Digital Twin-Based Personal IAQ Exposure

Workspace Decision Support Using Occupant Positioning

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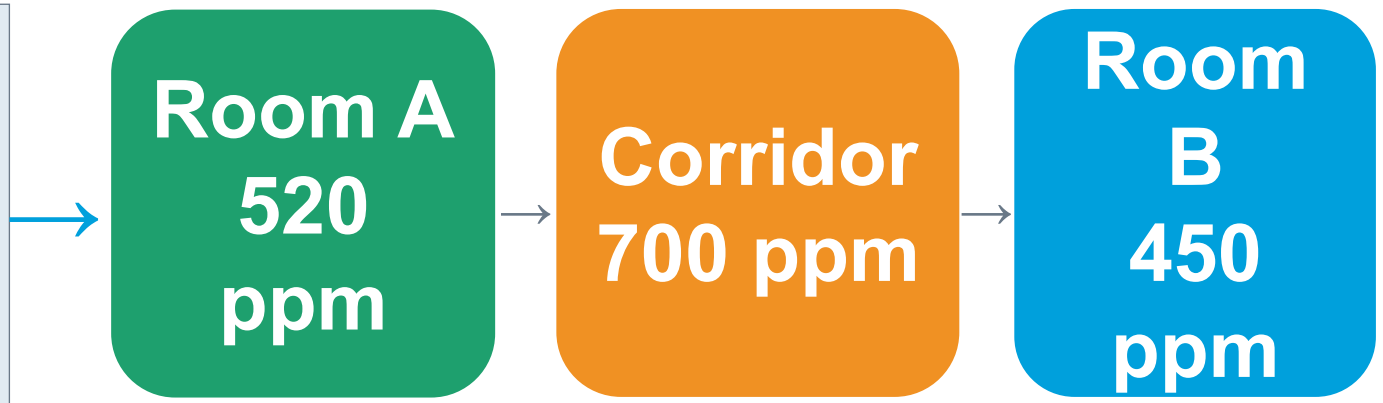
A room sensor does not tell us a person's exposure

Conventional view

CO_2

Room average ≈ one condition

Exposure-aware view

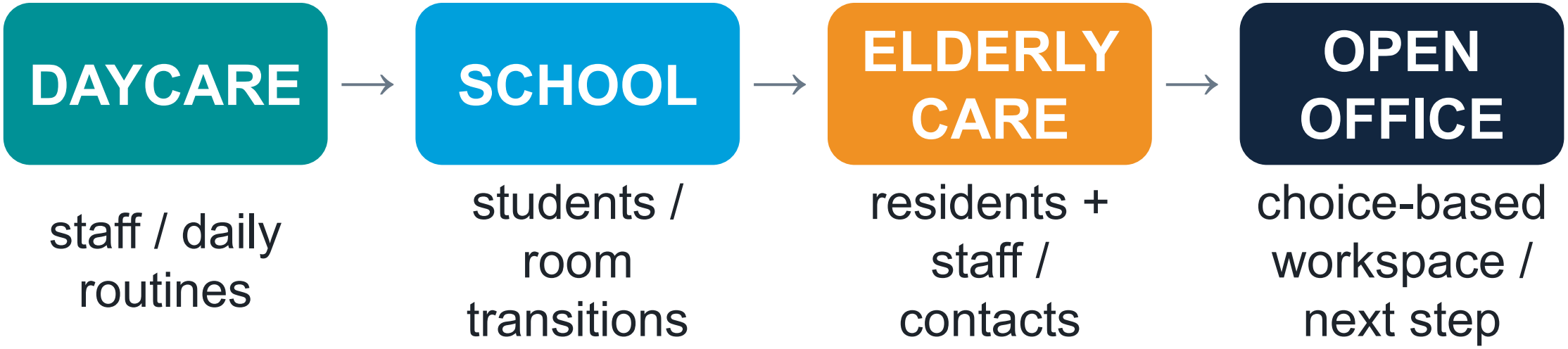


Good for monitoring a room — not a moving person.

Person + location + time + IAQ = personal exposure

A research path across real occupied buildings

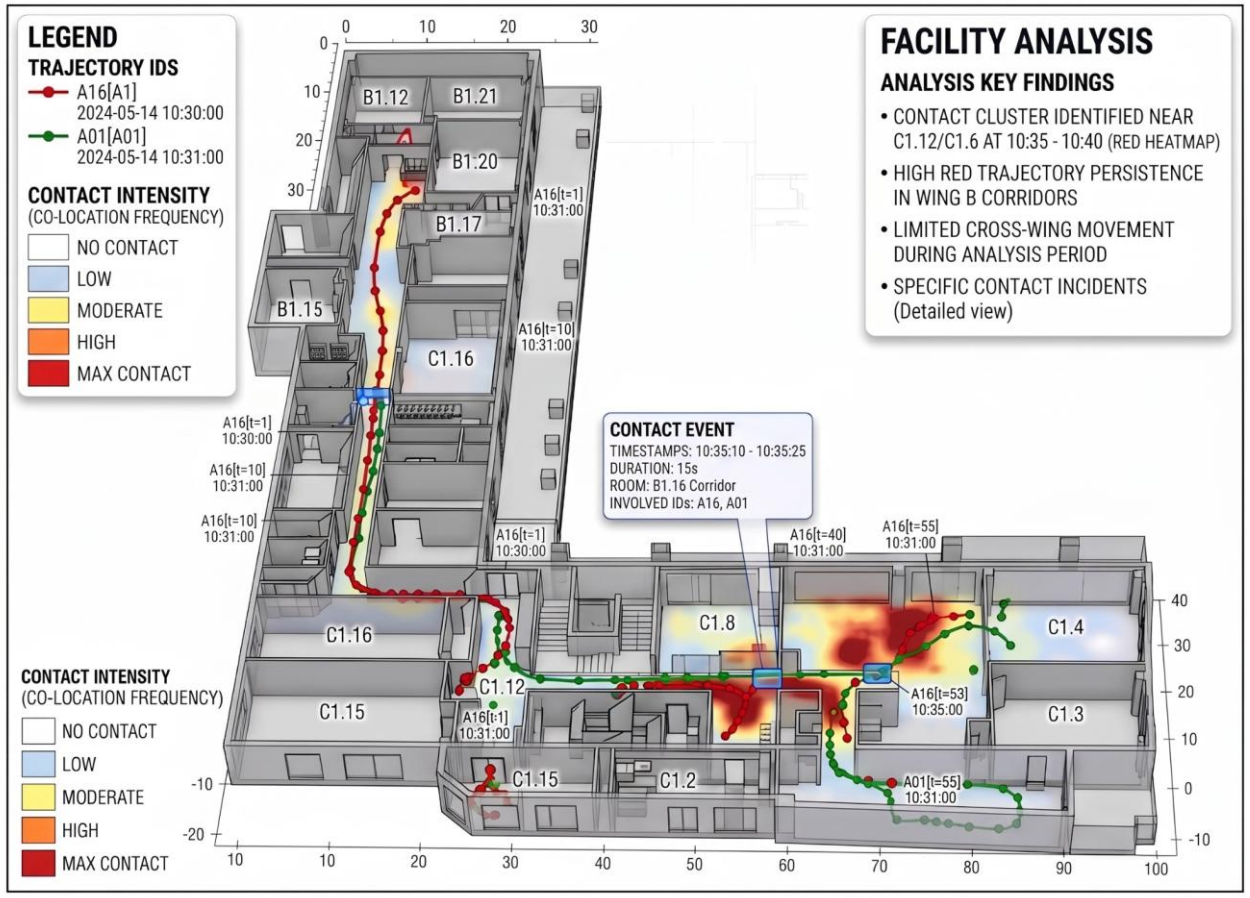
The same core method is being tested in different use environments



Continuous IAQ + occupant positioning → spatial-temporal patterns → exposure-aware building decisions

Field demonstration: contact events from positioning trajectories

Childcare example linking timeline, room layout and indoor positioning data



What it shows

TRAJECTORY

movement path by timestamp

CONTACT

co-location frequency / intensity

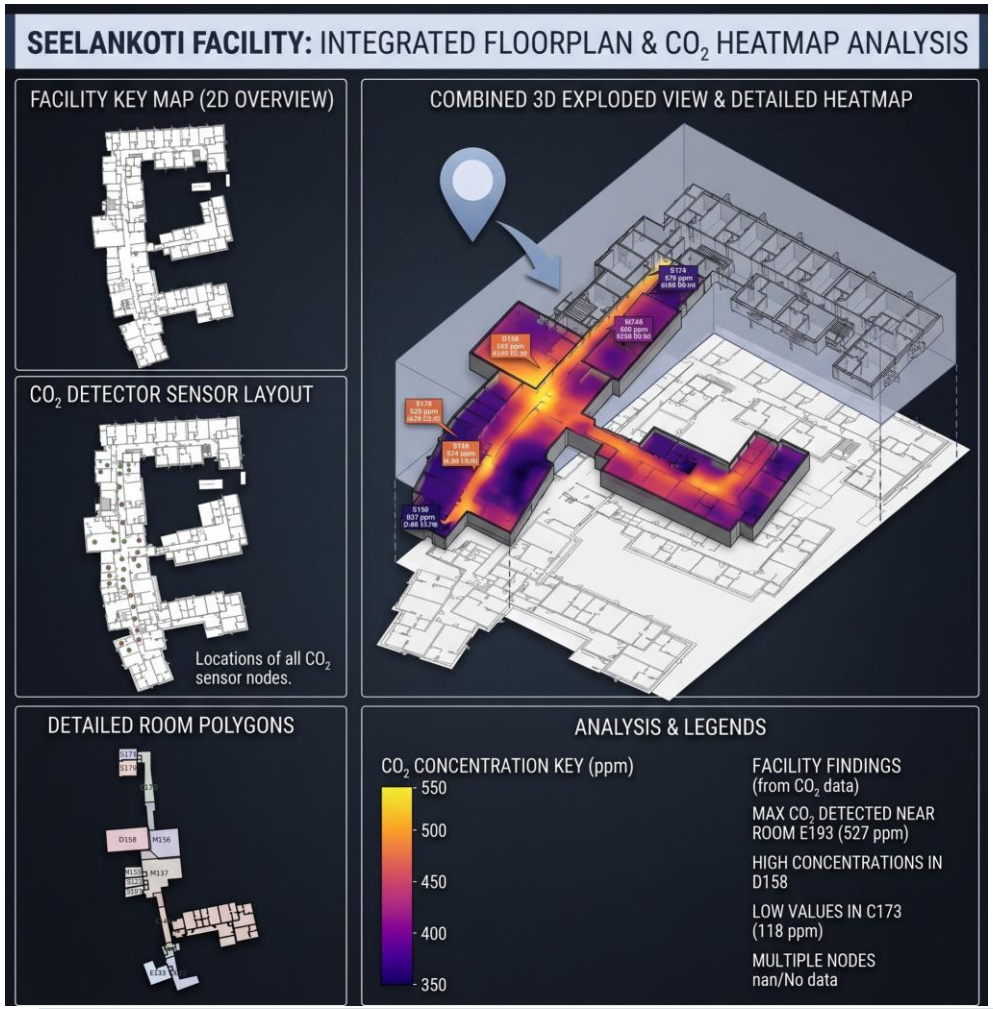
EVENT

who, where, and when

Useful for interpreting exposure and close-contact situations.

Field demonstration: IAQ heatmap in a care facility

Seelankoti example linking CO_2 sensors, room polygons and 3D floor-plan interpretation



Why this matters

SENSOR LAYOUT shows where the IAQ data comes from

ROOM POLYGONS translate measurements into spaces

3D HEATMAP makes hotspots easier to explain

This supports facility-level decisions, not only sensor-level readings.

How the pIAQ digital twin works

Four data layers are linked by room and timestamp

1

IAQ sensors

CO_2 • $PM_{2.5}$ • T • RH

2

Positioning

Bluetooth AoA trajectories

3

Space model

Rooms • zones • BIM

4

Time

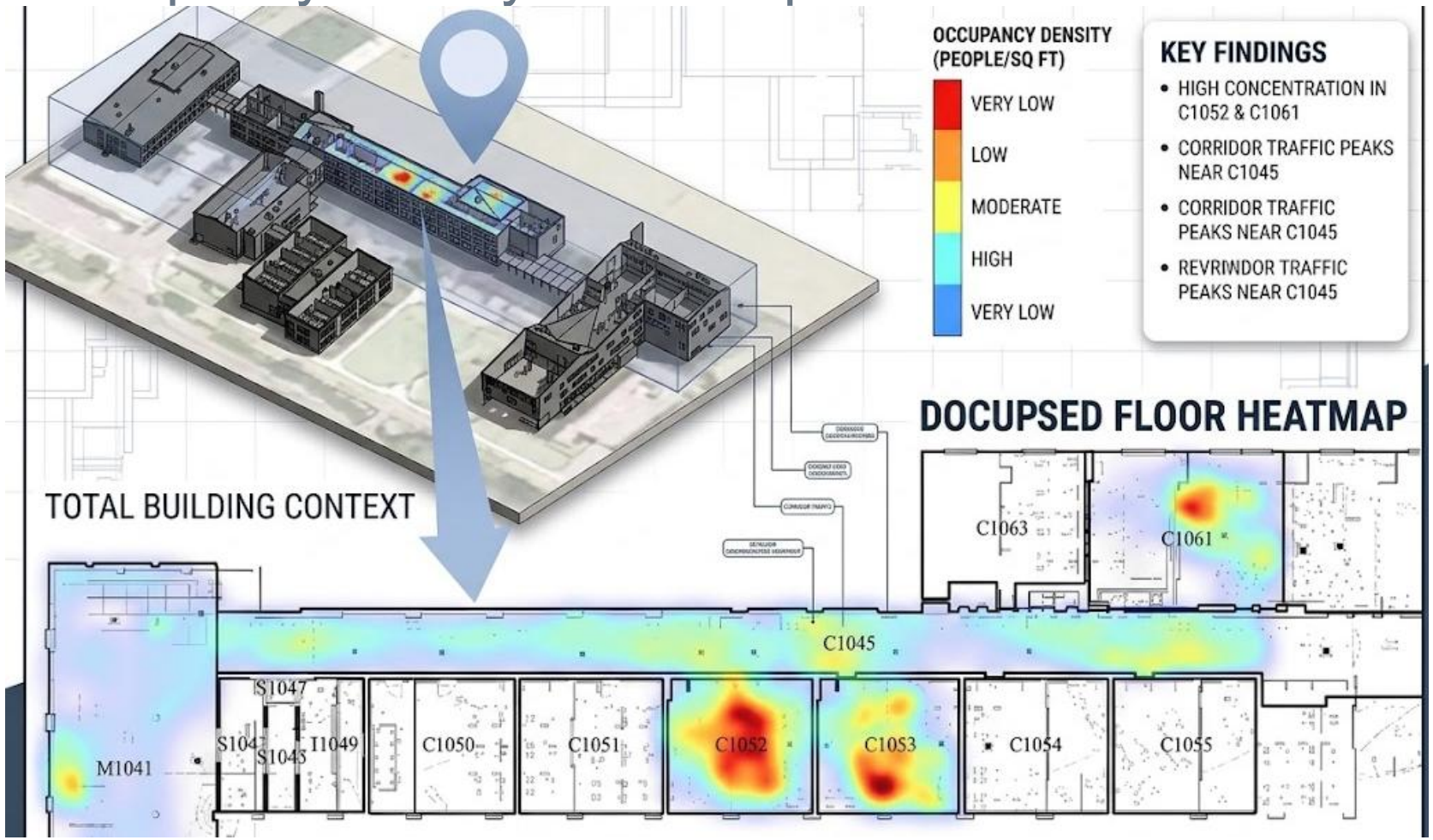
Where and how long

↓

PERSONAL EXPOSURE + WORKSPACE DECISION SUPPORT

School case: where people actually spent time

Occupancy density reveals spatial use that static floor plans cannot



What this adds

- Movement density across rooms and corridors
- Hotspots of repeated use
- A spatial layer for linking IAQ with actual occupancy

Room-level IAQ showed clear spatial differences

Selected results from the elementary school autumn case

≈1100 ppm

Highest max CO_2

Dining hall

≈1040 ppm

Max CO_2

Corridor

≈1030 ppm

Max CO_2

Classroom

≈397 µg/m³

Highest max $PM_{2.5}$

Main hall

Room hotspots are useful — but they still do not tell us which conditions each person experienced.

One participant's exposure was very different from the room maximum

330,000
one-second positioning records

43,090
matched with IAQ
≈ 12 hours

≈470 ppm
mean personal CO_2

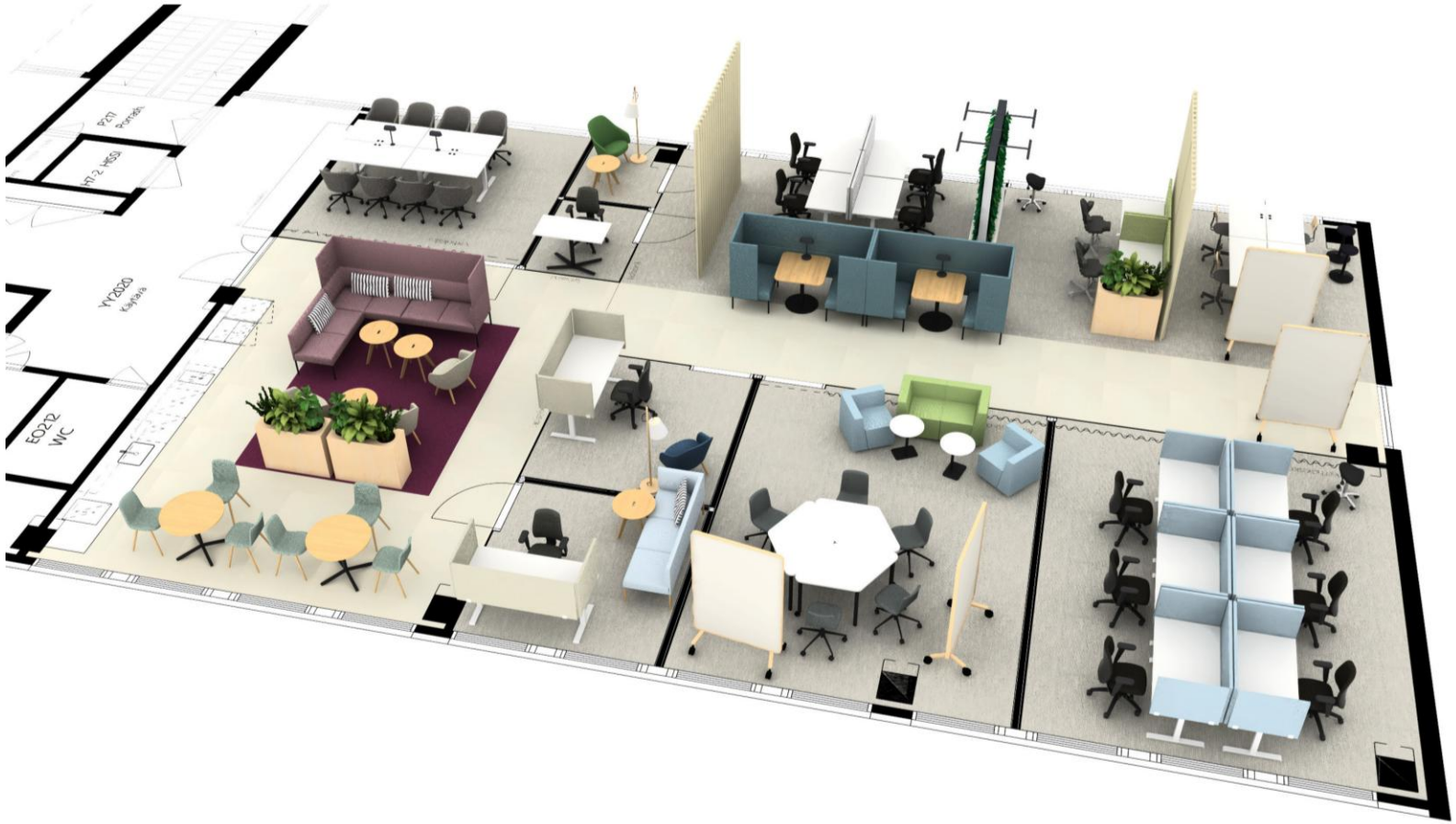
≈770 ppm
max matched personal CO_2

≈1100 ppm
highest room max CO_2

Key point: room maximum ≠ personal exposure.

Next field implementation: a modern open-office demo

A choice-based workspace creates a strong test case for exposure + space-use analytics

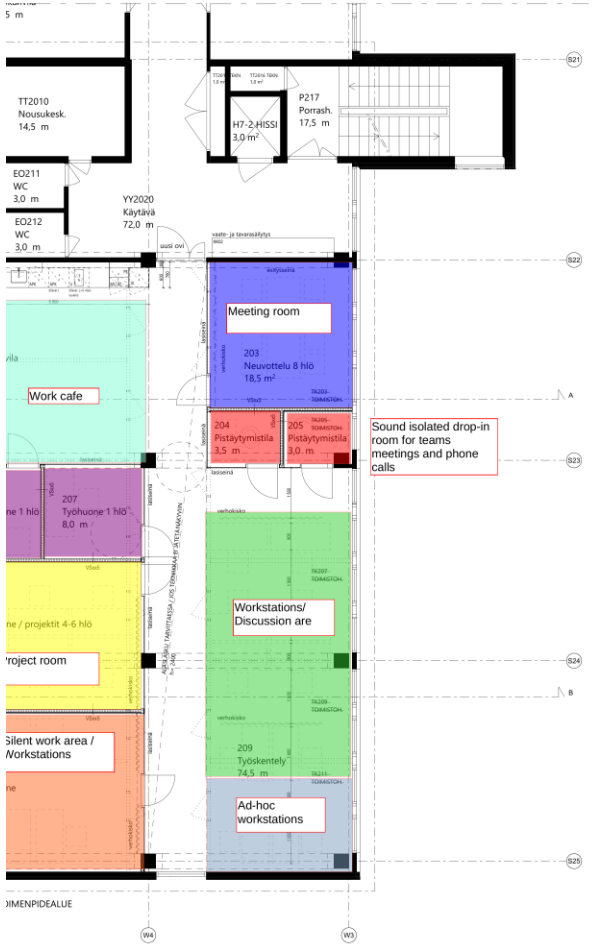


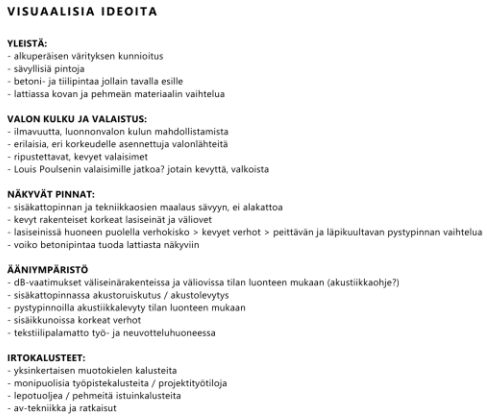
The setting

- ≈210 m² demo area
- Designed for ≈30 people
- Quiet work, project rooms, meeting spaces and work café
- Users can choose spaces according to current needs

What we will link in the open-office study

From a floor plan to an evidence-generating living laboratory





VISUAALISIA IDEOITA

YLEISTÄ:
- alkuperäisen värityksen kunnioitus
- sävyllisiä pintoja
- betoni- ja tiilipintaa jollain tavalla esille
- lattiassa kovan ja pehmeän materiaalin vaihtelua

VALON KULKU JA VALAISTUS:
- ilmavuutta, luonnonvalon kulun mahdollistamista
- erilaisia, eri korkeudelle asennettuja valonlähteitä
- ripustettavat, kevyet valaisimet
- Louis Poulsenin valaisimille jatkoa? jotain kevyttä, valkoista

NÄKYVÄT PINNAT:
- sisäkattopinnan ja tekniikkaosien maalaus sävyyn, ei alakattoa
- kevyt rakenteiset korkeat lasiseinät ja väliovet
- lasiseinissä huoneen puolella verhokisko > kevyet verhot > peittävän ja läpikuultavan pystypinnan vaihtelua
- voiko betonipintaa tuoda lattiasta näkyviin

ÄÄNIYMPÄRISTÖ
- dB-vaatimukset väliseinärakenteissa ja väliovissa tilan luonteen mukaan (akustiikkaohje?)
- sisäkattopinnassa akustoruiskutus / akustolevytys
- pystypinnoilla akustiikkalevyty tilan luonteen mukaan
- sisäikkunoissa korkeat verhot
- tekstiilipalamatto työ- ja neuvotteluhuoneessa

IRTOKALUSTEET:
- yksinkertaisen muotokielen kalusteita
- monipuolisia työpistekalusteita / projektityötiloja
- lepotuoljea / pehmeitä istuinkalusteita
- av-tekniikka ja ratkaisut

POSITION — pseudonymized tag trajectory

IAQ — CO_2 • PM • T • RH • VOC

ROOM + TIME — zone, dwell time, transitions

CONSENT — voluntary electronic consent via REDCap

Privacy first: pseudonymized, zone-level and non-identifiable outputs

What can this office demo tell us?

Questions that are directly useful for healthy-building decisions

Where?	Which spaces are actually used — and when?
How long?	How much time is spent in each room or zone?
Under what IAQ?	What conditions coincide with occupancy and dwell time?
So what?	Which workspace or ventilation decisions should change?

From measurements to decisions

OCCUPANCY
Where people are

+

IAQ
What they breathe

+

TIME
How long

→

EXPOSURE-AWARE DIGITAL TWIN

Space planning

Which zones need change?

Ventilation

Where is demand?

Healthy use

How can room choices reduce exposure?

TAKE-HOME MESSAGE

Healthy-building decisions improve when we know
not only the room condition — but who was where, for how long.

ROOM IAQ conditions + **OCCUPANT movement** = **PERSONAL EXPOSURE**

References & acknowledgements

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- Donkers et al. (2022), Buildings 12(10), 1522.
- Liedes, Shwe, Fedorik & Haverinen-Shaughnessy (2025), Indoor and Built Environment.
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