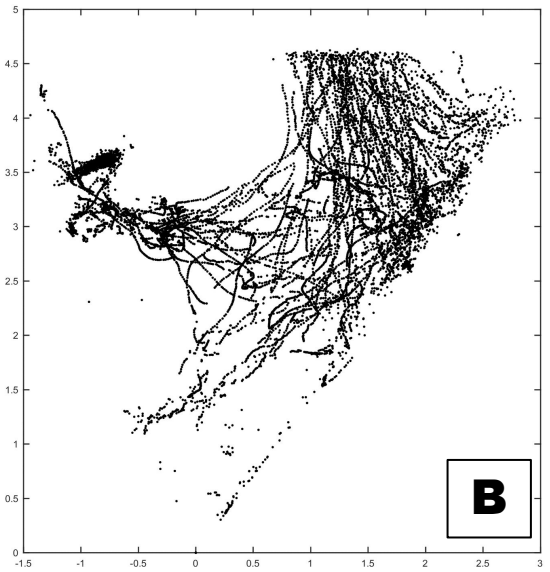
SENSOR: RGB D RGB D RGB D

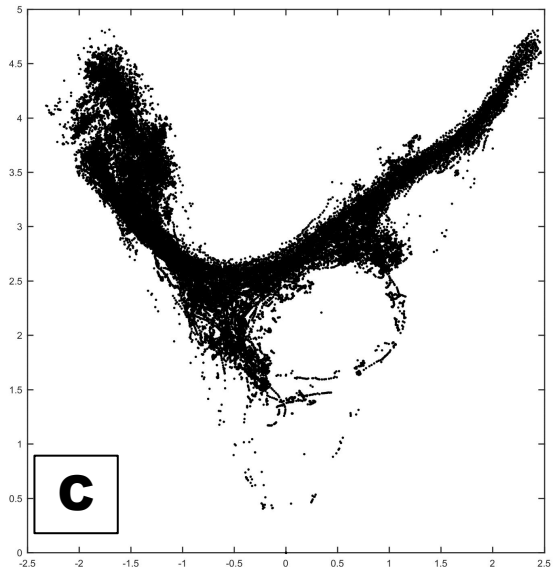
Detection modules

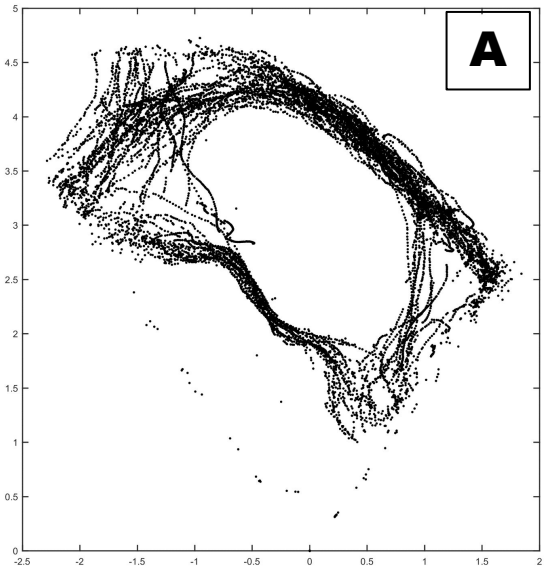


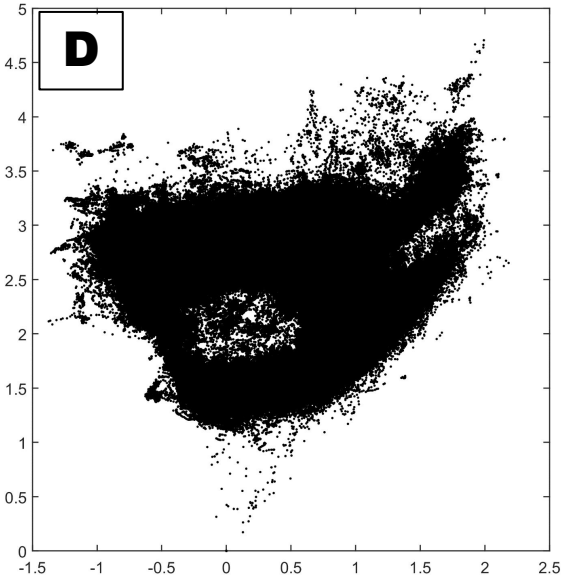
Raw data

- ZEB Living LAB measurements (A+B)
- Privet apartment (C)
- Kitchen during preparation for Christmas (D)

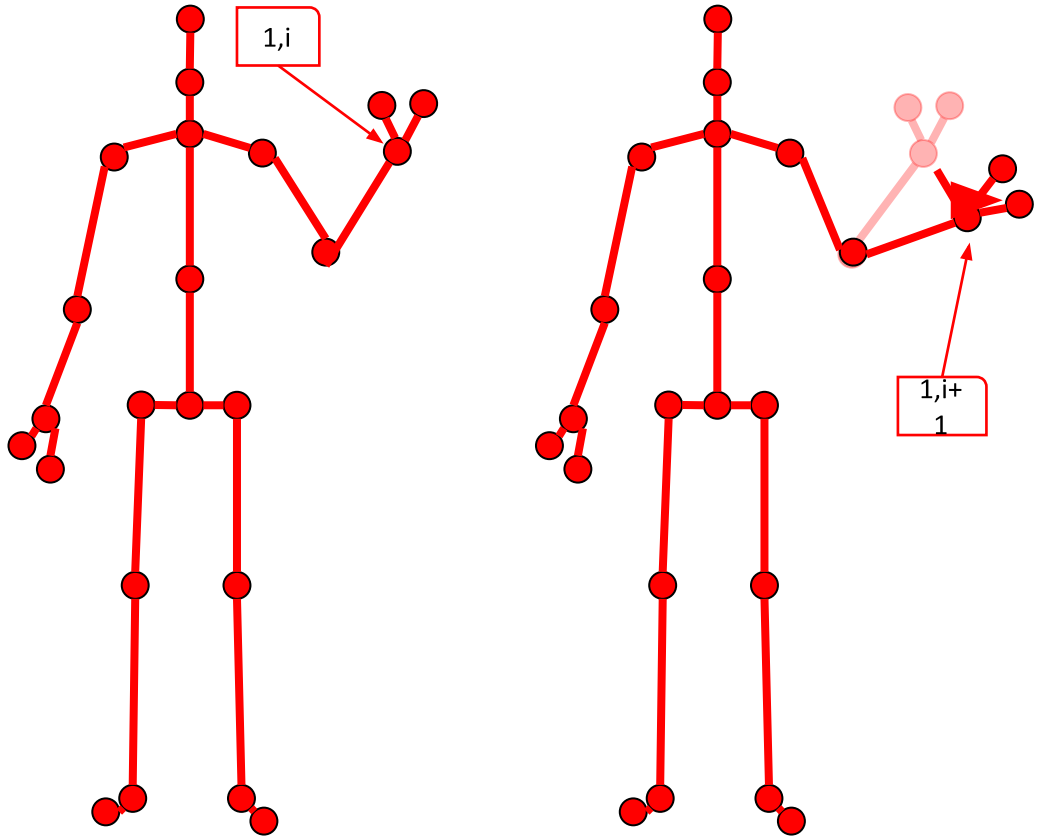






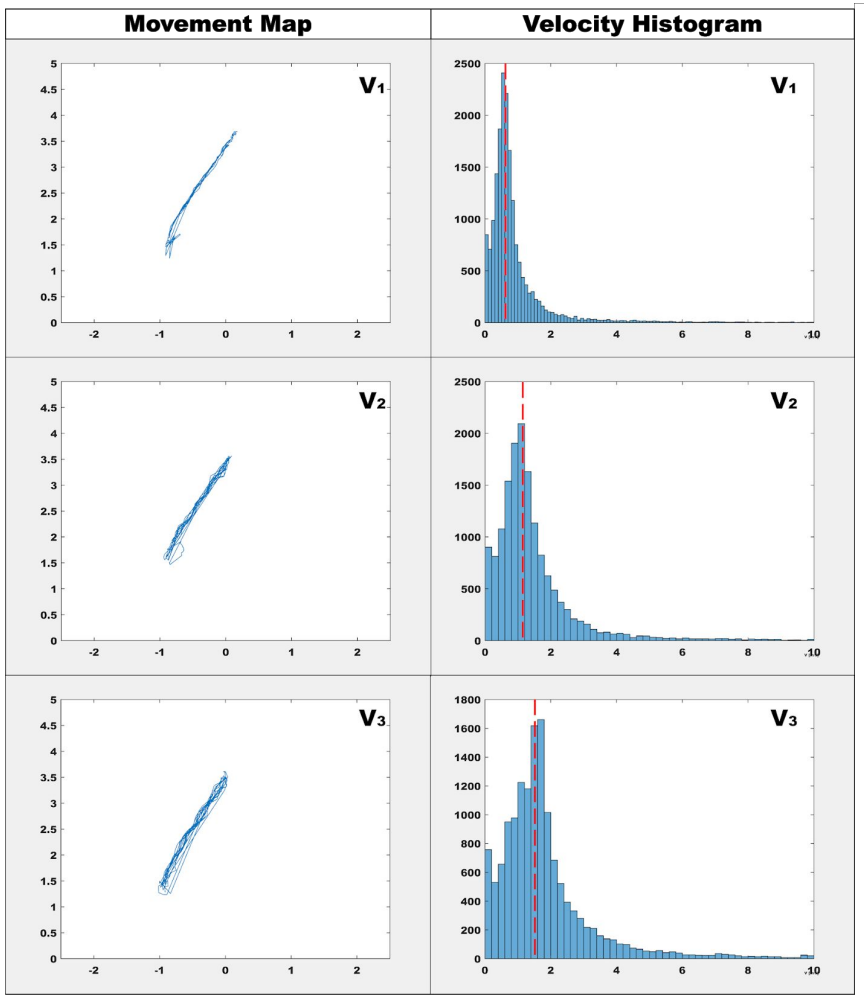


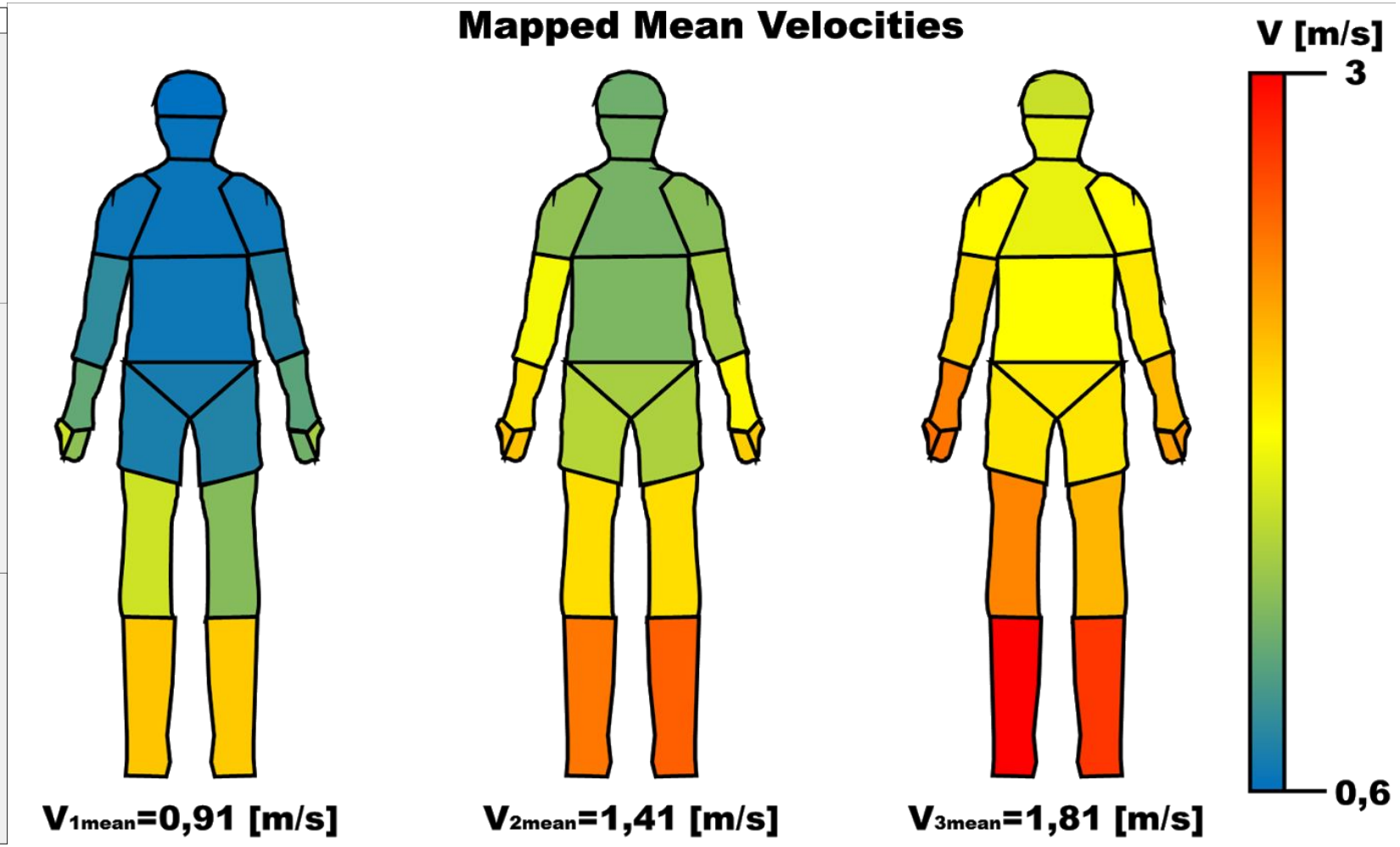
Identification



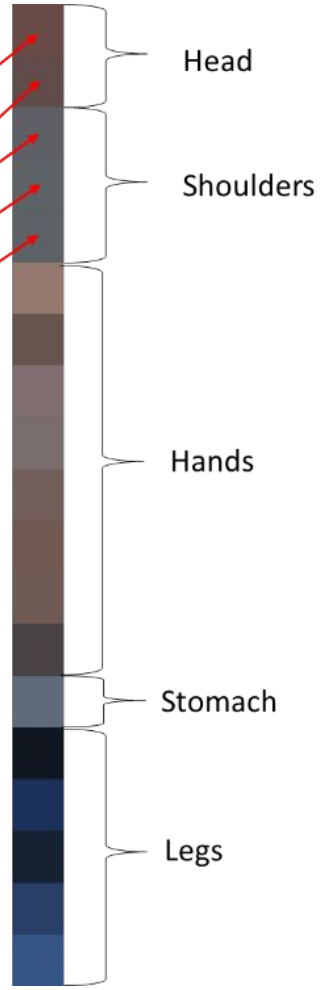
$$METv_{1,i} = \frac{\sqrt{\left(x_{1,i+1} - x_{1,i+1}\right)^2 + \left(y_{1,i+1} - y_{1,i+1}\right)^2 + \left(z_{1,i+1} - z_{1,i+1}\right)^2}}{\tau_{i+1} - \tau_i}$$

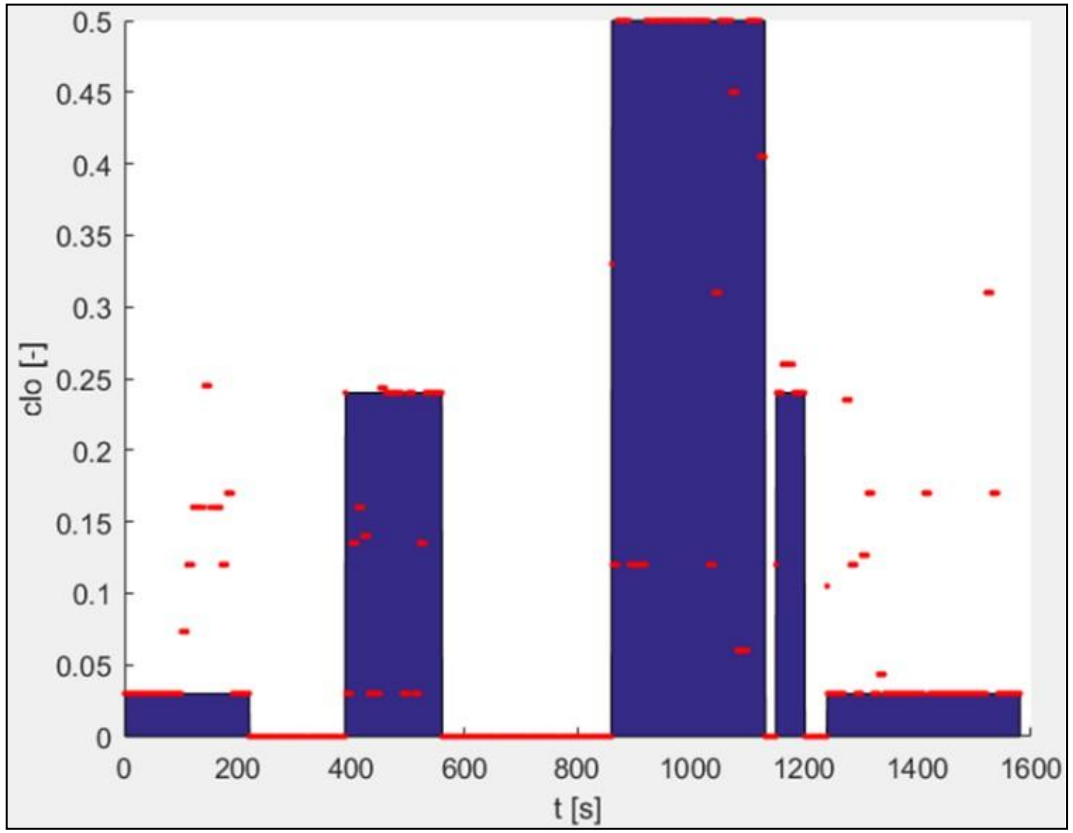
MET-factor estimation



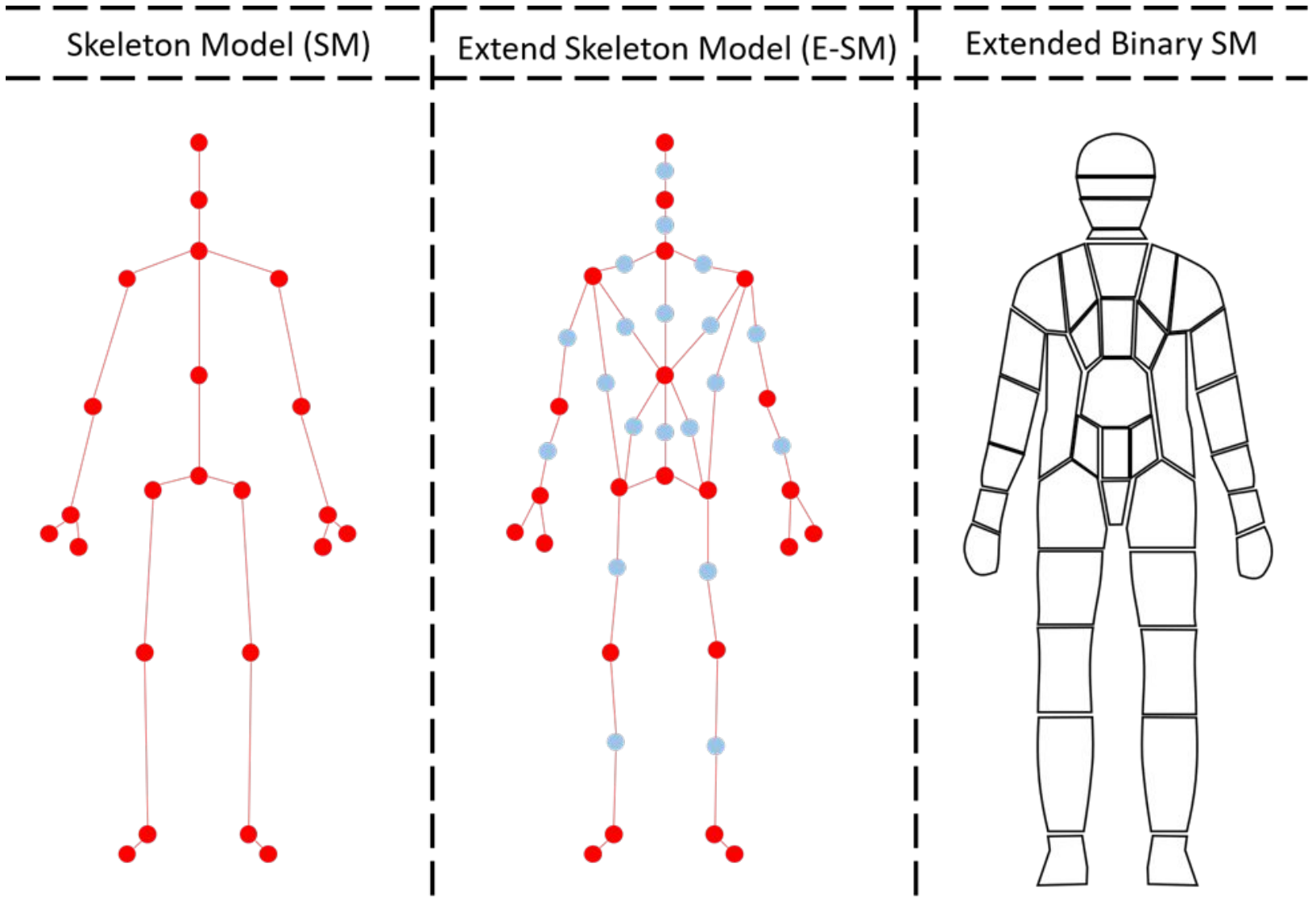


CLO-factor detection

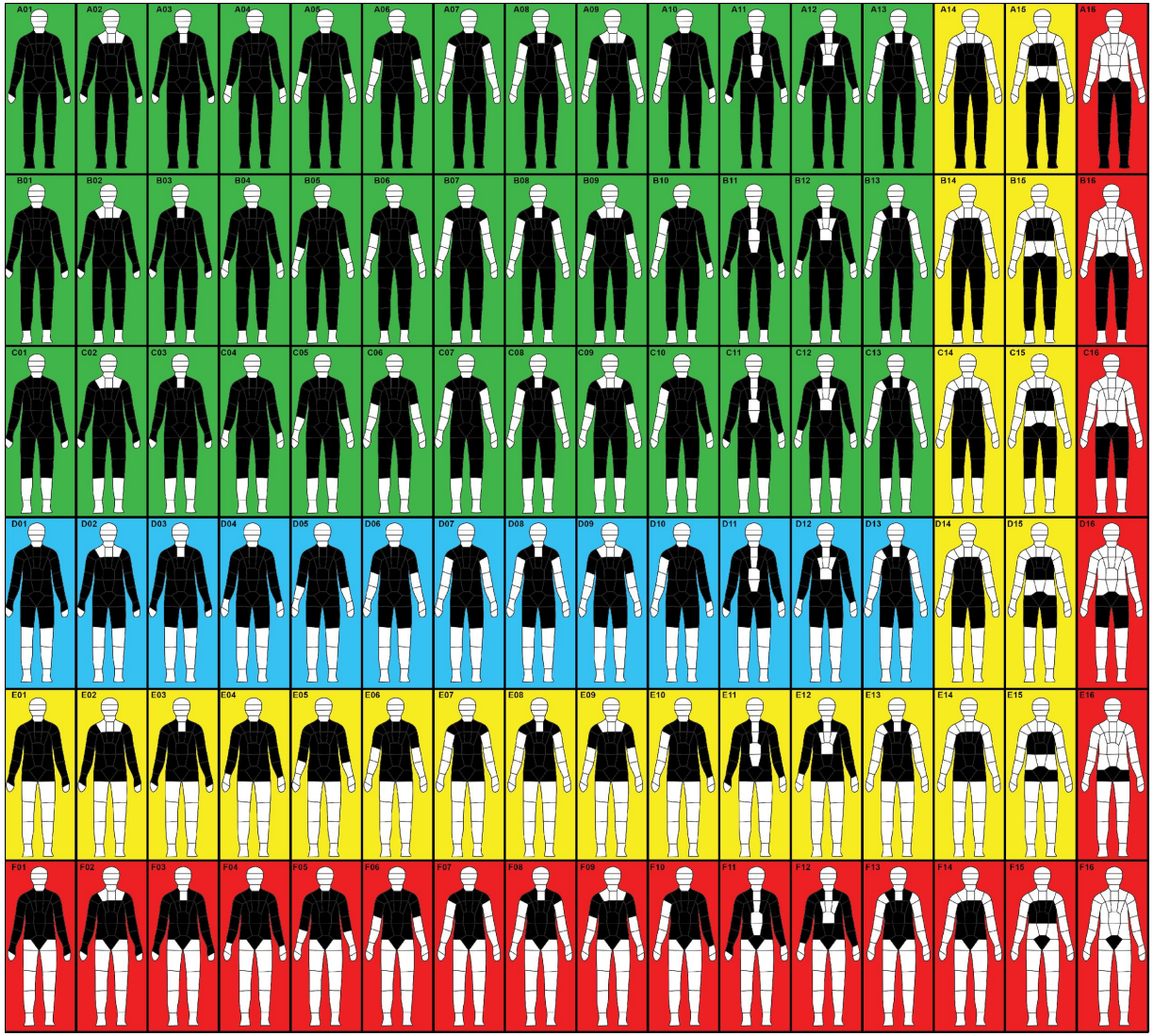




CLO-factor extension

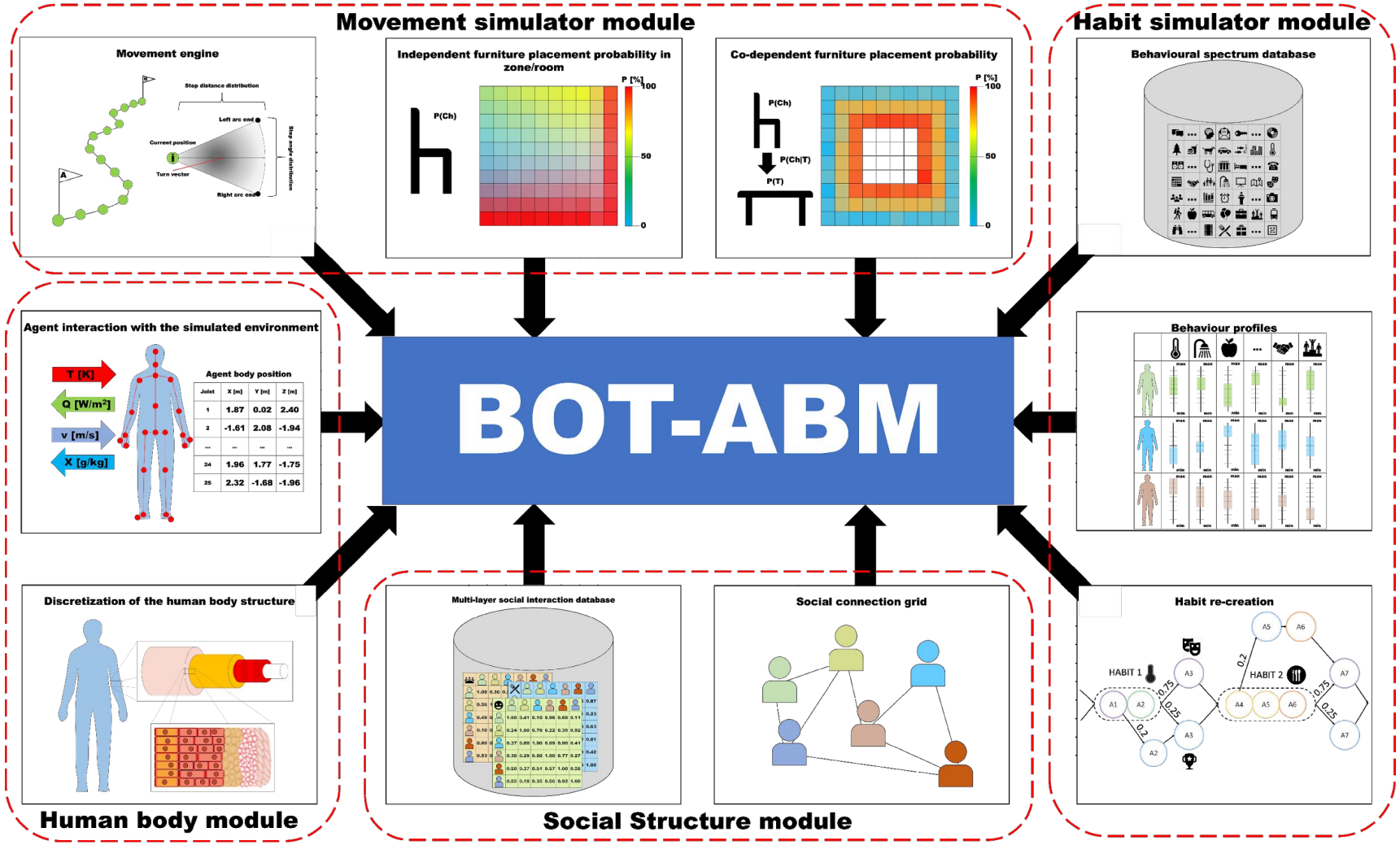


CLO-factor extension



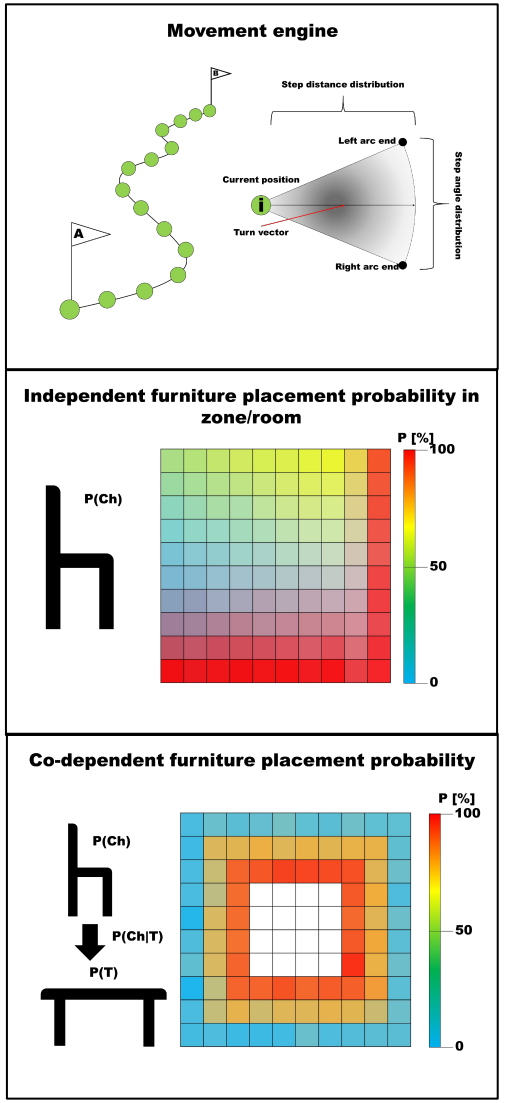
	All		Poor Light		Good Light	
	HLS	RGB	HLS	RGB	HLS	RGB
CATBOOST	97,58%	97,01%	97,54%	97,23%	98,78%	98,36%
GradientBoost	96,25%	95,83%	96,43%	96,21%	97,99%	97,60%
KNN	98,01%	97,28%	97,62%	97,11%	98,73%	97,88%
XGBoost	96,25%	95,11%	95,80%	95,70%	97,62%	96,96%
DBSCAN	81,65%	75,21%	73,81%	66,79%	85,43%	76,42%

Occupant as a main simulation subject

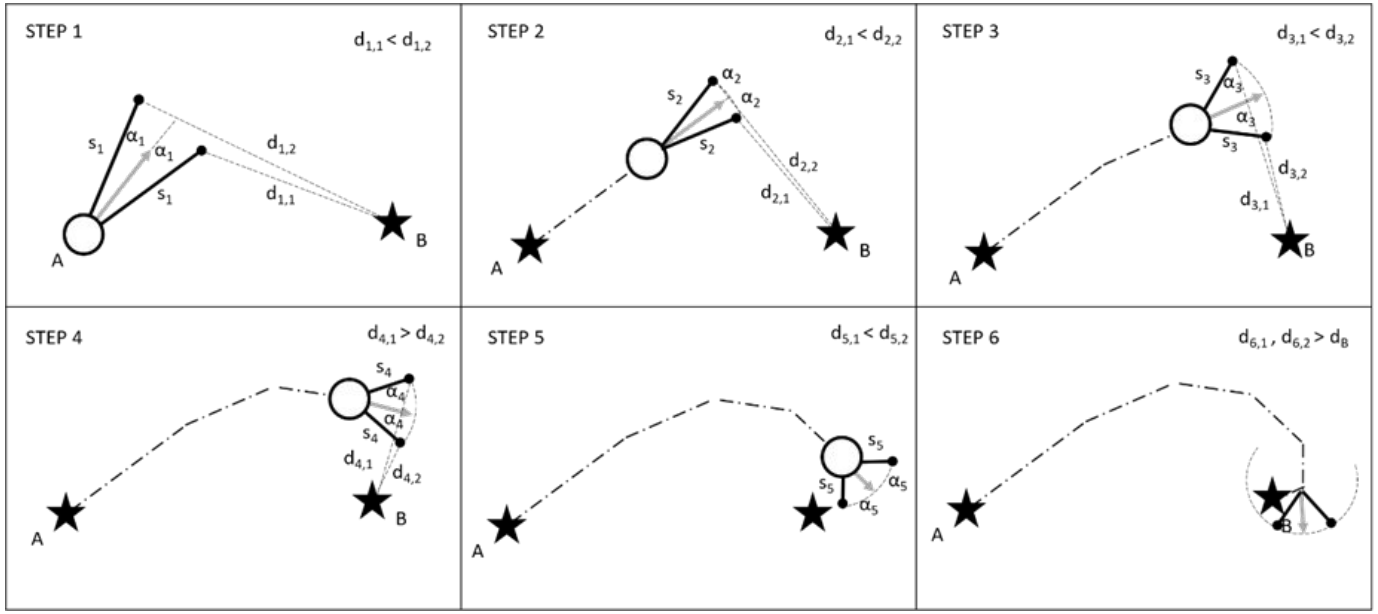


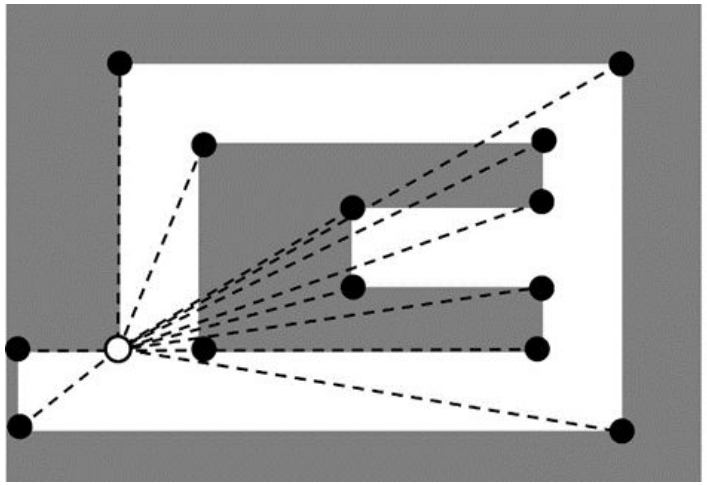
Movement simulator module

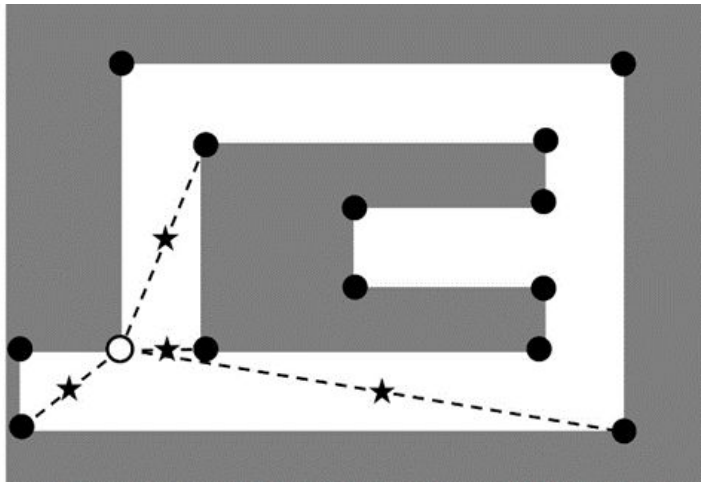
- Target
  - Allows for simulation of action-driven occupant indoor transitions
  - Can be used to simulate various layouts,
  - The platform for collection of data about appliances placement
- Status
  - Fully functional movement engine
  - Device placement surveying implemented as application
  - Ongoing data collection campaign



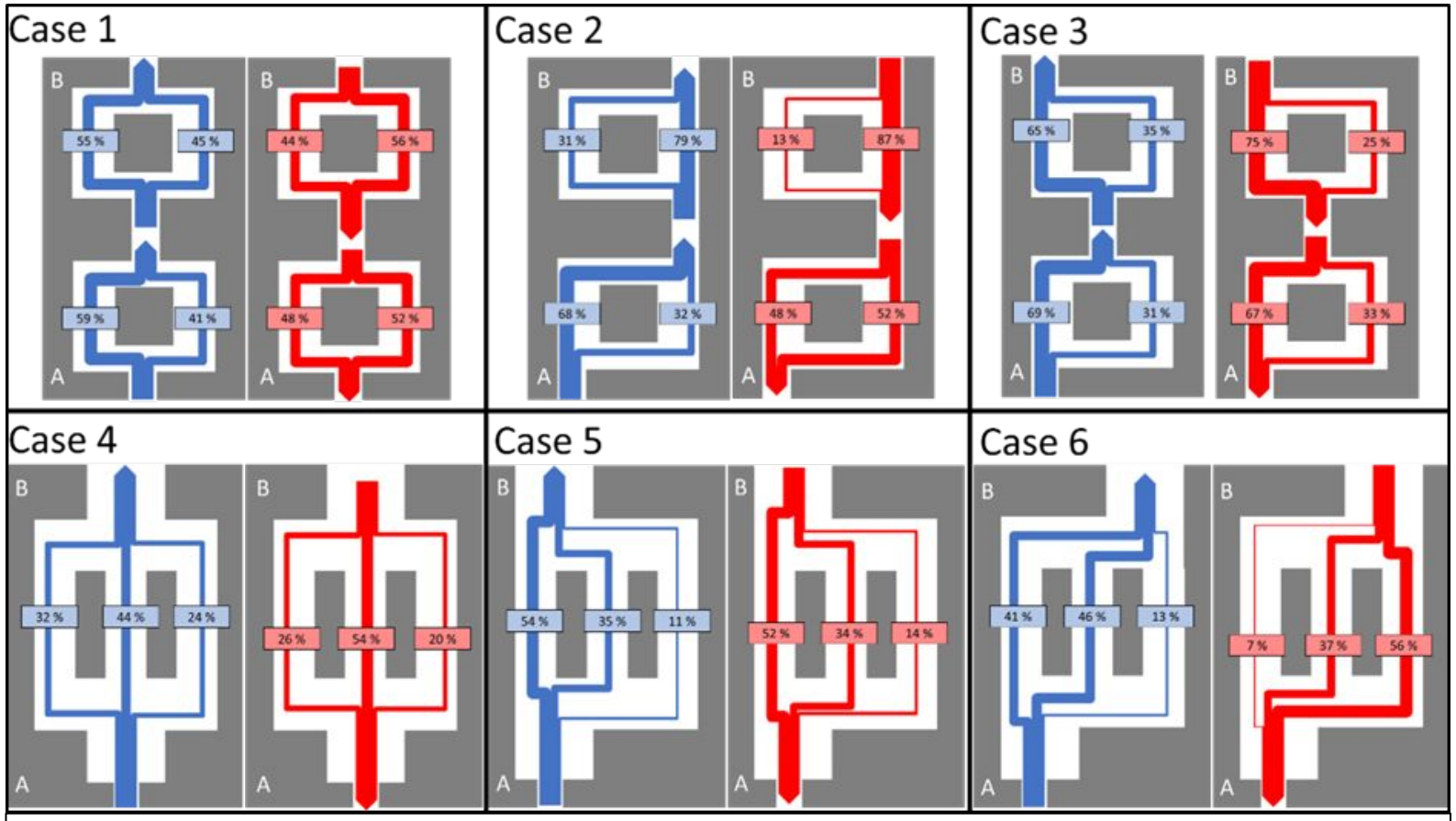
Movement simulator module



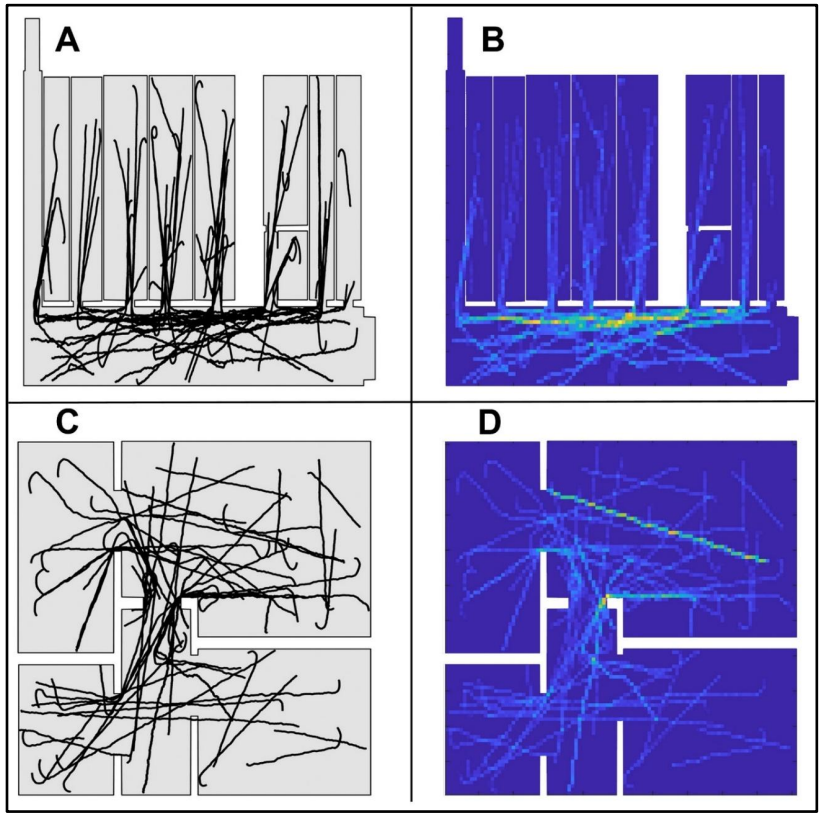




Movement simulator module

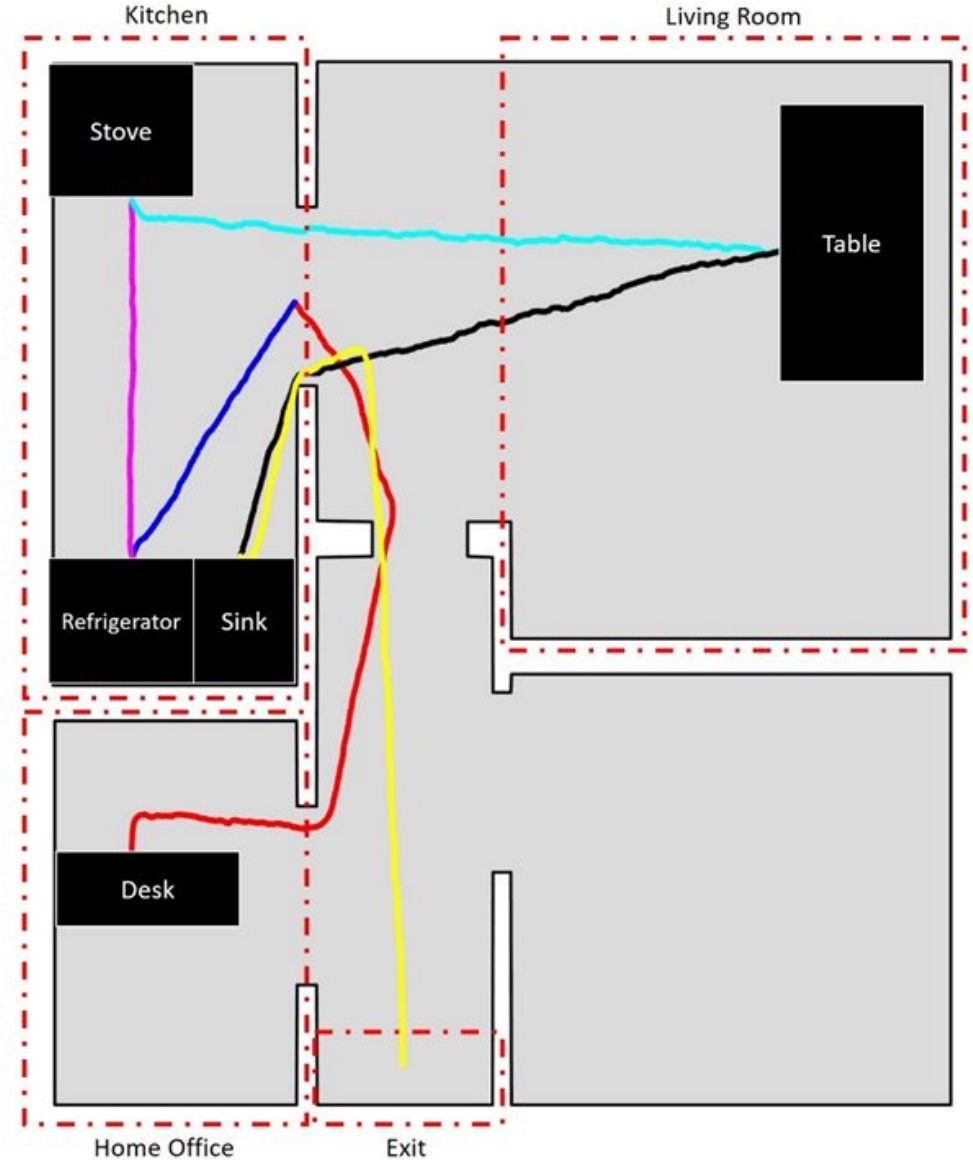


path selection experiment



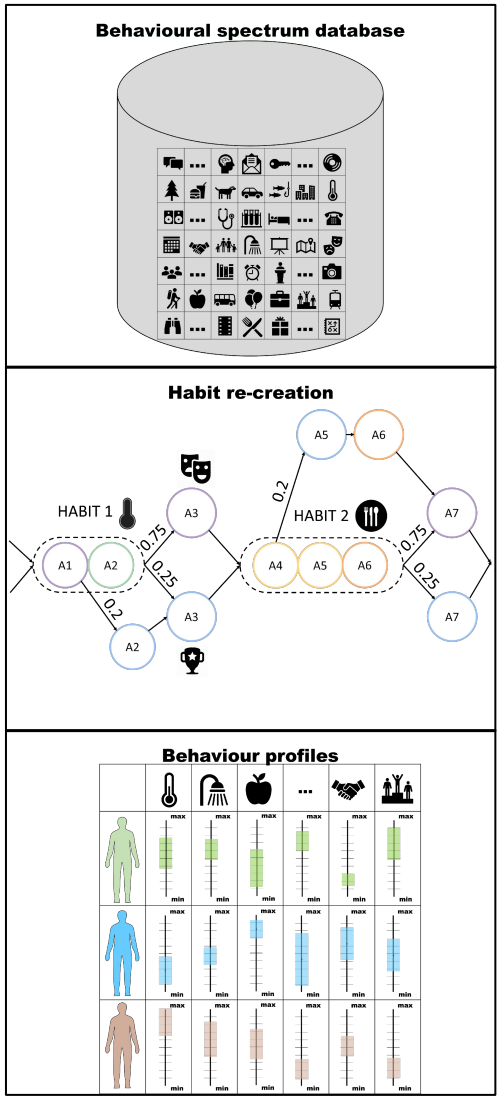
Simulation results

Movement simulator module

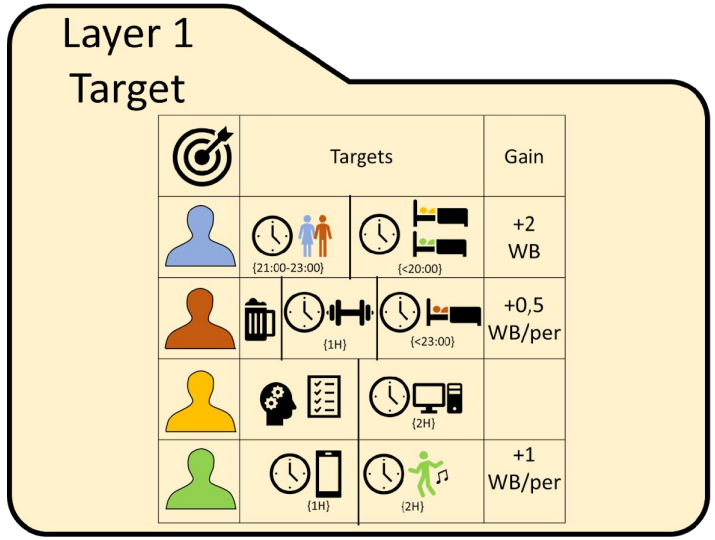


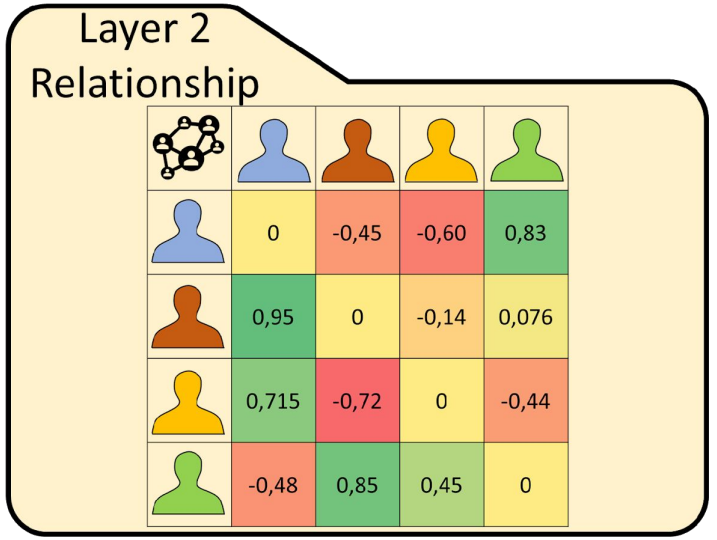
Habit simulator module

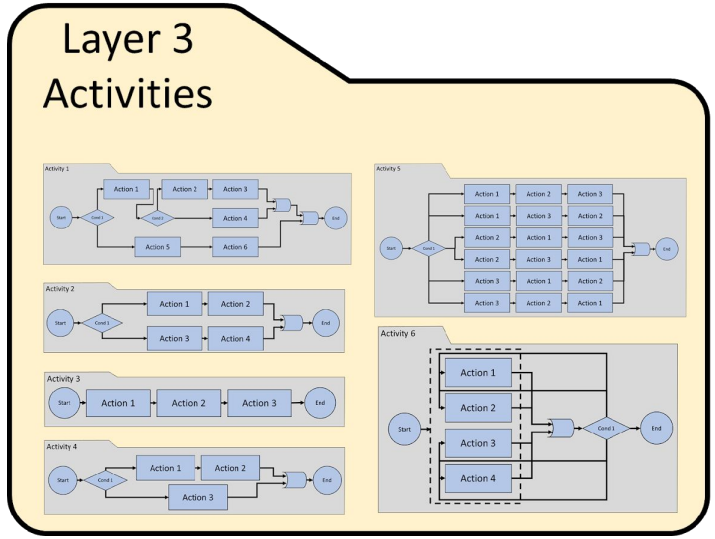
- Target
  - Library repository of all potential activates,
  - Database of occupant profile preference
  - Action/habit sequencer
- Status
  - Ongoing development of the multi-layer action sequencer
  - Development of the motion capture activity database
  - Lack of the real occupant behaviour profiles, only numerical

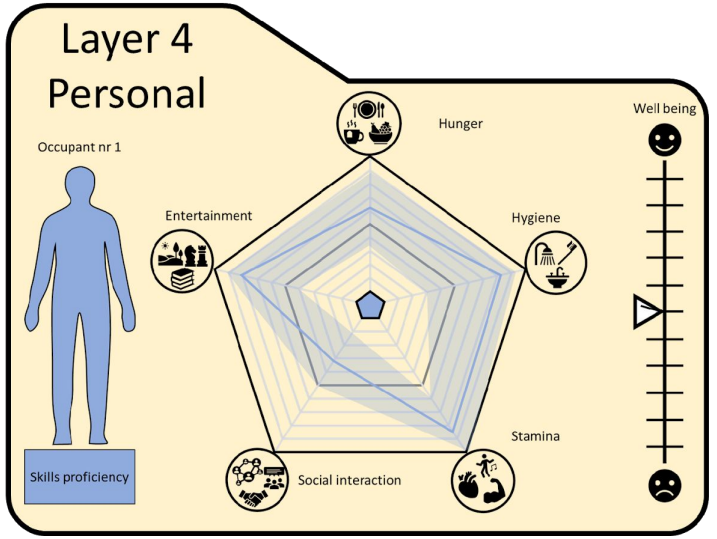


Habit simulator module

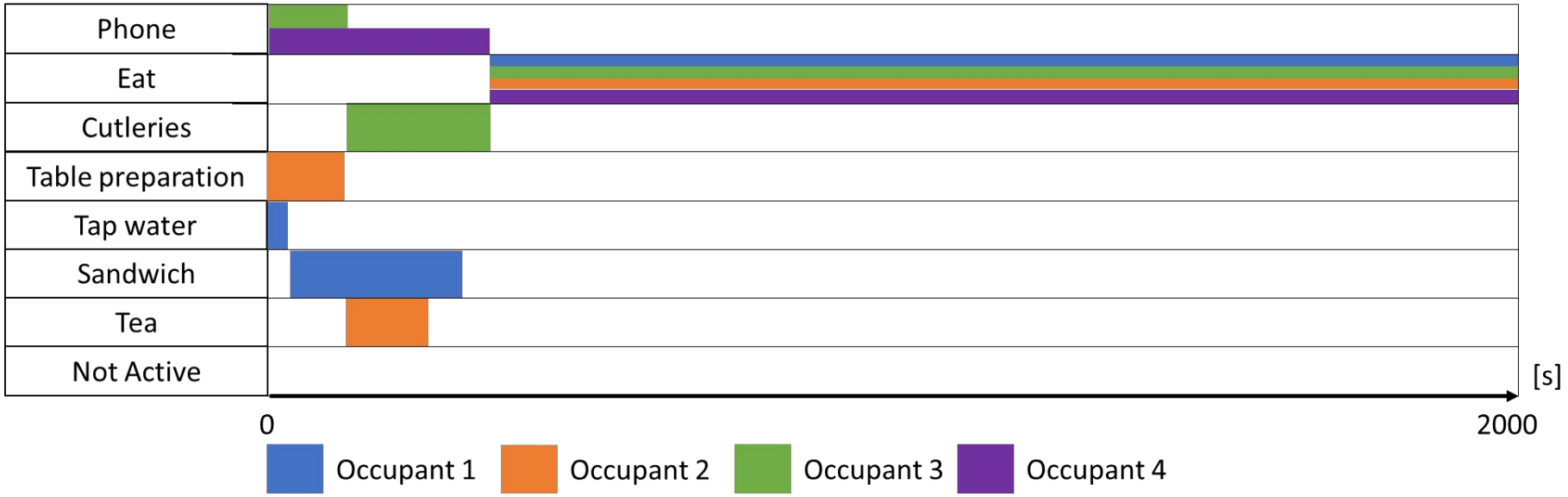


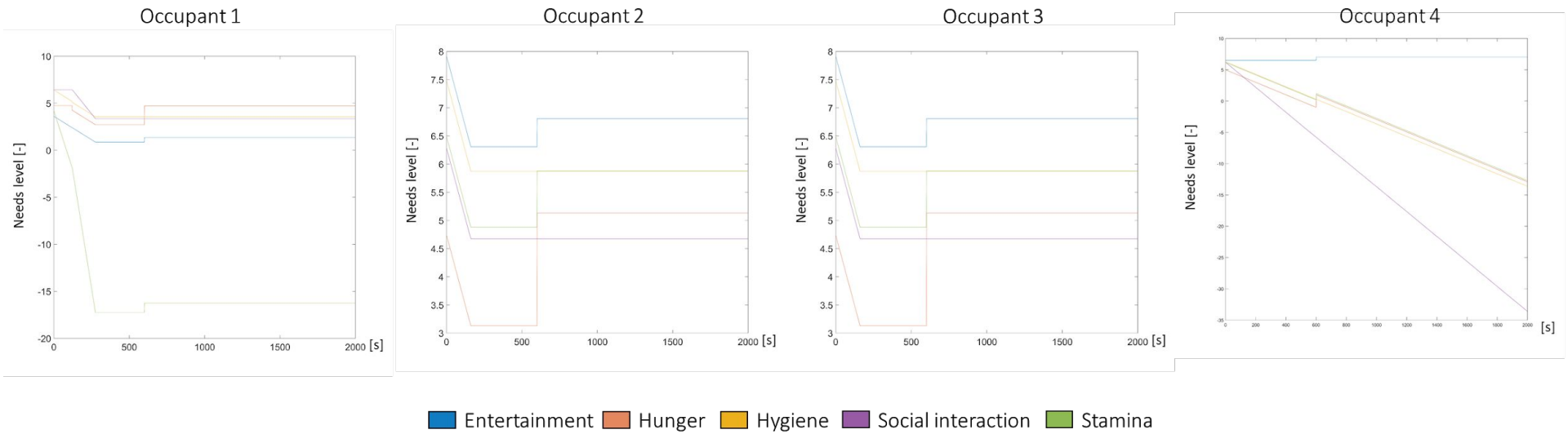






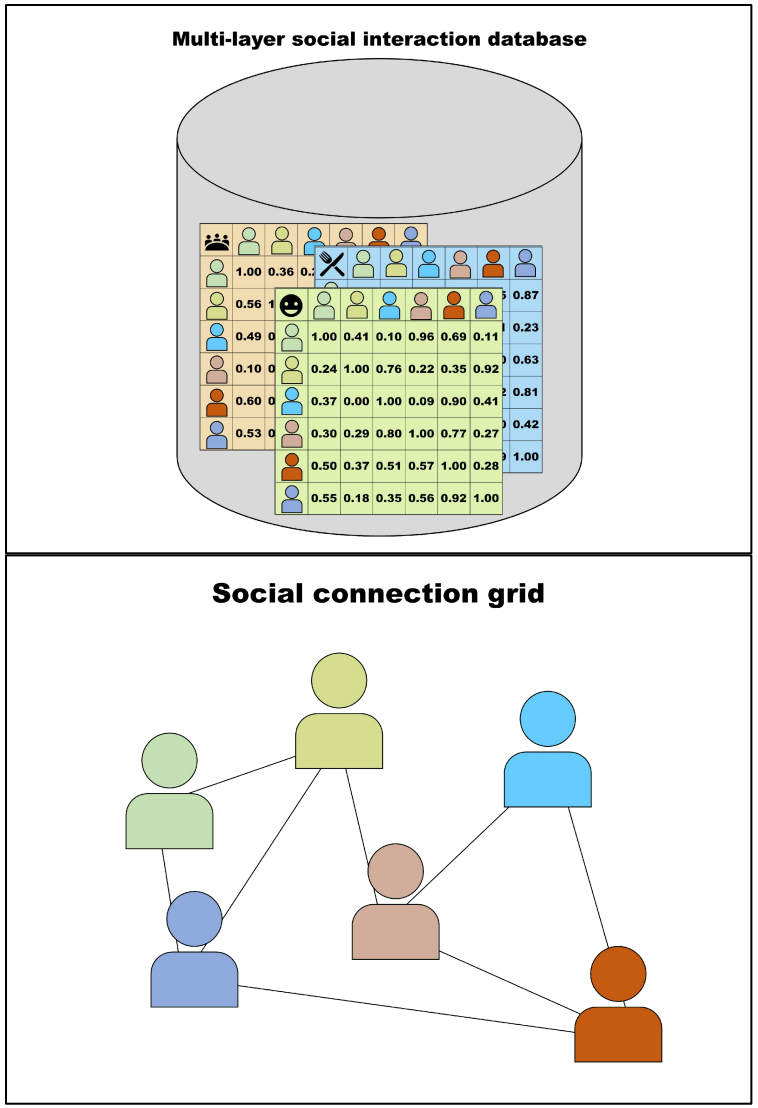
Habit simulator module





Social Structure module

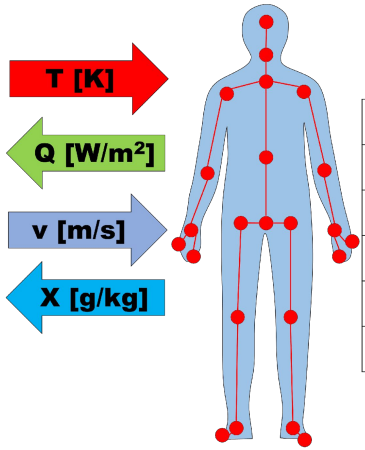
- Target
  - Interaction with other agents
  - Relationship of the agent with the other group
  - Hierarchy structure of social groups
- Status
  - PhD position that focus on a development of this module
  - Development of the sub-model structure
  - Review of already existing models



Human body module

- Target
  - Sensation and interaction with the indoor environment
  - The natural representation of the human body transition
  - Simulation of the multilayer tissue model
- Status
  - Implementation of the cumulative environment sensing
  - Established collaboration with medical department for discretization of the human body structure
  - Ongoing investigation of human body geometry discretization for CFD purpose

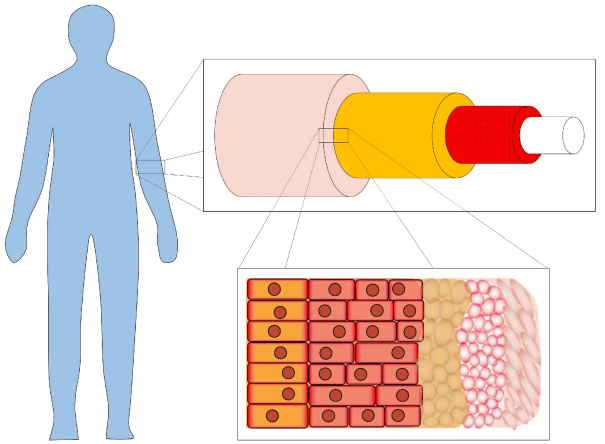
Agent interaction with the simulated environment



Agent body position

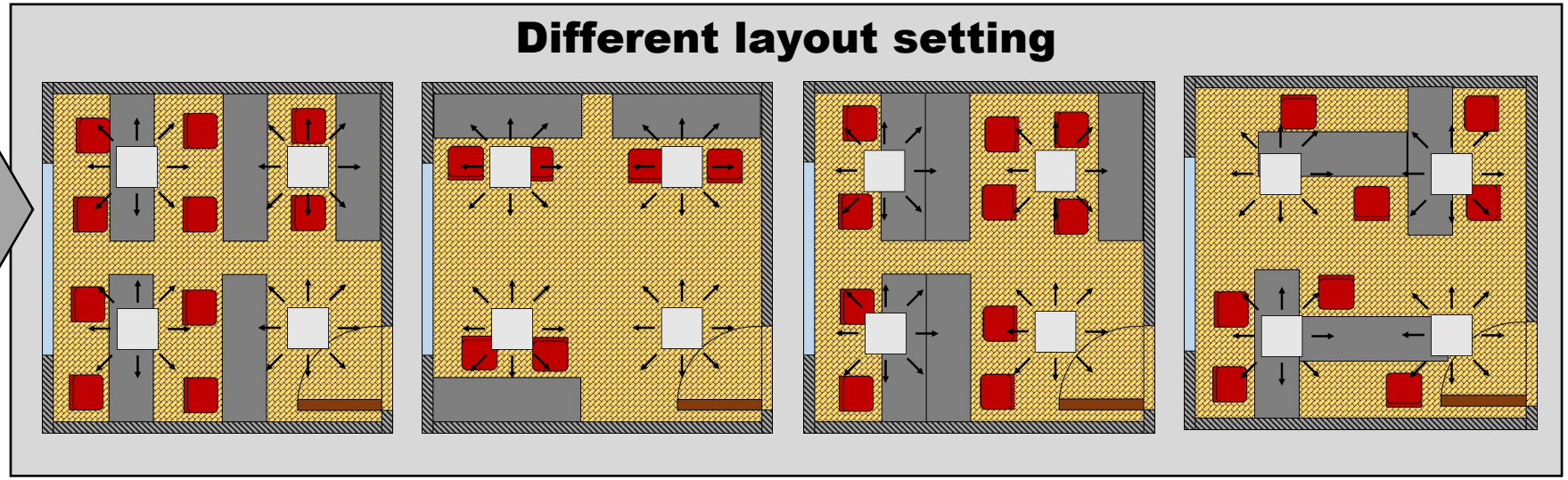
Joint	X [m]	Y [m]	Z [m]
1	1.87	0.02	2.40
2	-1.61	2.08	-1.94
...	...	...	...
24	1.96	1.77	-1.75
25	2.32	-1.68	-1.96

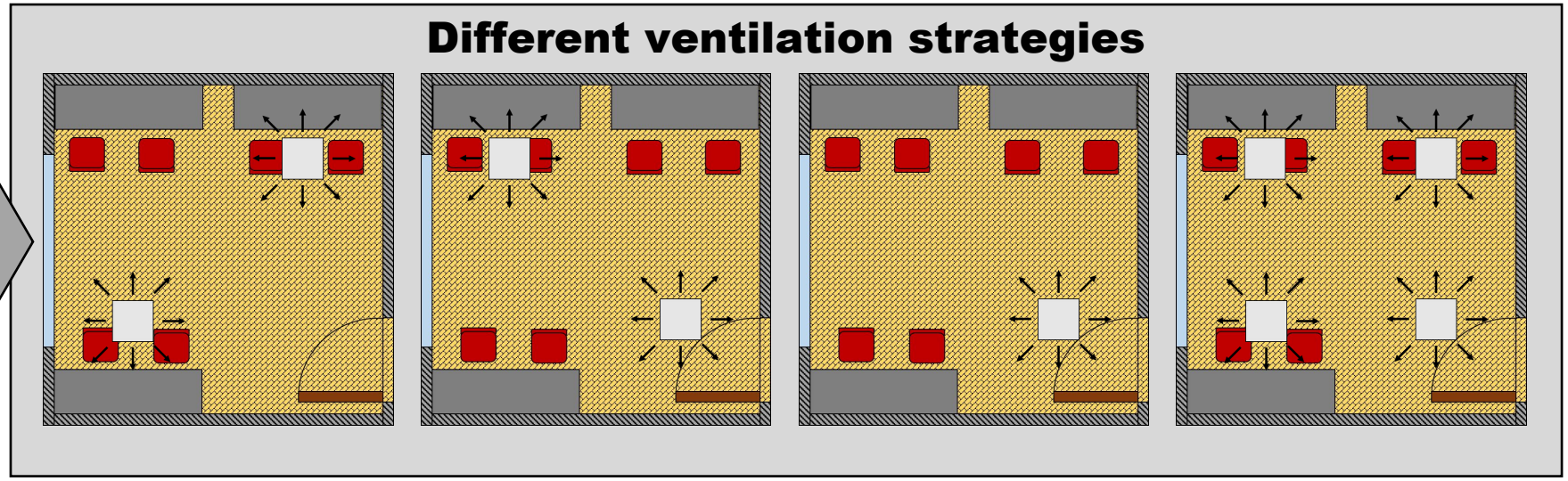
Discretization of the human body structure



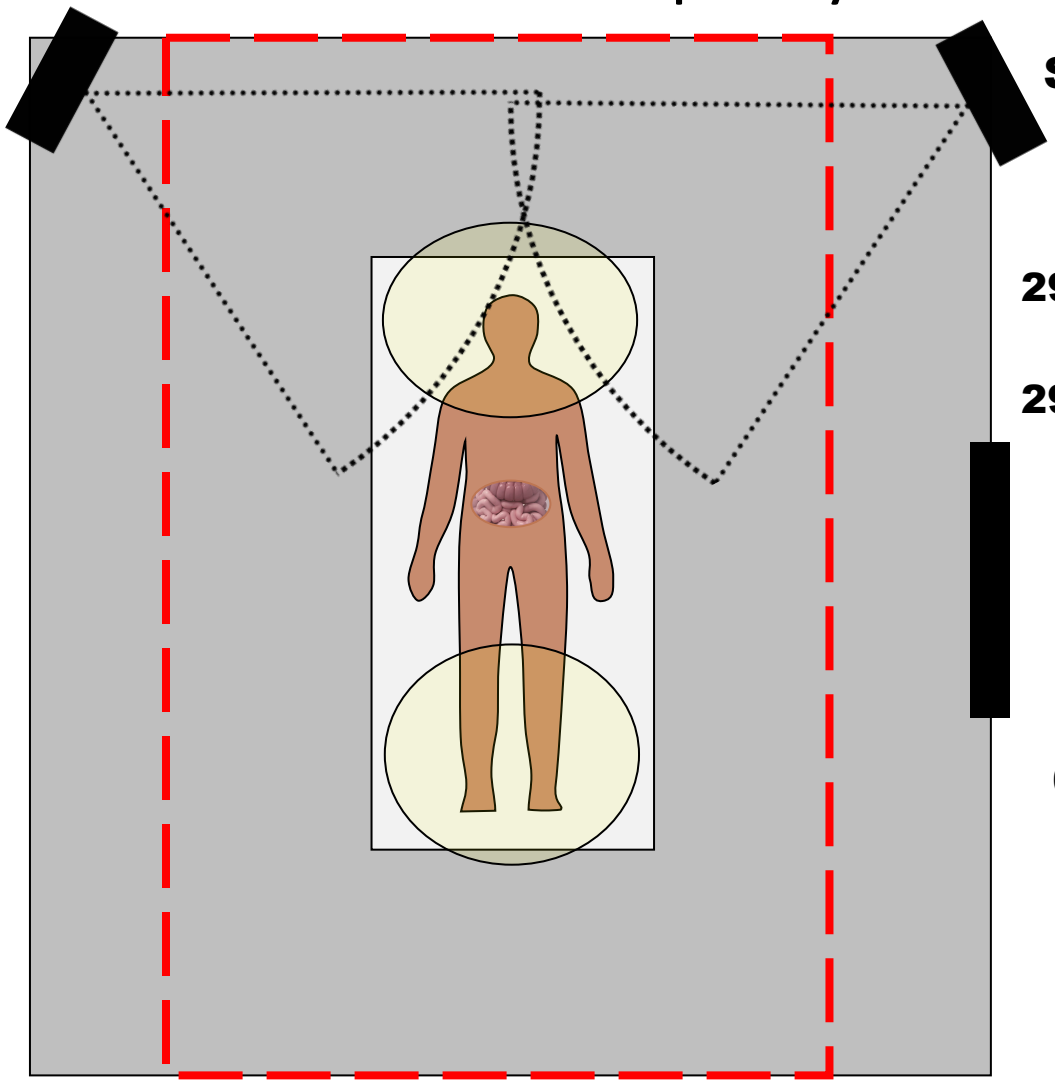
The goal : User oriented design

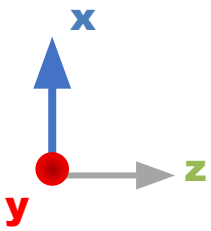
OB simulator

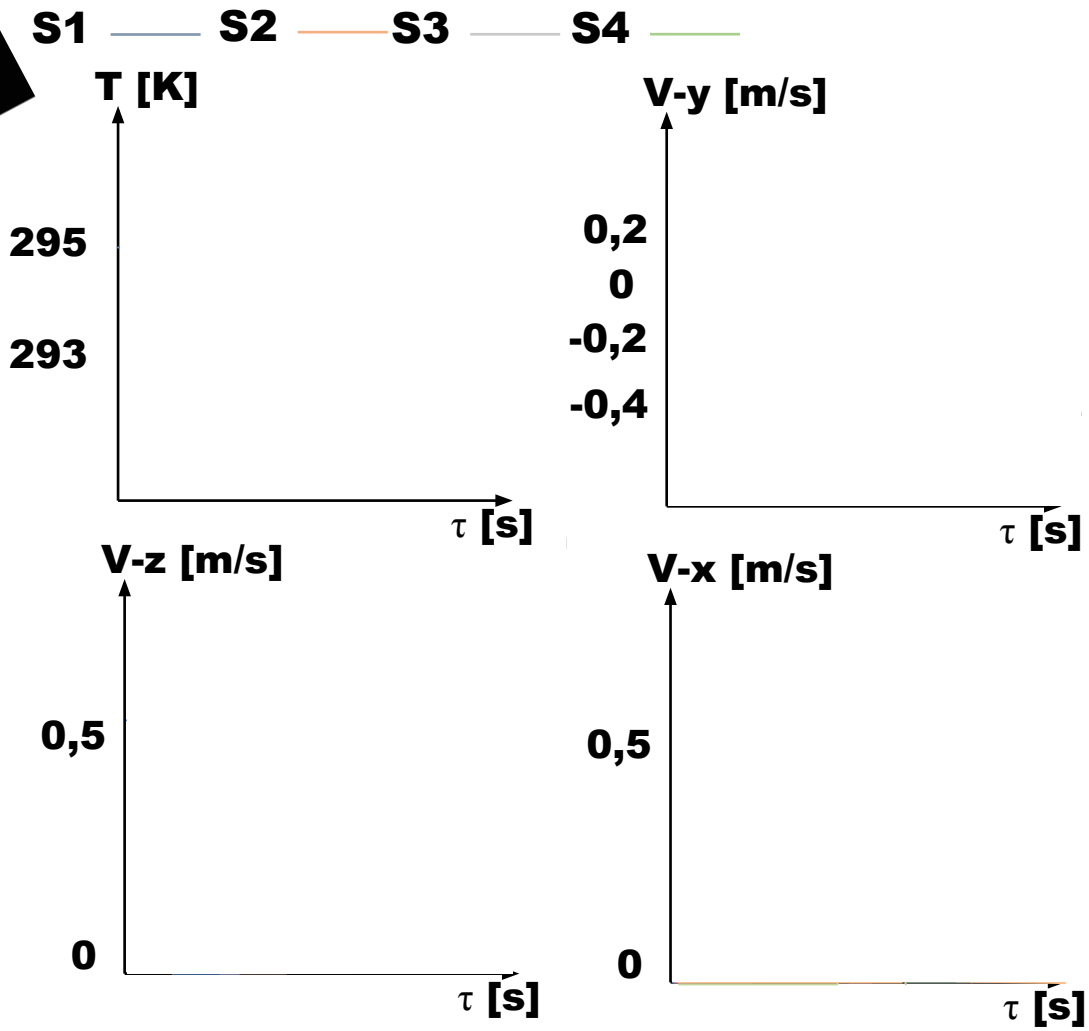




Other applications: Surgeons exposition to the thermal condition and their influence on the air quality







Koniec