# Supplemental Materials

## Ocupado: Visualizing Location-Based Counts Over Time Across Buildings

**Michael Oppermann**, opperman@cs.ubc.ca
**Tamara Munzner**, tmm@cs.ubc.ca

University of British Columbia

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# 1. Data Sources

| Organization | Data source | Time period | Device count recordings | Buildings | Floors | Zones | |
|---|---|---|---|---|---|---|---|
| university campus A | static export | 2016-05-15 — 2017-05-19 | 24.669 million | 49 | 247 | 730 | Many system outages |
| university campus B | static export | 2016-10-28 — 2017-09-13 | 28.576 million | 11 | 38 | 181 | |
| university campus A | live stream | 2018-04-21 — 2018-12-31<br>(+ few days in 2019) | 62.749 million | 25 | 104 | 778 | |
| company<br>+ synthetic data | live stream | since 2018-02-13 | 3.628 million | 1 (+1) | 1 (+1) | 27 (+6) | This Ocupado instance includes additional synthetic data: 1 building, 1 floor, and 6 zones |

# 2. Stakeholders and Demos

| Table 1. N. of demos and informal interviews conducted by us and Sensible Building Science (SBS). | | |
|---|---|---|
| *Focus domains* | **1) Custodial services** | **6** |
| | University 1-A | 4 |
| | University 1-B | 1 |
| | Company 1 | 1 |
| | **2) Building management** | **3** |
| | University 1-A | 3 |
| | **3) Space planning** | **4** |
| | University 1-A | 3 |
| | University 2 | 1 |
| | **4) Classroom management** | **2** |
| | University 1-A | 2 |
| | **5) Data quality control** | |
| | SBS | *Continuous feedback* |
| *Winnowing* | Physical security (University 1-A) | 1 |
| | Risk management (University 1-A) | 1 |
| | Energy management (University 1-B) | 3 |
| | Transportation Authority | 1 |

| Table 2. Demos and informal interviews conducted by SBS without our direct involvement. | |
|---|---|
| *Potential customers, sponsors, and partners* | |
| Universities | 9 |
| Government agencies | 6 |
| Companies | 5 |
| *Number of demos per sector* | |
| Innovation program | 3 |
| Technology partner | 6 |
| Facilities planning and management | 12 |
| Energy management | 3 |

# 2. Stakeholders and Tasks

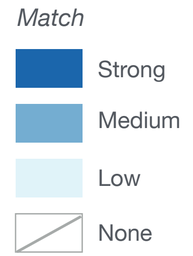
| | *Tasks* | *Custodial Services* | | **Building Management** | **Space Planning** | **Classroom Management** | **Data Quality Control** |
|---|---|---|---|---|---|---|---|
| | | **Custodial Head** | **Custodial Manager** | | | | |
| T1 | **Confirm** observations that have been made | | | | | | |
| T2 | **Monitor** the current/recent utilization rate | | | | | | |
| T3 | **Communicate** space usage and justify decisions | | | | | | |
| T4 | **Validate** the data (quality control) | | | | | | |

*Match*

- Strong
- Medium
- Low
- None

# 2. Stakeholders, Domain Questions, and Tasks

| *Stakeholder* | *Domain Questions and Needs* | T1 | T2 | T3 | T4 |
|---|---|---|---|---|---|
| **Custodial Head** | Want something informative at start of shift, to prioritize areas | | | | |
| | Which regions were heavily used recently and are empty now? If space not used, don't have to do things (not room level, more building/floor level) | | | | |
| | Which regions are normally heavy used but current occupancy is low? (or inverse; current anomaly vs. average) | | | | |
| **Custodial Manager** | When should we clean? Have to wait until students leave. Still students sitting there using room and screens. Custodians can't get them cleaned and get complaints in the morning that they're dirty | | | | |
| | Justify with hard data when there's pushback about resource needs. | | | | |
| **Building Manager** | Get a better understanding how space is used. Labs are open early from morning until late at night. We don’t know when people are using it and want to know what is going on. | | | | |
| | What are typical usage patterns of informal learning spaces on the 3rd floor? | | | | |
| | We want to proof capacity bottlenecks for discussions about new buildings | | | | |
| | How often are rooms (meetings rooms, project rooms) booked but not used? | | | | |
| **Space Planning** | When do people leave buildings in the evening? Which rooms should be kept open for students in the evening or on weekends? | | | | |
| | Where (on the campus) are most of the people during the day? | | | | |
| | Interested in whether there are tons of rooms that are supposed to be used, but are not actually in use. Perception that this is happening. | | | | |
| | What is our summer use? We think it is a lot more than people think. Is it going up? | | | | |
| **Classroom Management** | Start a flood of consultation around changing the scheduling model. Some of this might be able to inform that. Attrition rates, start times, front/rear loading, actual occupancy vs. registration of the term | | | | |
| | Do students show up for different classes than they’re scheduled for? (e.g. 11 am instead of 8 am class) | | | | |
| **Data Quality Control** | Analyze if there are unusual characteristics or gaps | | | | |
| | Take another look at how accurate the device numbers are (especially for small rooms). What is the minimum size of a zone that can be captured? | | | | |
| | How are adjacent zones affected by a large number of devices in one room? | | | | |



# 3. Ocupado Architecture & Design

# Notation: Spatial and Temporal Data Granularity

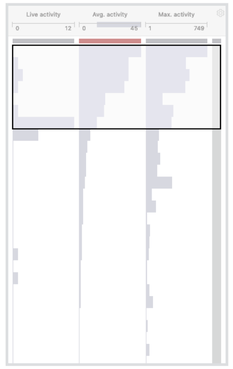
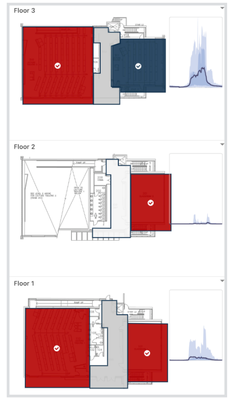
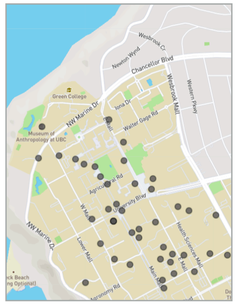
| | | |
|---|---|---|
| Space | **Region** ← | { ***Z**one*, ***F**loor*, ***B**uilding* } |
| | **Context** ← | { ***F**loor*, ***B**uilding*, ***C**ampus* } |
| | **Cardinality** ← | { ***One***, ***Few***, ***All*** } Regions |
| Time | **Period** ← | { ***S**hort-Term*, ***L**ong-Term* } |
| | **Rollup** ← | { ***A**ggregate*, ***I**ndividual* } Counts |

Examples:

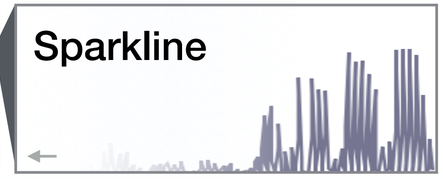
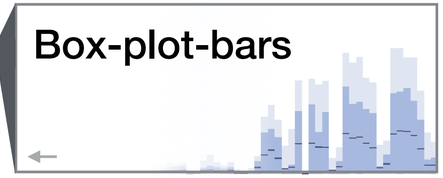
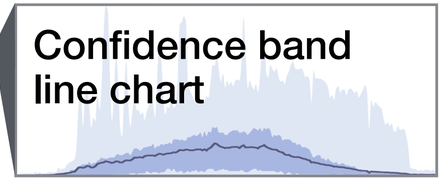
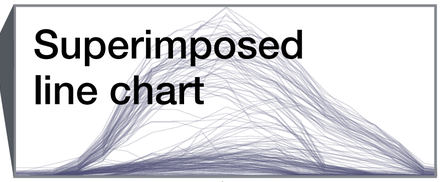
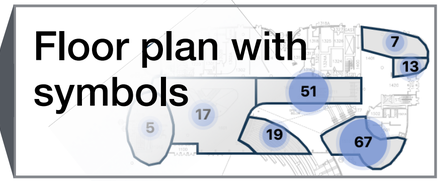
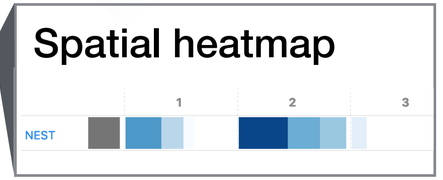
`ZF-ALL:SI` *Compare the utilization of all zones on a floor over the past 12 hours.*

`FB-Few:LA` *Compare the average utilization of floors 1-3 in the CS building.*

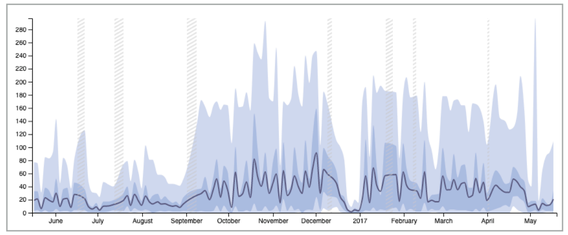
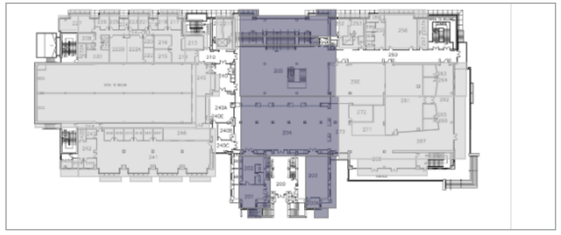
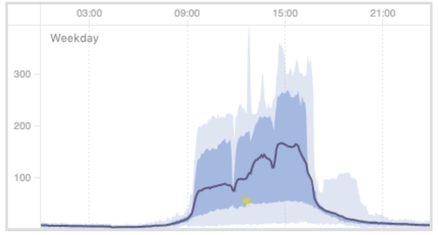
# Visualization Components: Region Selectors

| | Visual encoding | Scale | Interfaces | Data Granularity |
|---|---|---|---|---|
| A | **Data stripes**  | < 1000 regions | Campus Explorer | (all combinations if they are within the *scale* limit) |
| B | **Floor plans**  | ≤ 8 floors | Building Long-Term | [ZF,ZB,FB]-* |
| C | **Geo map**  | (only computational limit) | Sandbox | BC-* |

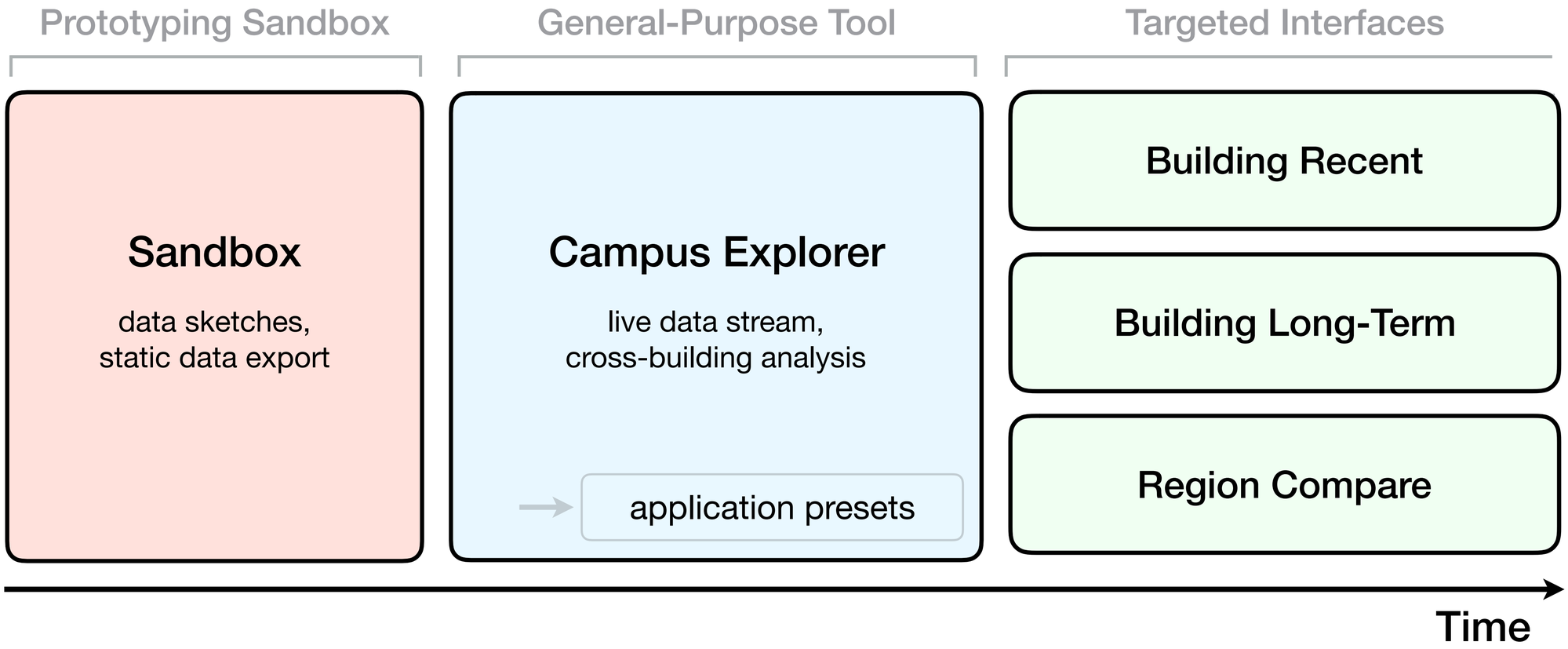
# Visualization Components: Region Subset Views

| | Layout | Visual Encoding | Facet | Comparisons | Interfaces | Data Granularity |
|---|---|---|---|---|---|---|
| Temporal | A | Sparkline  | juxtaposition | repeating patterns, trends, outliers *(contiguous)* | • Sandbox<br>• Campus Explorer<br>• Building Long-Term | *:LI<br>≤ *30 regions* |
| | B | Box-plot-bars  | juxtaposition | repeating patterns, trends, outliers *(non-contiguous)* | • Campus Explorer | *:LA<br>≤ *30 regions* |
| | C | Confidence band line chart  | aggregation | typical profiles | • Campus Explorer<br>• Building Long-Term | *:LA<br>≤ *30 regions* |
| | D | Superimposed line chart  | superposition | within-session patterns, outliers | • Sandbox<br>• Campus Explorer<br>• Region Compare | *:LI<br>≤ *30 regions* |
| Spatial | E | Floor plan with symbols   | superposition | within local spatial neighborhood | • Building Recent | [ZF,ZB]-*:S*<br>≤ *10 floors* |
| | F | Spatial heatmap   | containment (nested) | across distributed regions | • Campus Explorer | [ZF,ZB,ZC]-*:S* |

# Visualization Components: Region Detail Views

| Visual encoding | Interfaces | Data Granularity |
|---|---|---|
| **A** Zoomable binned line chart   | • Sandbox<br>• Campus Explorer<br>• Building Long-Term<br>• Building Recent | *-One:L* |
| **B** Floor plan  | • Sandbox<br>• Campus Explorer<br>• Building Long-Term<br>• Building Recent | ZF-* |
| **C** Confidence-band line chart   | • Campus Explorer<br>• Building Long-Term<br>• Building Recent | *-[One,Few]:LA |

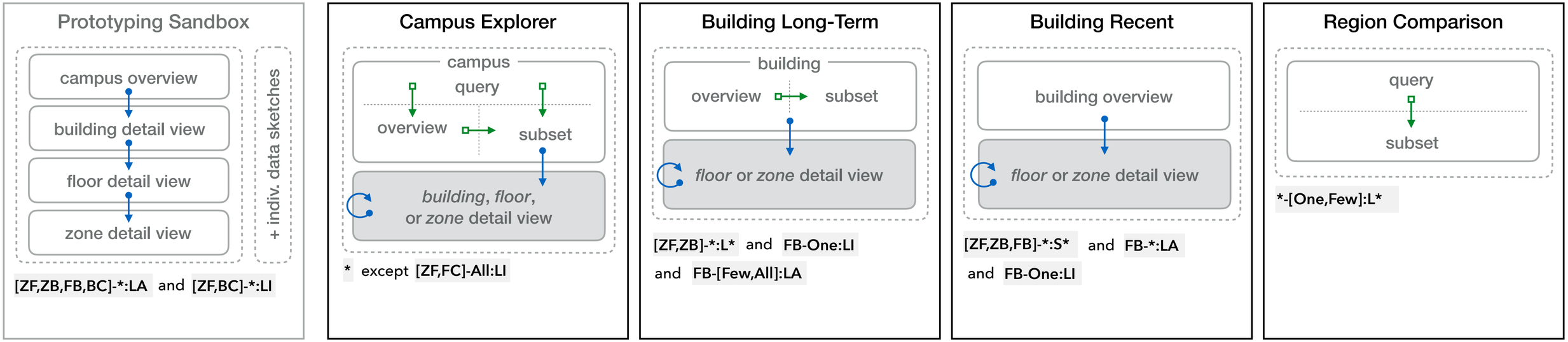
# Ocupado Evolution



# Interfaces: Spatial and Temporal Data Granularity

| *Interface* | *Region* | *Context* | *One region* | | | | *Few regions* | | | | *All regions* | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | Short-Term Individual | Short-Term Aggregated | Long-Term Individual | Long-Term Aggregated | Short-Term Individual | Short-Term Aggregated | Long-Term Individual | Long-Term Aggregated | Short-Term Individual | Short-Term Aggregated | Long-Term Individual | Long-Term Aggregated |
| **Sandbox** | **Zone** | **Floor** | | | ZF-One:LI | ZF-One:LA | | | ZF-Few:LI | ZF-Few:LA | | | ZF-All:LI | ZF-All:LA |
| | **Zone** | **Building** | | | | ZB-One:LA | | | | ZB-Few:LA | | | | ZB-All:LA |
| | **Floor** | **Building** | | | | FB-One:LA | | | | FB-Few:LA | | | | FB-All: LA |
| | **Building** | **Campus** | | | BC-One:LI | BC-One:LA | | | BC-Few:LI | BC-Few:LA | | | BC-All:LI | BC-All:LA |
| **Campus Explorer** | **Zone** | **Floor** | ZF-One:SI | ZF-One:SA | ZF-One:LI | ZF-One:LA | ZF-Few:SI | ZF-Few:SA | ZF-Few:LI | ZF-Few:LA | ZF-All:SI | ZF-All:SA | ZF-All:LI | ZF-All:LA |
| | **Zone** | **Building** | ZB-One:SI | ZB-One:SA | ZB-One:LI | ZB-One:LA | ZB-Few:SI | ZB-Few:SA | ZB-Few:LI | ZB-Few:LA | ZB-All:SI | ZB-All:SA | ZB-All:LI | ZB-All:LA |
| | **Floor** | **Building** | FB-One:SI | FB-One:SA | FB-One:LI | FB-One:LA | FB-Few:SI | FB-Few:SA | FB-Few:LI | FB-Few:LA | FB-All:SI | FB-All:SA | FB-All:LI | FB-All:LA |
| | **Zone** | **Campus** | ZC-One:SI | ZC-One:SA | ZC-One:LI | ZC-One:LA | ZC-Few:SI | ZC-Few:SA | ZC-Few:LI | ZC-Few:LA | ZC-All:SI | ZC-All:SA | | ZC-All:LA |
| | **Floor** | **Campus** | FC-One:SI | FC-One:SA | FC-One:LI | FC-One:LA | FC-Few:SI | FC-Few:SA | FC-Few:LI | FC-Few:LA | FC-All:SI | FC-All:SA | | FC-All:LA |
| | **Building** | **Campus** | BC-One:SI | BC-One:SA | BC-One:LI | BC-One:LA | BC-Few:SI | BC-Few:SA | BC-Few:LI | BC-Few:LA | BC-All:SI | BC-All:SA | BC-All:LI | BC-All:LA |
| **Building Long-Term** | **Zone** | **Floor** | | | ZF-One:LI | ZF-One:LA | | | ZB-Few:LI | ZB-Few:LA | | | ZB-All:LI | ZB-All:LA |
| | **Zone** | **Building** | | | ZB-One:LI | ZB-One:LA | | | FB-Few:LI | FB-Few:LA | | | FB-All:LI | FB-All:LA |
| | **Floor** | **Building** | | | FB-One:LI | FB-One:LA | | | | FB-Few:LA | | | | FB-All:LA |
| **Building Recent** | **Zone** | **Floor** | ZF-One:SI | ZF-One:SA | | | ZF-Few:SI | ZF-Few:SA | | | ZF-All:SI | ZF-All:SA | | |
| | **Zone** | **Building** | ZB-One:SI | ZB-One:SA | | | ZB-Few:SI | ZB-Few:SA | | | ZB-All:SI | ZB-All:SA | | |
| | **Floor** | **Building** | FB-One:SI | FB-One:SA | FB-One:LI | FB-One:LA | FB-Few:SI | FB-Few:SA | | FB-Few:LA | FB-All:SI | FB-All:SA | | FB-All:LA |
| **Region Compare** | **Zone** | **Floor** | | | ZF-One:LI | ZF-One:LA | | | ZF-Few:LI | ZF-Few:LA | | | | |
| | **Zone** | **Building** | | | ZB-One:LI | ZB-One:LA | | | ZB-Few:LI | ZB-Few:LA | | | | |
| | **Floor** | **Building** | | | FB-One:LI | FB-One:LA | | | FB-Few:LI | FB-Few:LA | | | | |
| | **Zone** | **Campus** | | | ZC-One:LI | ZC-One:LA | | | ZC-Few:LI | ZC-Few:LA | | | | |
| | **Floor** | **Campus** | | | FC-One:LI | FC-One:LA | | | FC-Few:LI | FC-Few:LA | | | | |
| | **Building** | **Campus** | | | BC-One:LI | BC-One:LA | | | BC-Few:LI | BC-Few:LA | | | | |

# Architectural Overview of All Ocupado Applications




Interface

Page

Modal window (overlay)

Open new view (1 region)

User selection (subset)

# Ocupado Interfaces and Tasks

| | *Tasks* | **Campus Explorer** | **Building Long-Term** | **Building Recent** | **Region Compare** |
|---|---|---|---|---|---|
| T1 | **Confirm** observations that have been made | | | | |
| T2 | **Monitor** the current/recent utilization rate | | | | |
| T3 | **Communicate** space usage and justify decisions | | | | |
| T4 | **Validate** the data (quality control) | | | | |

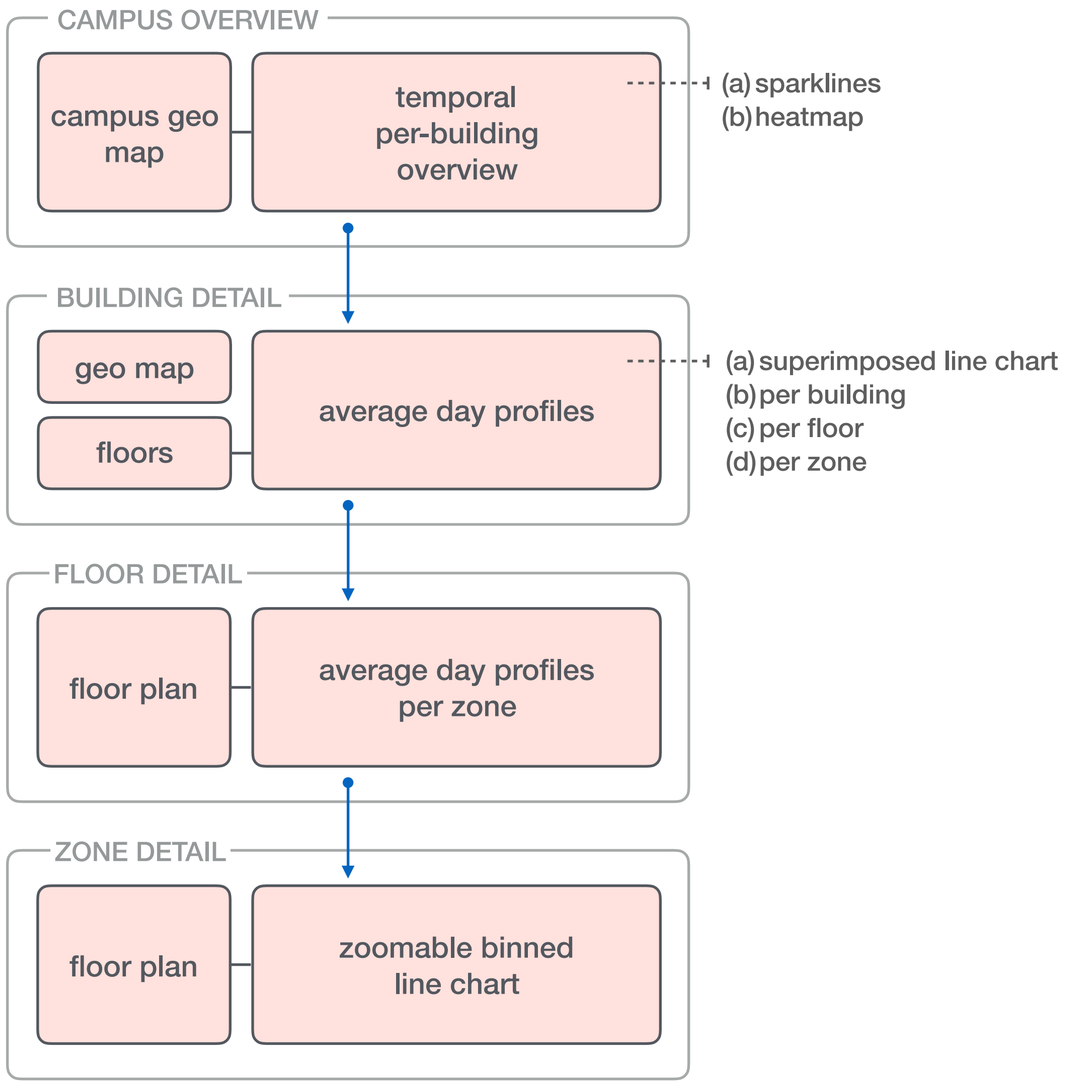
*Match*

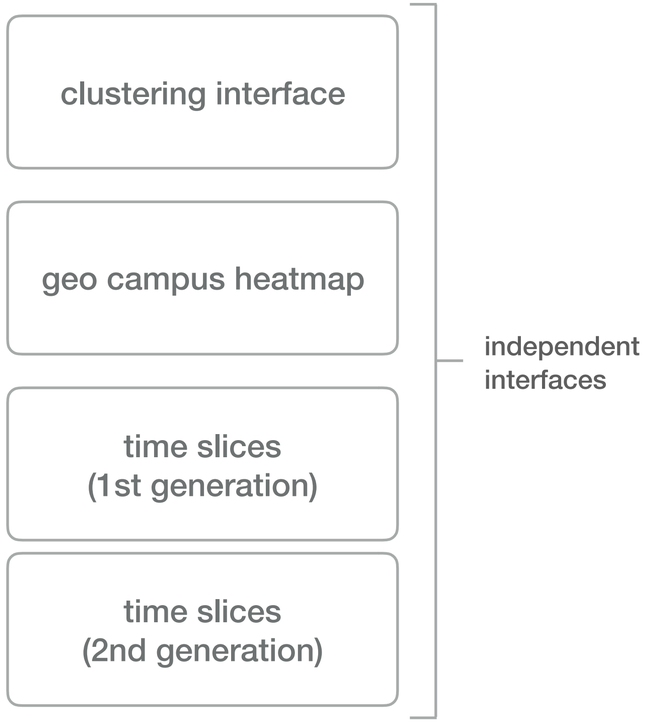
- Strong
- Medium
- Low
- None

# 4. Ocupado Interfaces

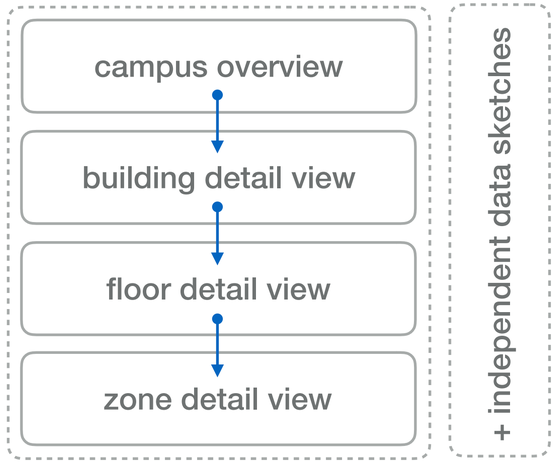
# 4.1 Prototyping Sandbox

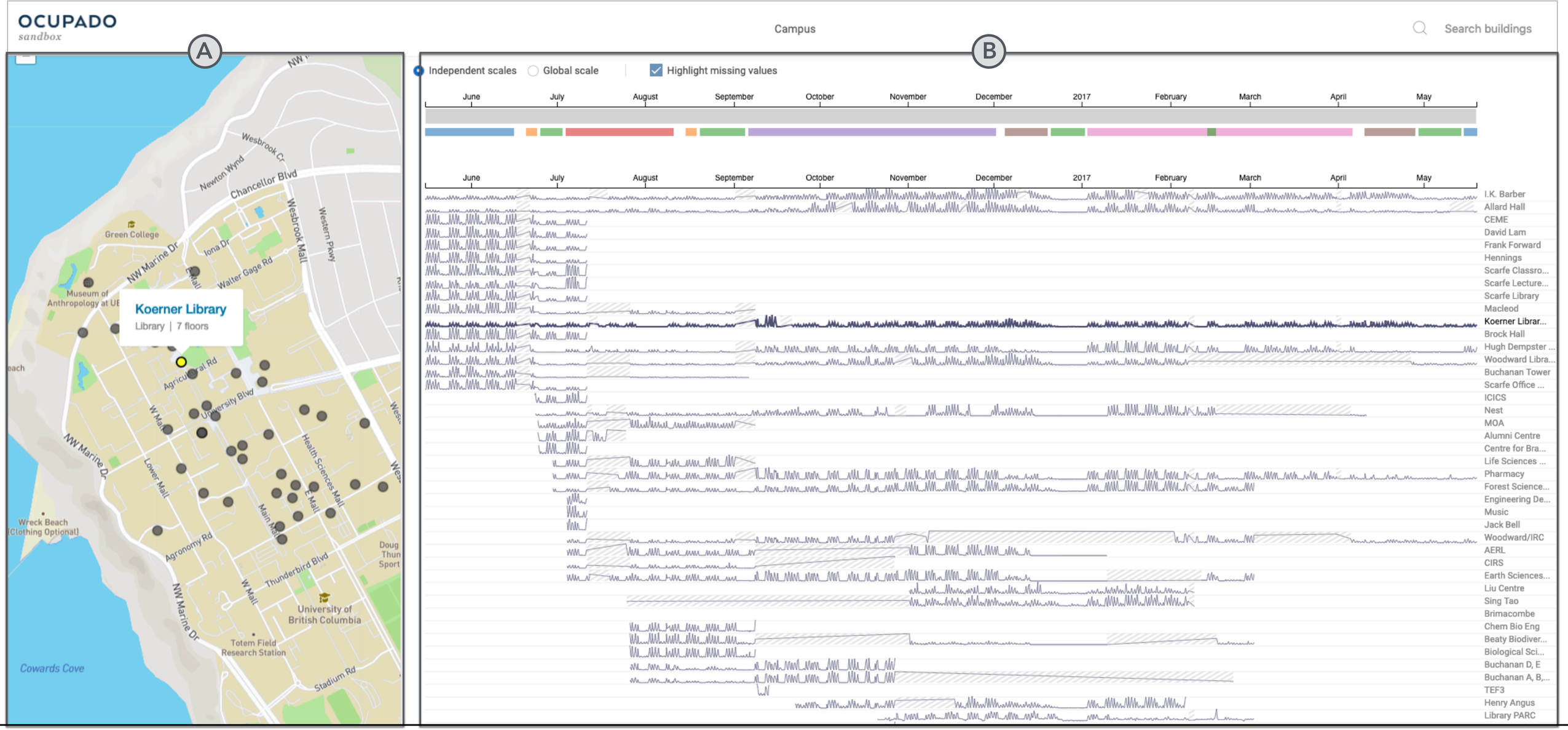
# Prototyping Sandbox: View Coordination & Layout



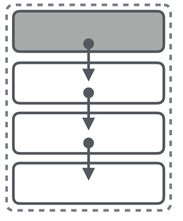




*Compact summary:*

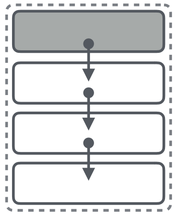


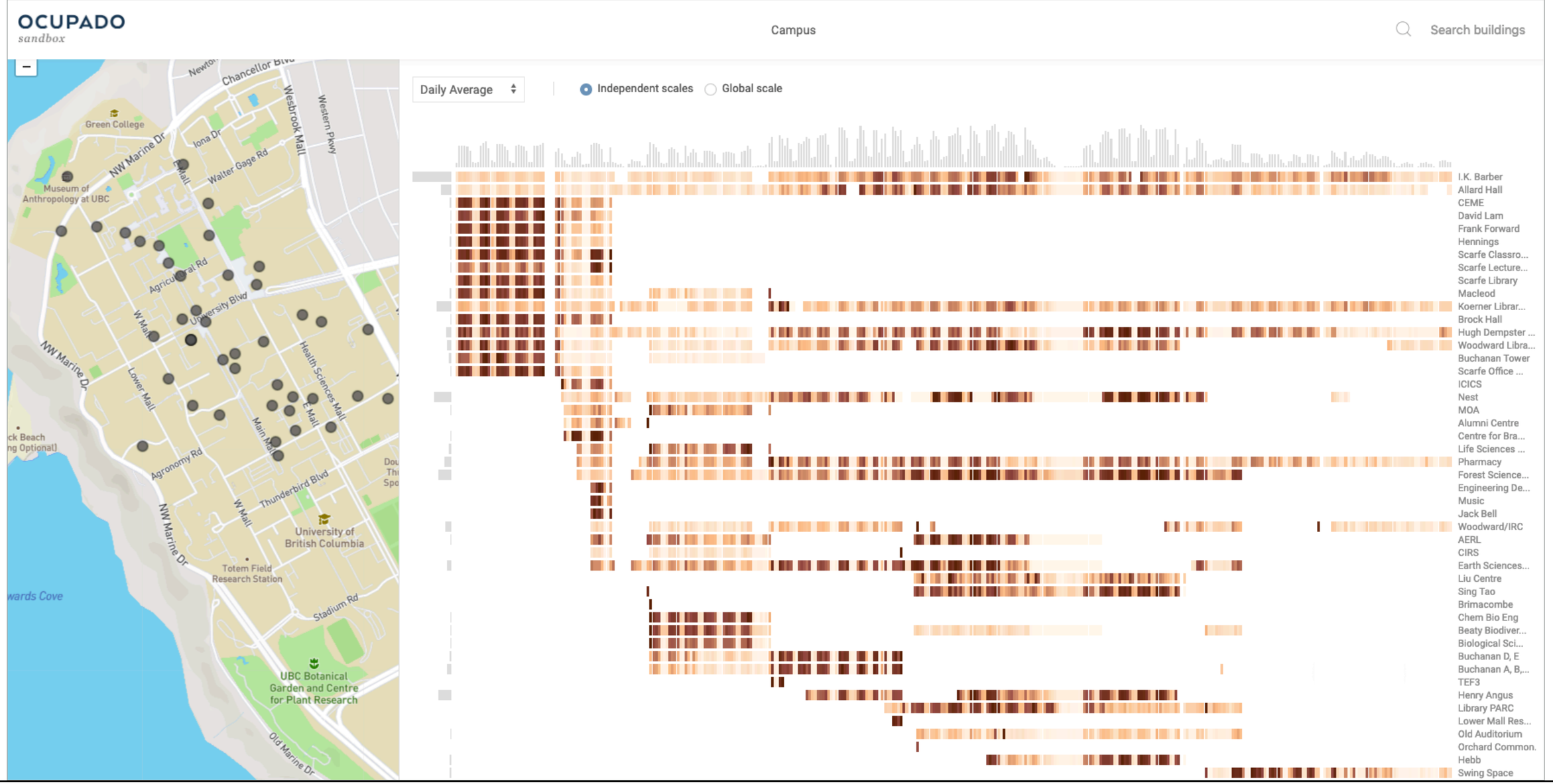



**Sandbox overview.** Side-by-side views provide a high-level overview: (a) Campus map with geographical locations of all buildings. (b) Temporal overview uses sparklines to show aggregated device counts over the course of one year. Y-scales are normalized to the maximum device count per building to reveal patterns despite varying occupancy rates between buildings. The first dataset was characterized by a large number of outages and short recording periods for some of the buildings. Grey stripes explicitly indicate missing data. BC-AII:LI

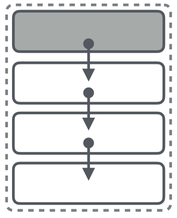


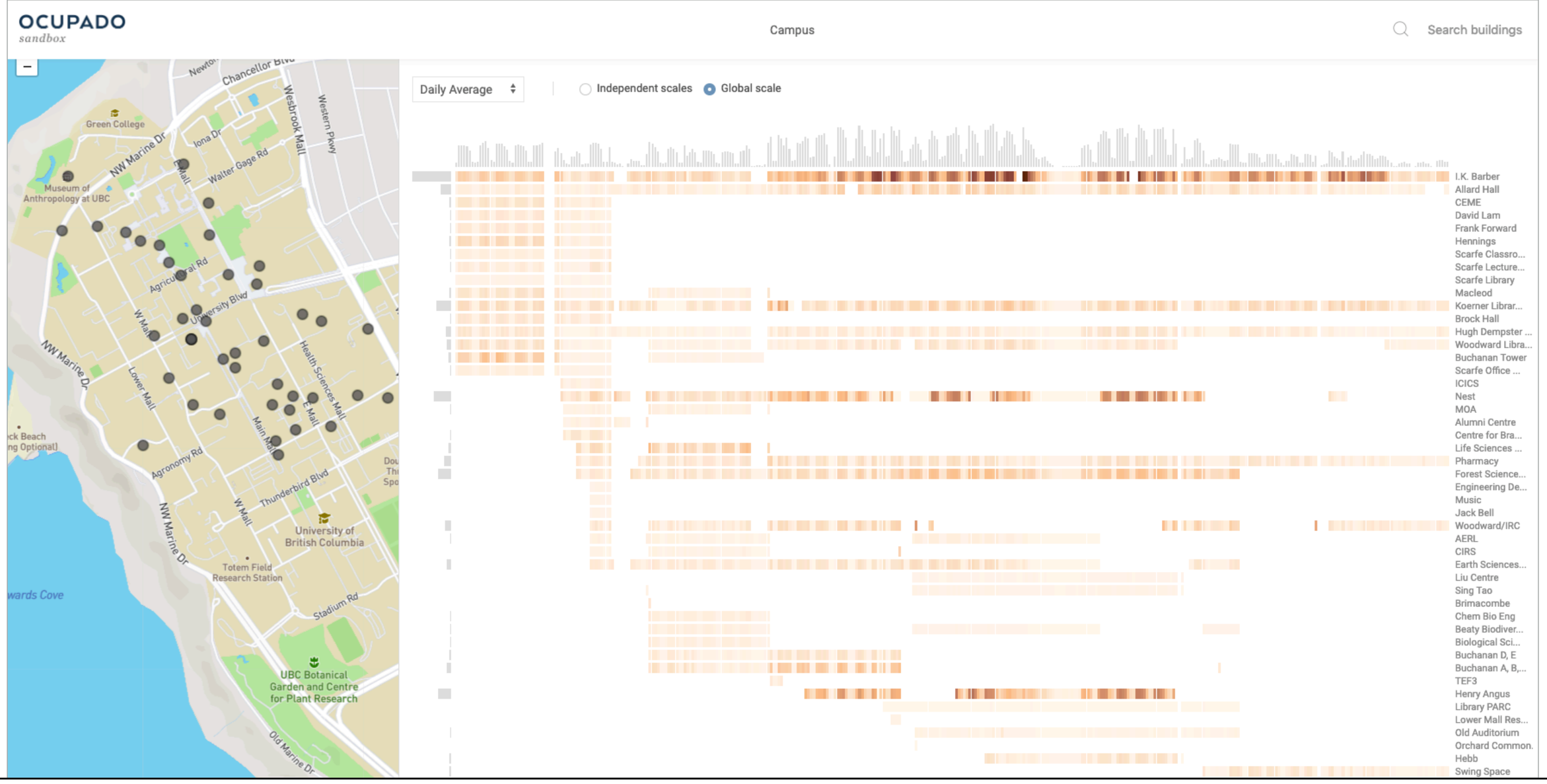

**Sandbox overview.** Users can choose absolute y-scales to compare device counts of different buildings. BC-AII:LI



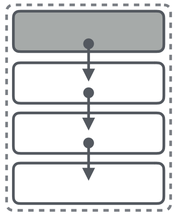


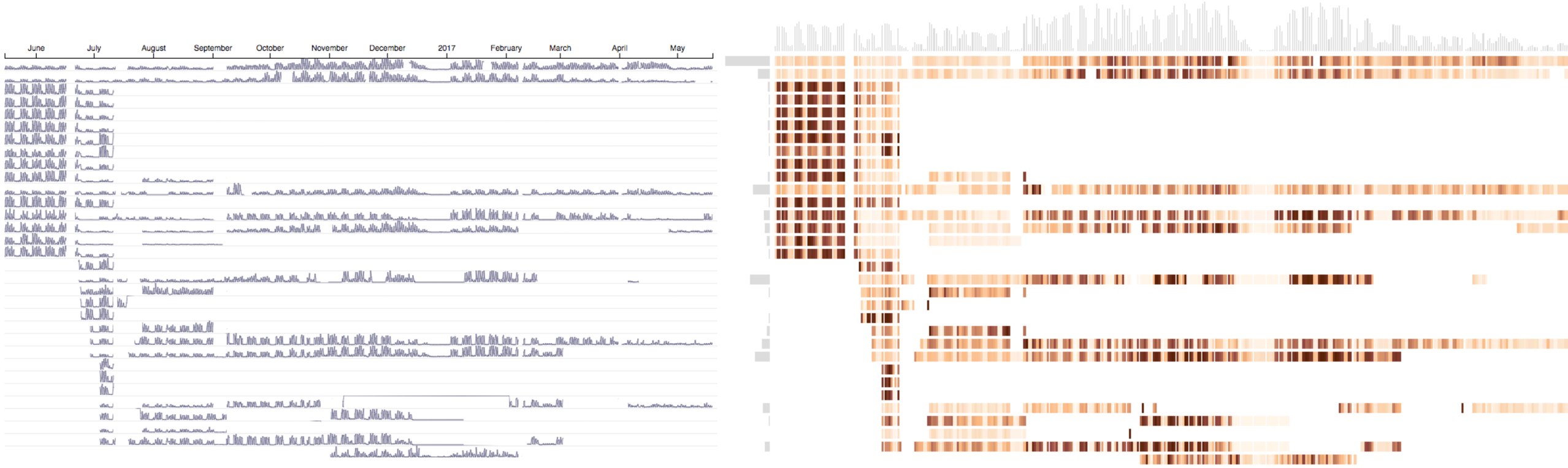

**Sandbox overview.** We experimented with an interactive heatmap as an alternative visual encoding for the overview visualization. Users can choose between different daily metrics that define the color of each cell: *average*, *minimum*, *maximum*, and *stddev*. This screenshot shows independent scales, normalized to the maximum value of each building. BC-AII:LA



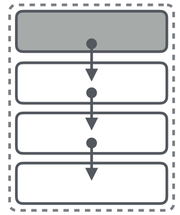


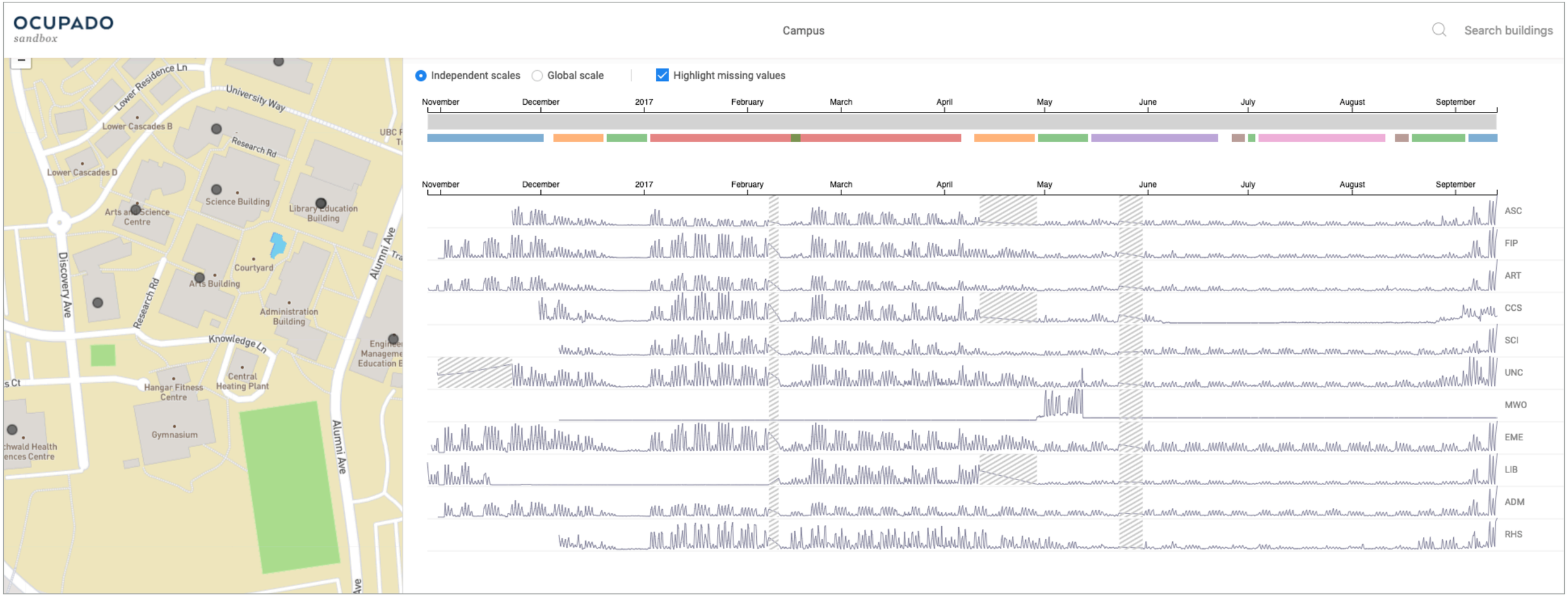

**Sandbox overview.** Heatmap with absolute scales to facilitate cross-building comparisons. BC-AII:LA



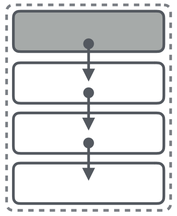


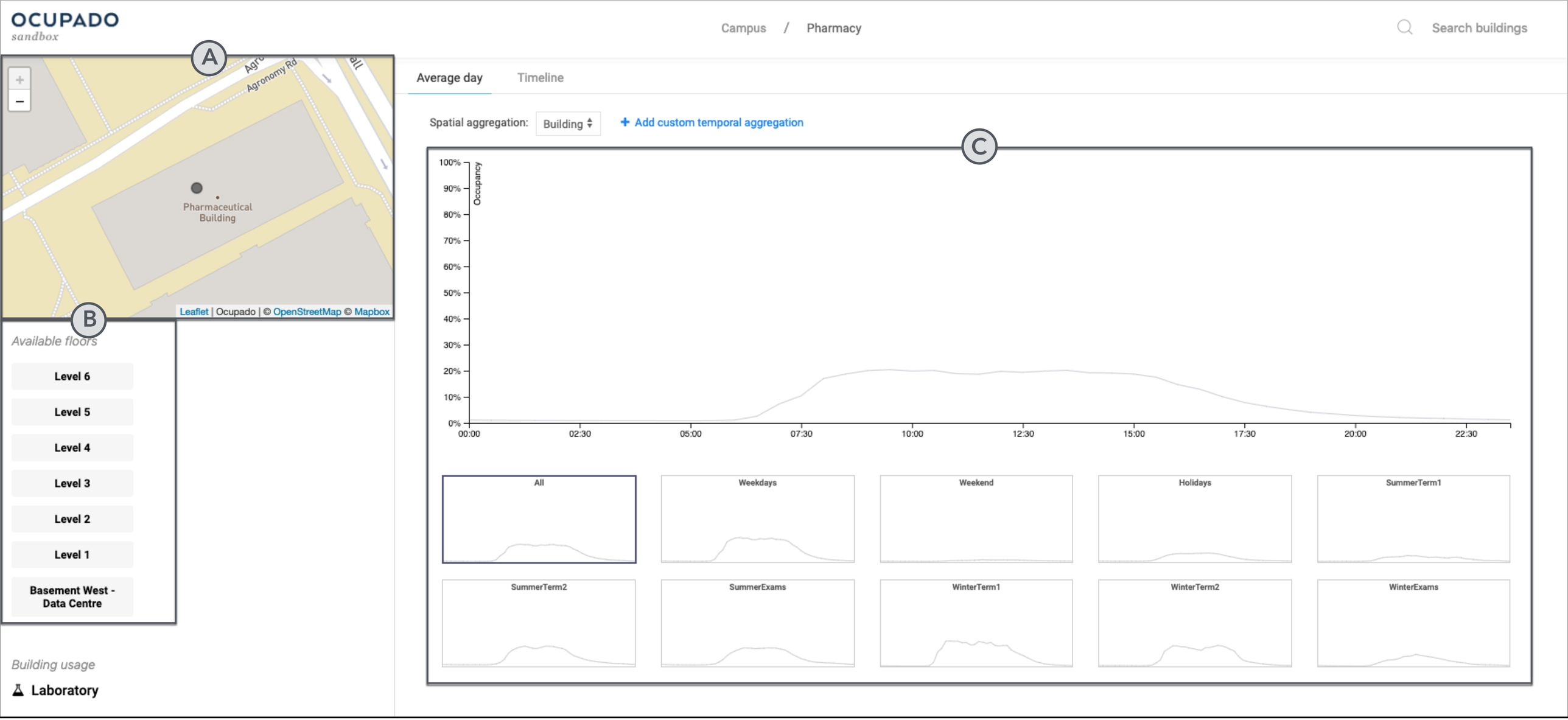

**Comparison between sparklines and heatmaps.** We tried interactive heatmaps but ruled them out quickly: the higher precision of the positional vs. the color channel for visual encoding was indeed crucial in this case, as discussed with *Pathline* [Meyer, 2010] and studied by Lam et al. [Lam, 2007]. BC-AII:L*



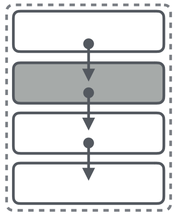


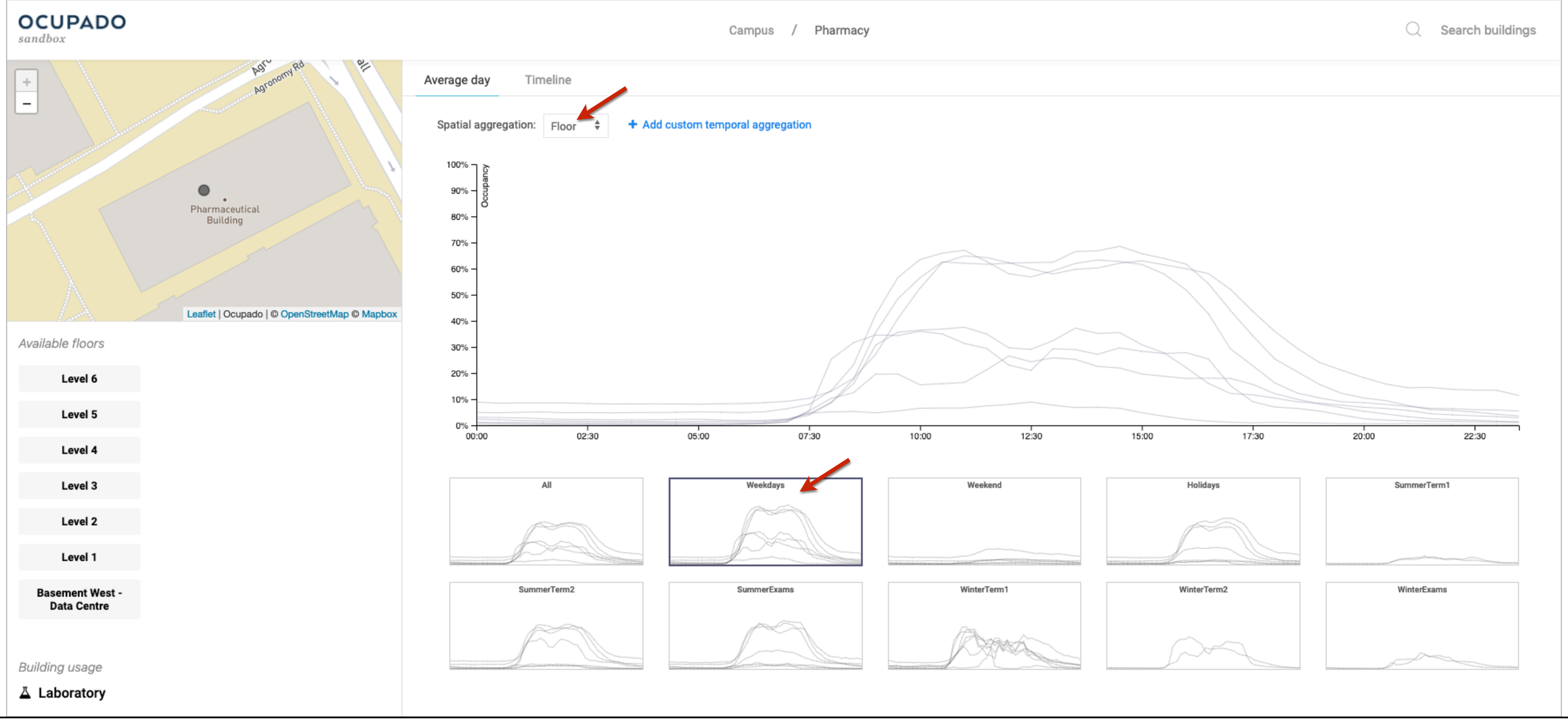

**Sandbox overview.** Smaller university campus. BC-AII:LI



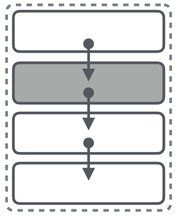


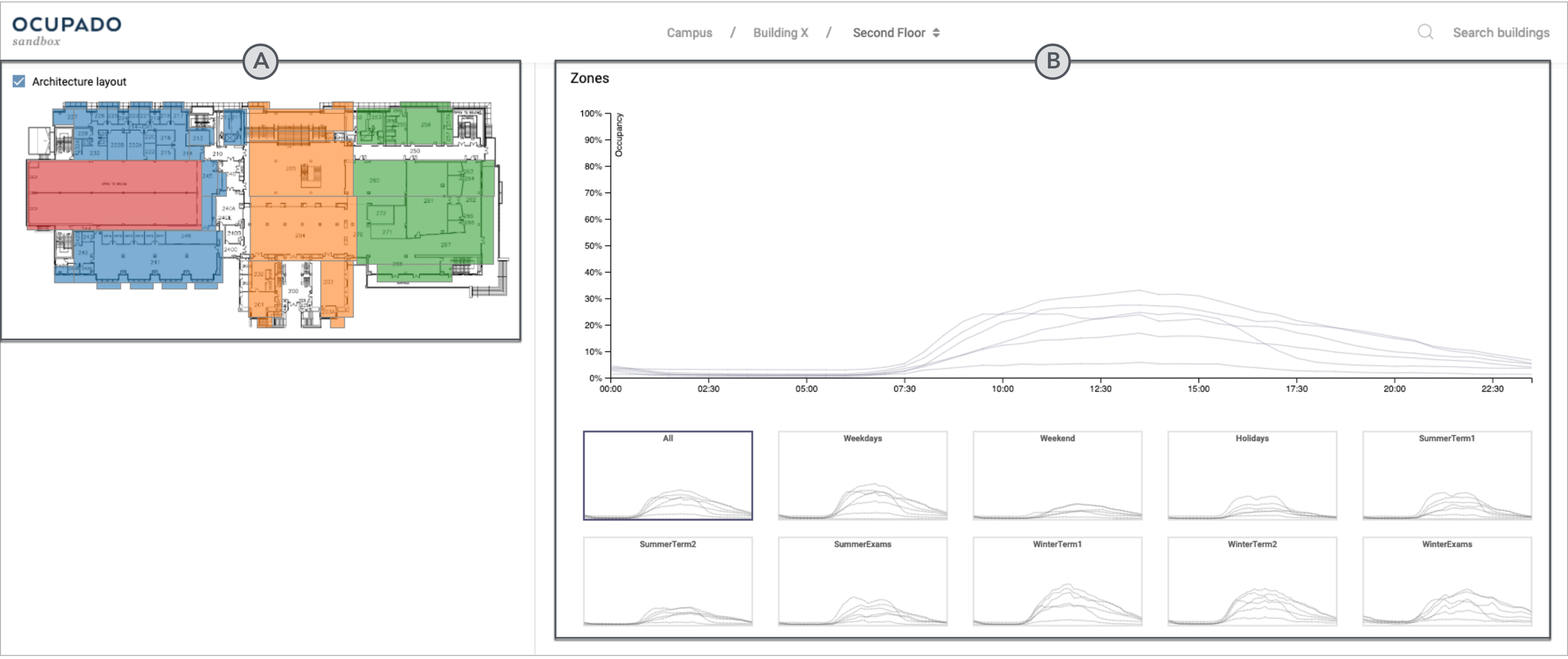

**Sandbox, building details.** The building detail view contains: (a) geo map that shows the location of the building; (b) list of floors that can be used to navigate; (c) average day profiles for different temporal resolutions. The y-axis shows normalized device counts (%) and the x-axis the hours of the day. Users can, for example, analyze the typical daily utilization on weekdays or during the summer term. A click on one of the small multiples opens the results for the selected time period in the main view. We can change the spatial aggregation from *building* to *floor* or *zone* (see next page). B-One:LA



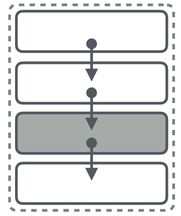



**Sandbox, building details.** Average per-floor device count on weekdays. One line corresponds to one floor. FB-AII:LA






**Sandbox, floor details.** (a) interactive floor plan for spatial context and to navigate to specific zones; (b) superimposed average day profiles for all zones on this floor. ZF-AII:LA



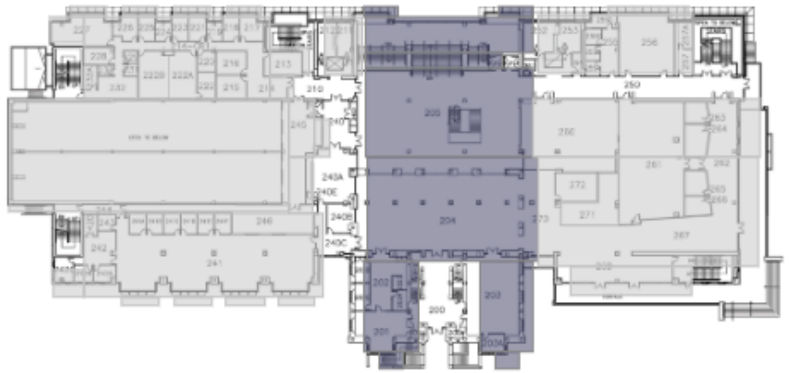
OCUPADO
sandbox

Campus / Building / Second Floor / Zone 11

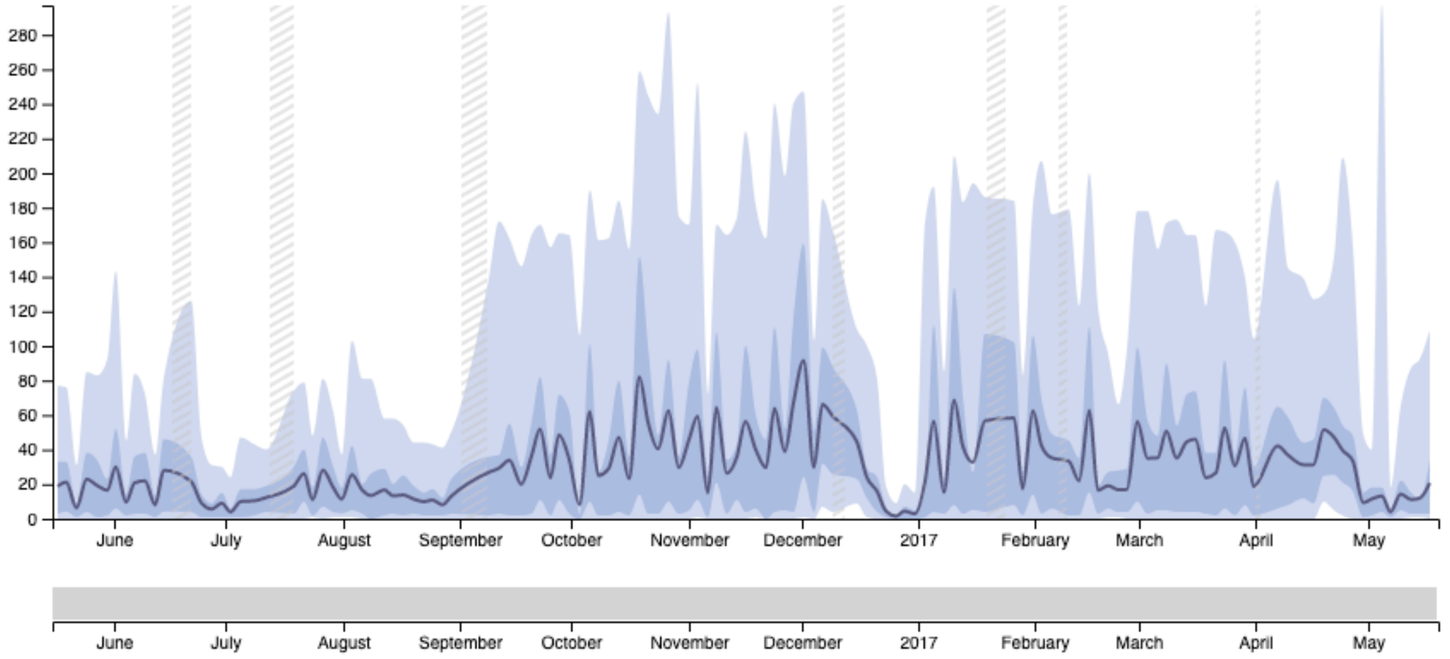
Search buildings

*Floor plan*

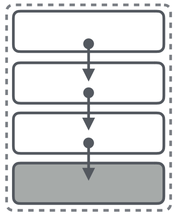
Architecture layout

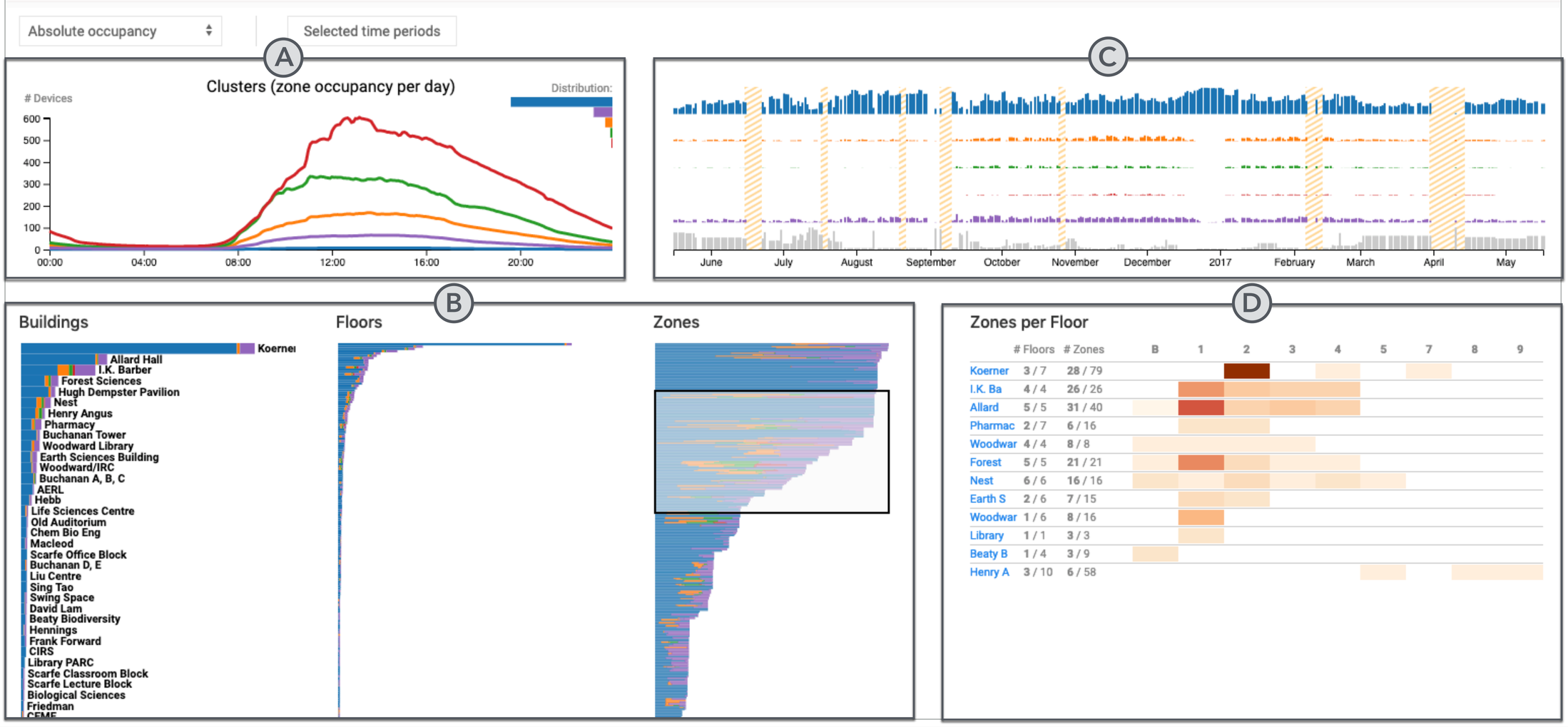


Timeline

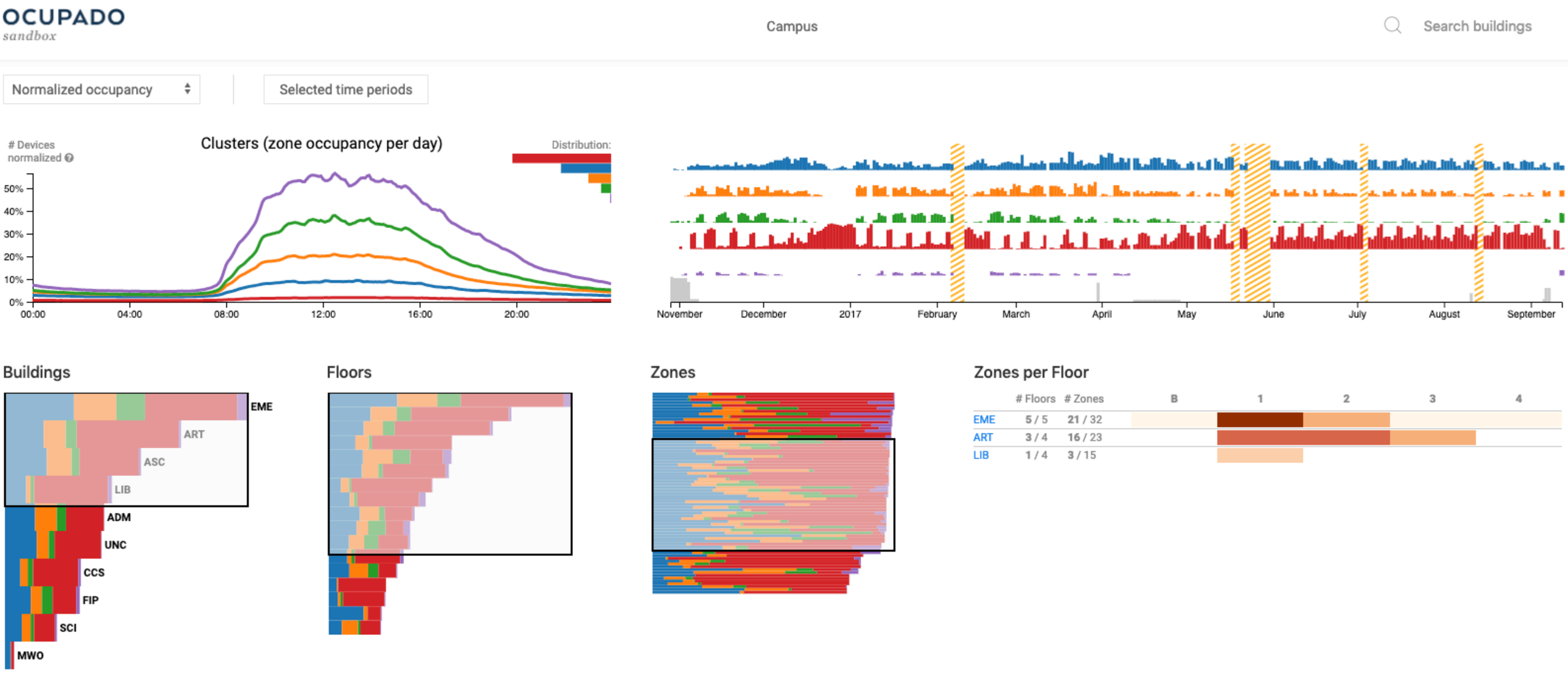



**Sandbox, floor details.** Zone detail view includes a zoomable binned timeline to show the absolute device count over time. ZF-One:LI

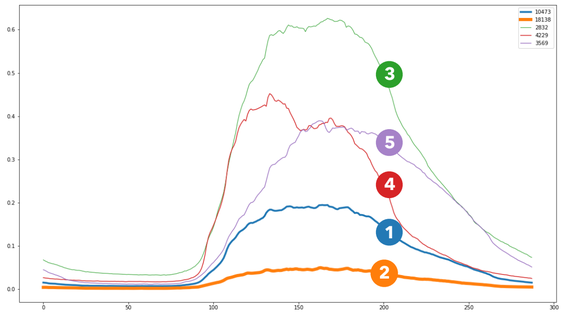




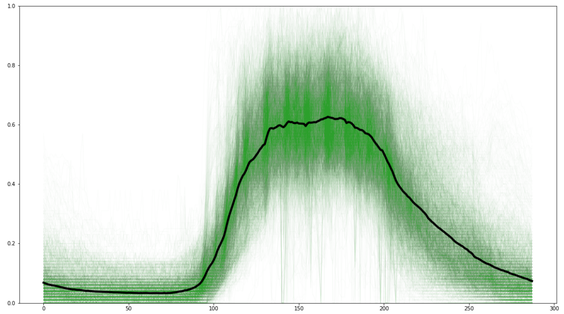

**Clustering interface.** The goal of this endeavour was to identify regions on a campus that are usually very quiet or only busy in the morning based on a clustering approach. During an early project stage, we thought about embedding extensive clustering and prediction models into Ocupado. This interface was intended as an internal tool for us and our collaborator to inspect clustering results that we generated offline because of the large volume of data (input for clustering: 1 row = 1 “region” day).
For the example shown above, we generated 5 clusters and the user can choose between absolute device counts or normalized counts based on the maximum of each region. (a) Multi-series line chart shows the average of each cluster. We can see that most of the days are in the blue cluster. The absolute device count during these days was very low. (b) Stacked bar charts for different regional levels. Each row corresponds to a building, floor or zone. The width of a bar denotes the number of days a region is in one of the 5 clusters. Selection windows can be dragged across the the stacked bar charts to filter regions. (c) The timeline displays the temporal distribution of each cluster as bars. (d) The heatmap displays the locations (building, floor) of the selected zones.
We abandoned this approach completely because of its lack of semantic meaning for our focus domain. Similar to the average day profiles, we lose a lot of nuances by clustering that are needed to answer common stakeholder questions. The workflow may be of interest for other use cases.



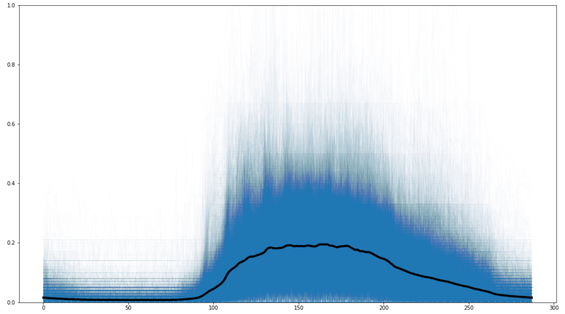

**Clustering interface with data from a smaller campus.** We selected *normalized device counts* and filtered the regions with selection windows that are displayed as black-bordered rectangles on top of stacked bar charts.



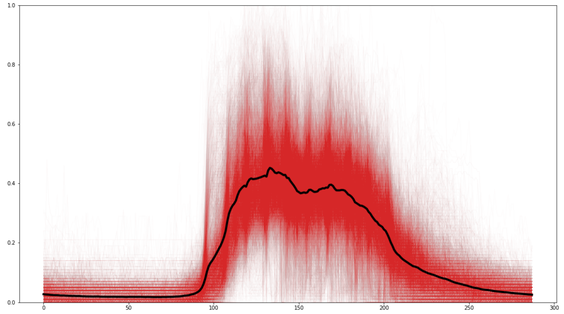

Cluster 3



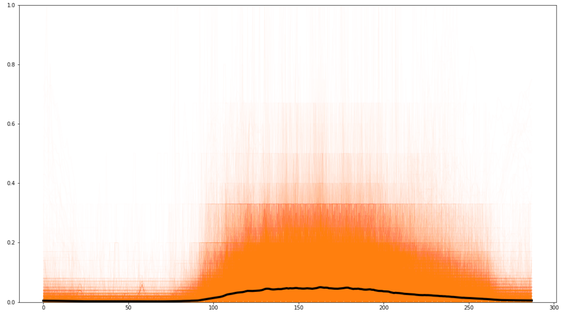
Cluster 1



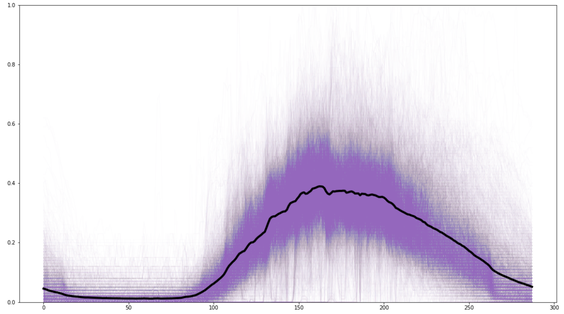
Cluster 4



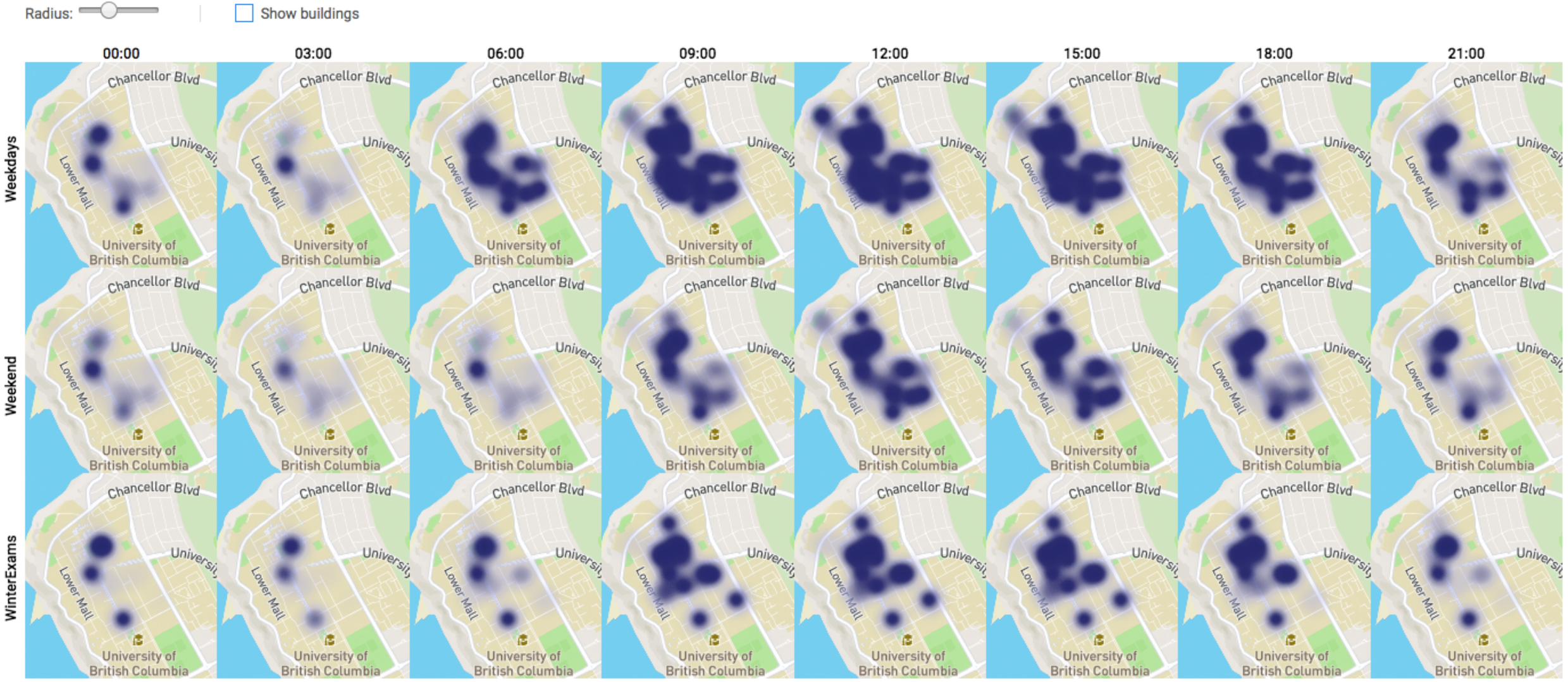
Cluster 2



Cluster 5



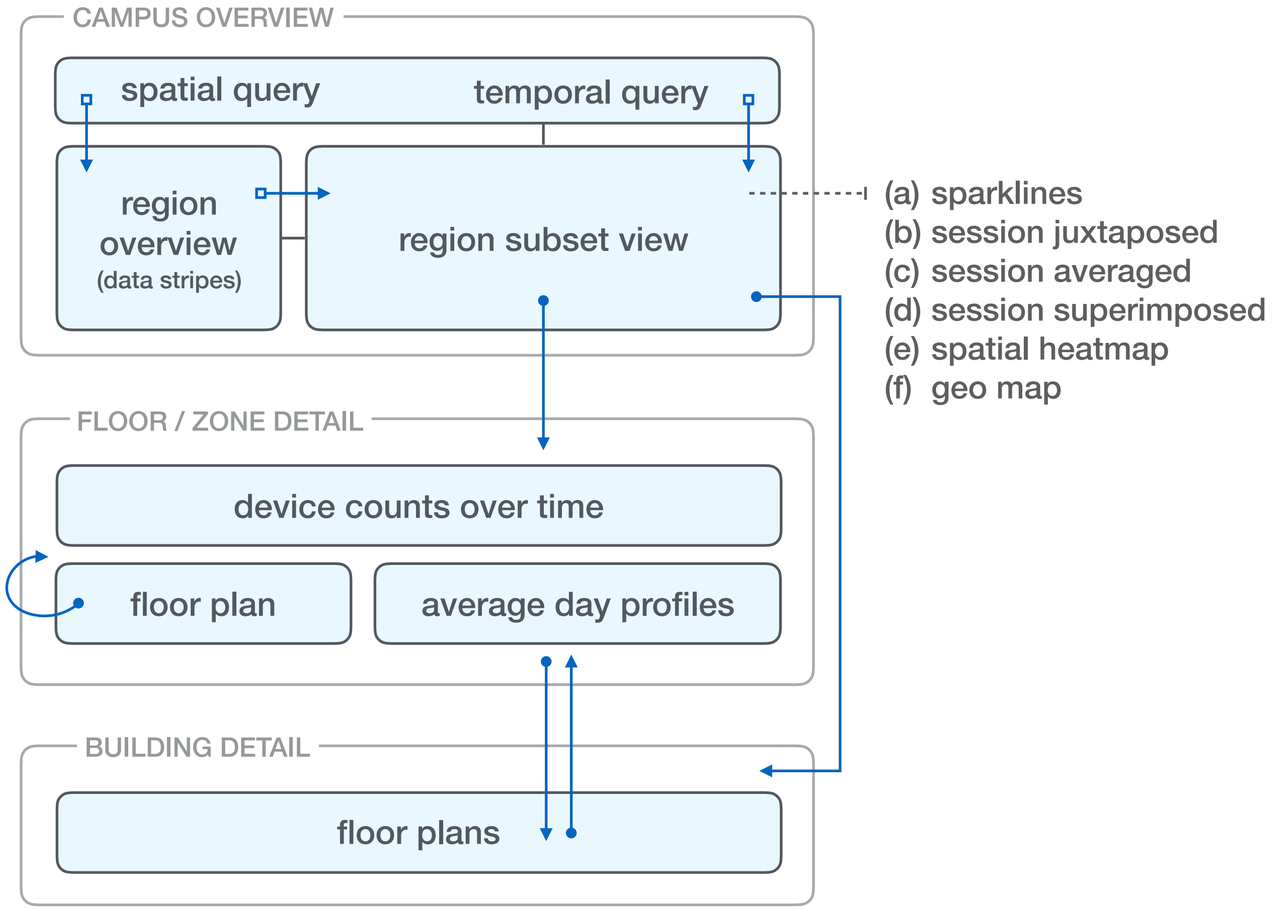
**Clustering interface with data from a smaller campus.** Static visualization that shows individual cluster items (= individual days).



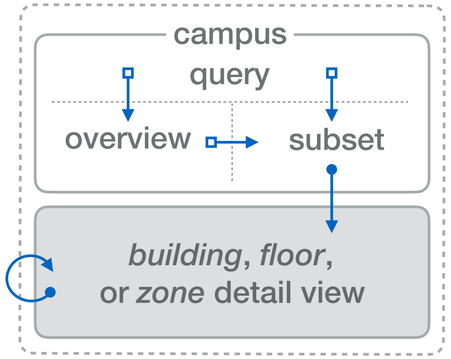

**Campus map small multiples.** We examined the use of geographical maps to show the distribution of devices on a university campus. The maps are created with the open-source library leaflet.js that uses kernel density estimation to generate the heatmap overlays. This prototype was rejected because it shows location-based counts averaged over a long time period and only from a bird's eye view. This view was not directly relevant to our stakeholders because their analysis questions are at a much lower data granularity level. BC-All:*A

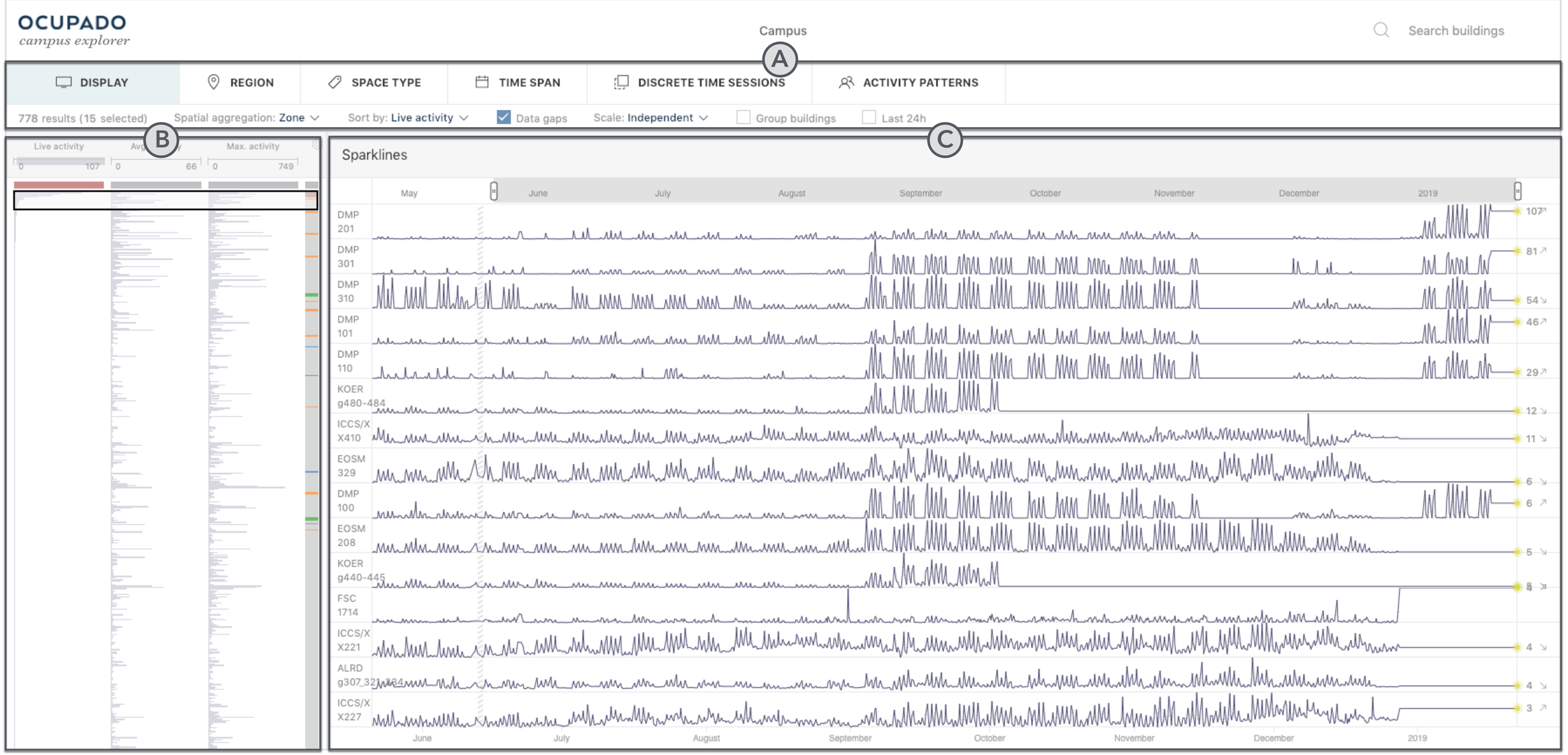
# 4.2 Campus Explorer Interface

# Campus Explorer: View Coordination & Layout

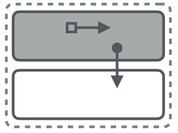


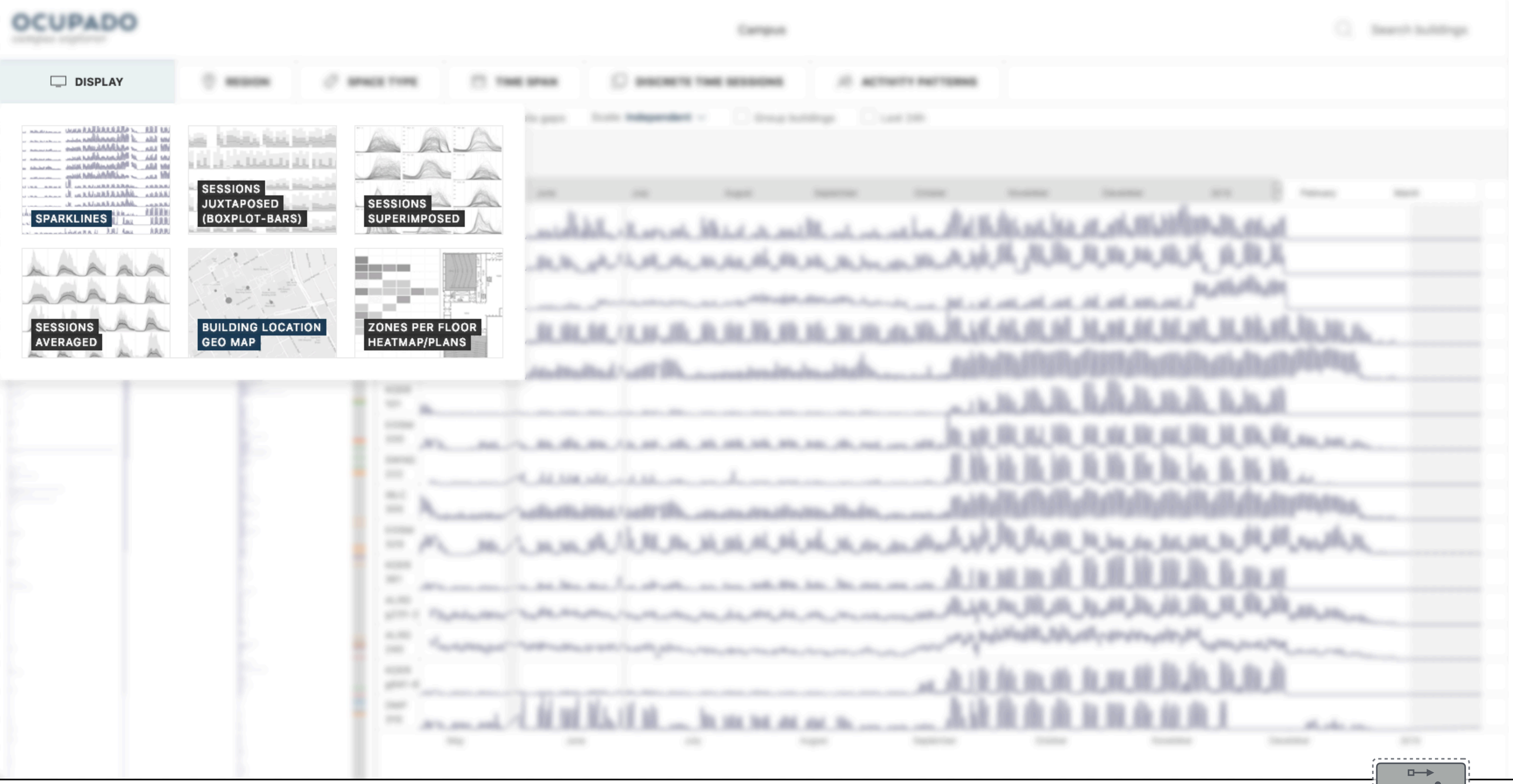

*Compact summary:*



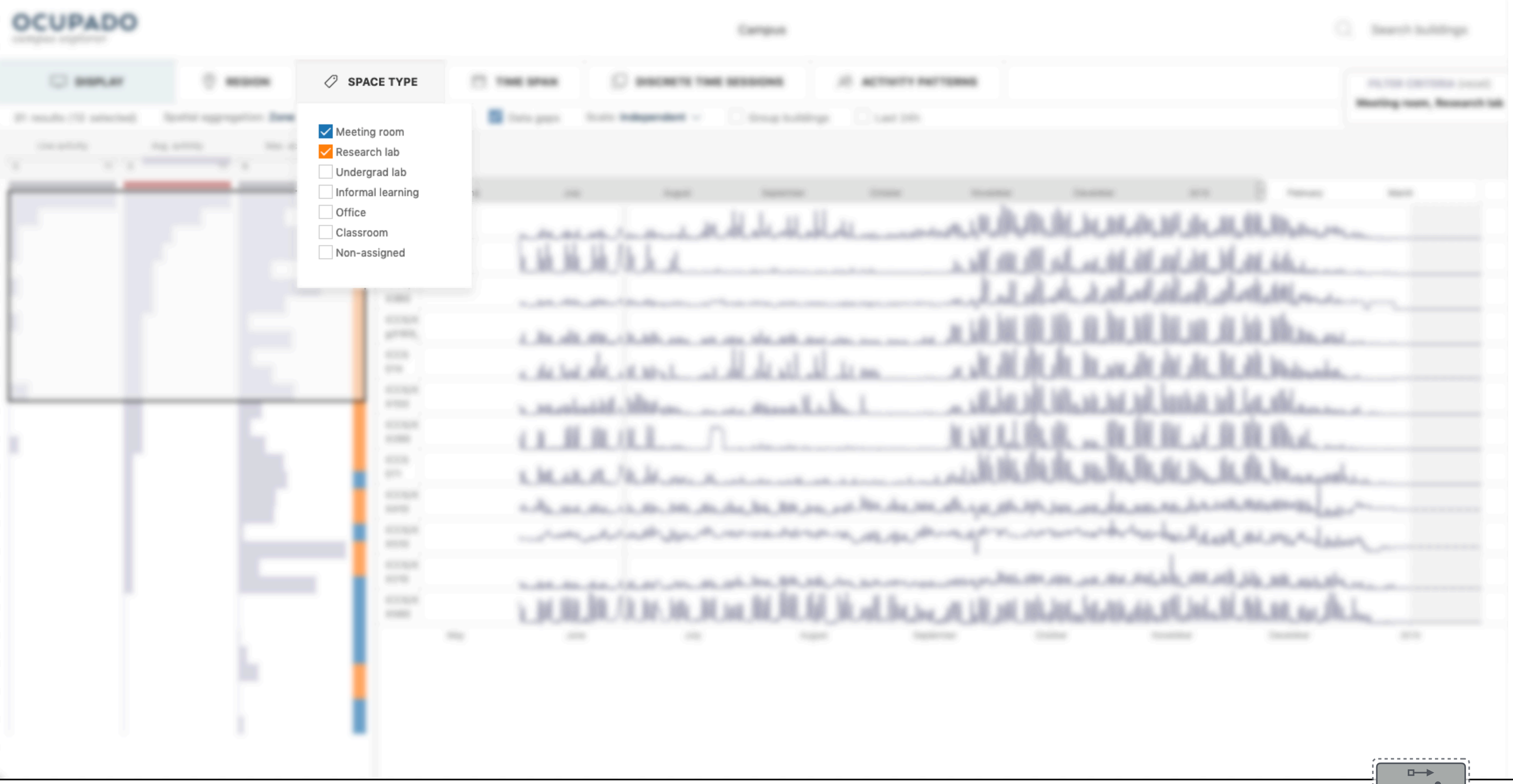



**Campus explorer.** (a) Control panel for filter and display settings; (b) Region selector shown as quantitative and categorical data stripes to provide a high-level overview `ZC-All:*A` ; (c) Region subset view provides mid-level details for selected regions `ZC-Few:LI` . Users can choose between different visual encodings for the region subset view. Clicking on one region opens a modal window with low-level details.

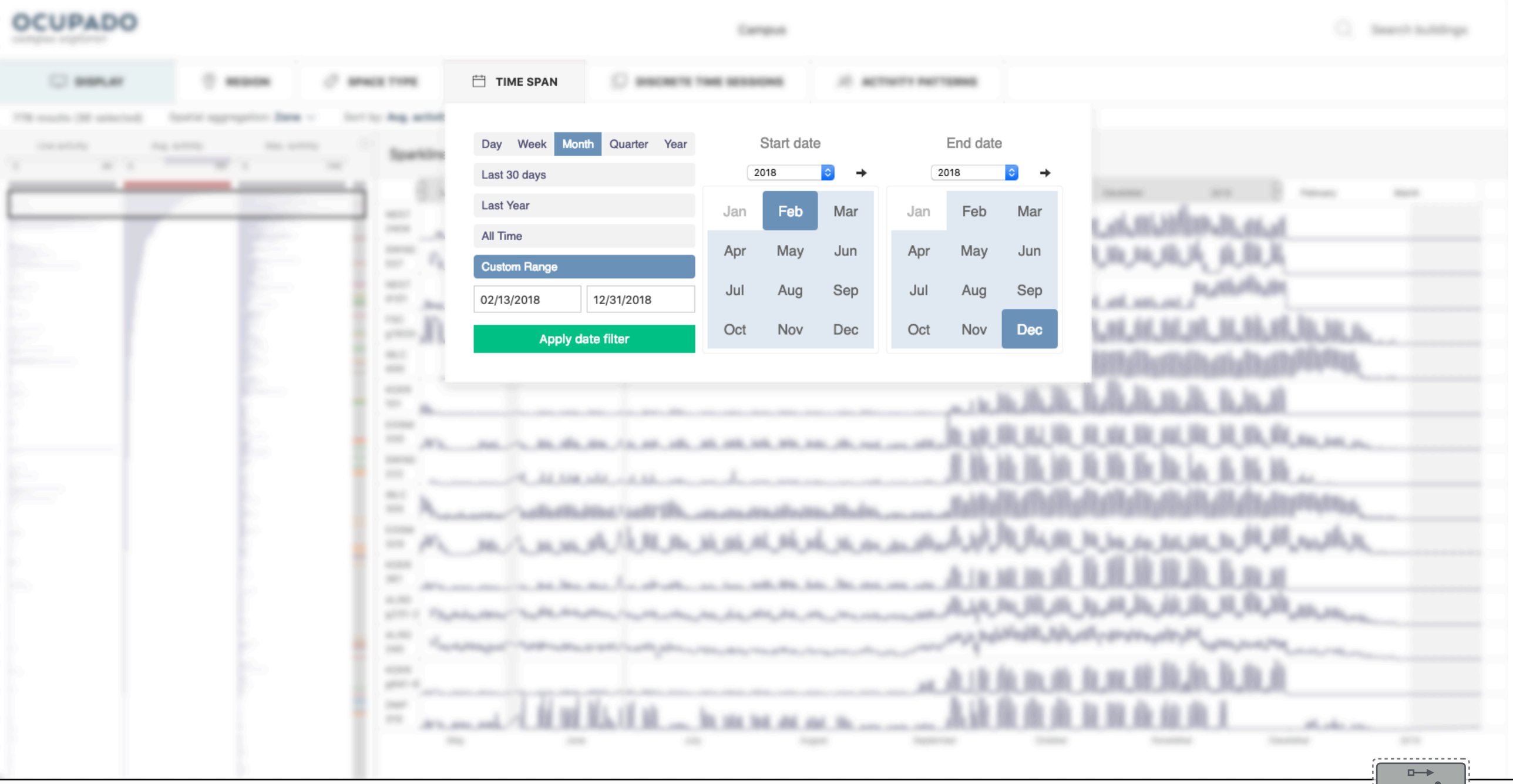




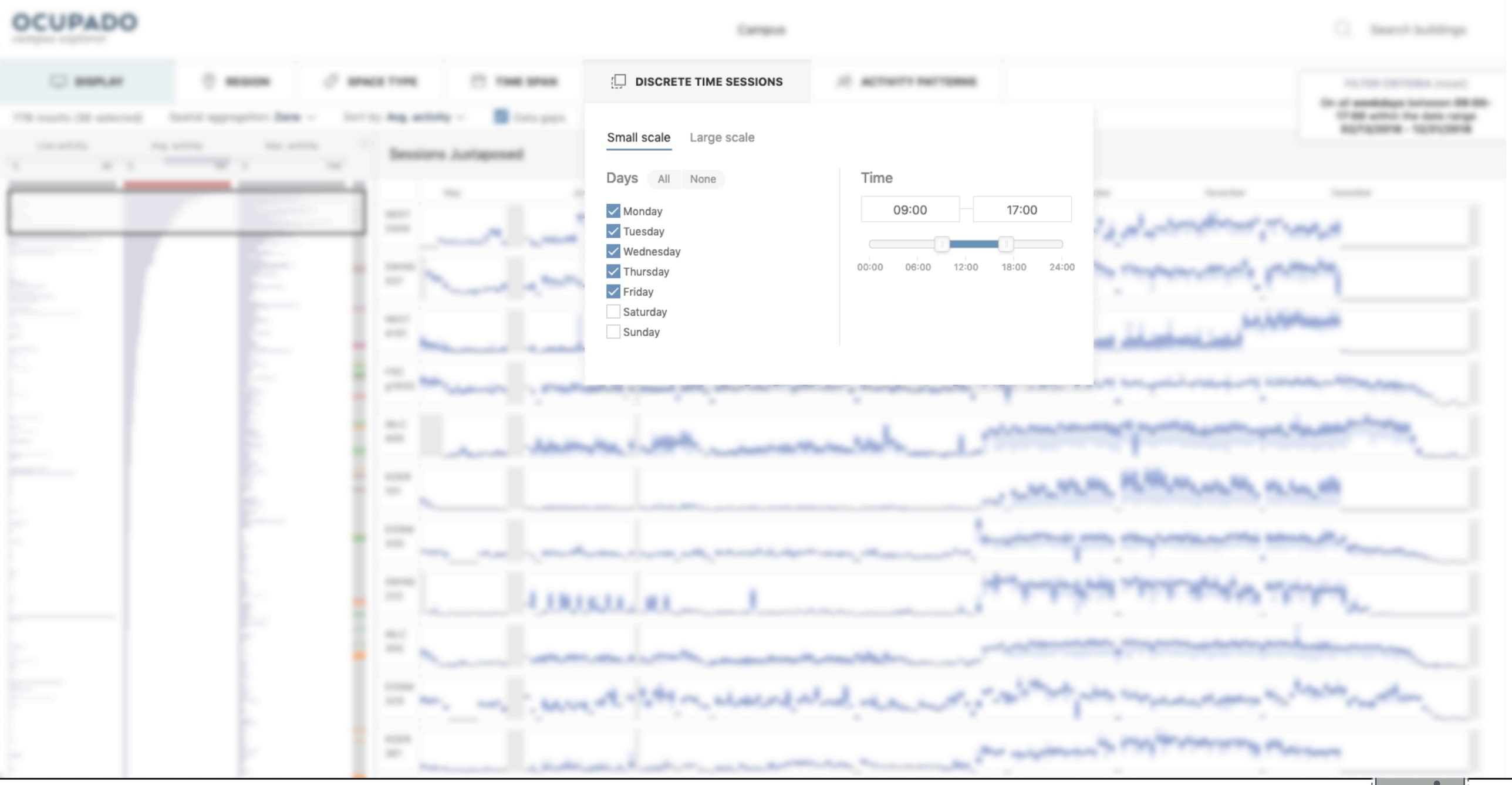

**Campus explorer, control panel.** Users can choose between different visual encoding idioms for the region subset view.



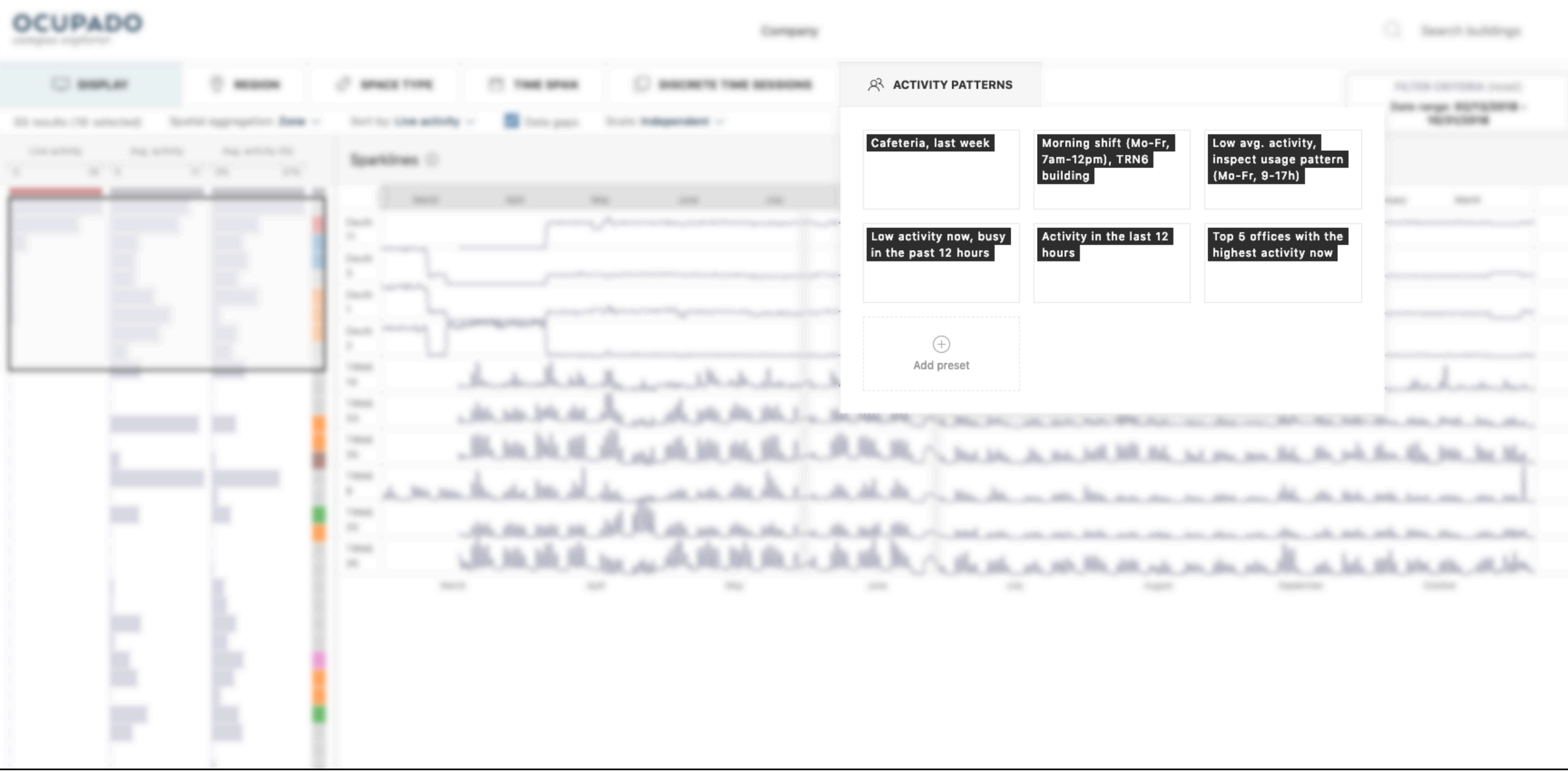

**Campus explorer, control panel.** Regions can be filtered by building or space type.



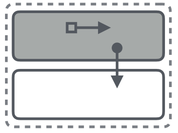

**Campus explorer, control panel.** Time range filter (continuous)



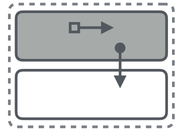

**Campus explorer, control panel.** Advanced temporal filter for discrete time slices.

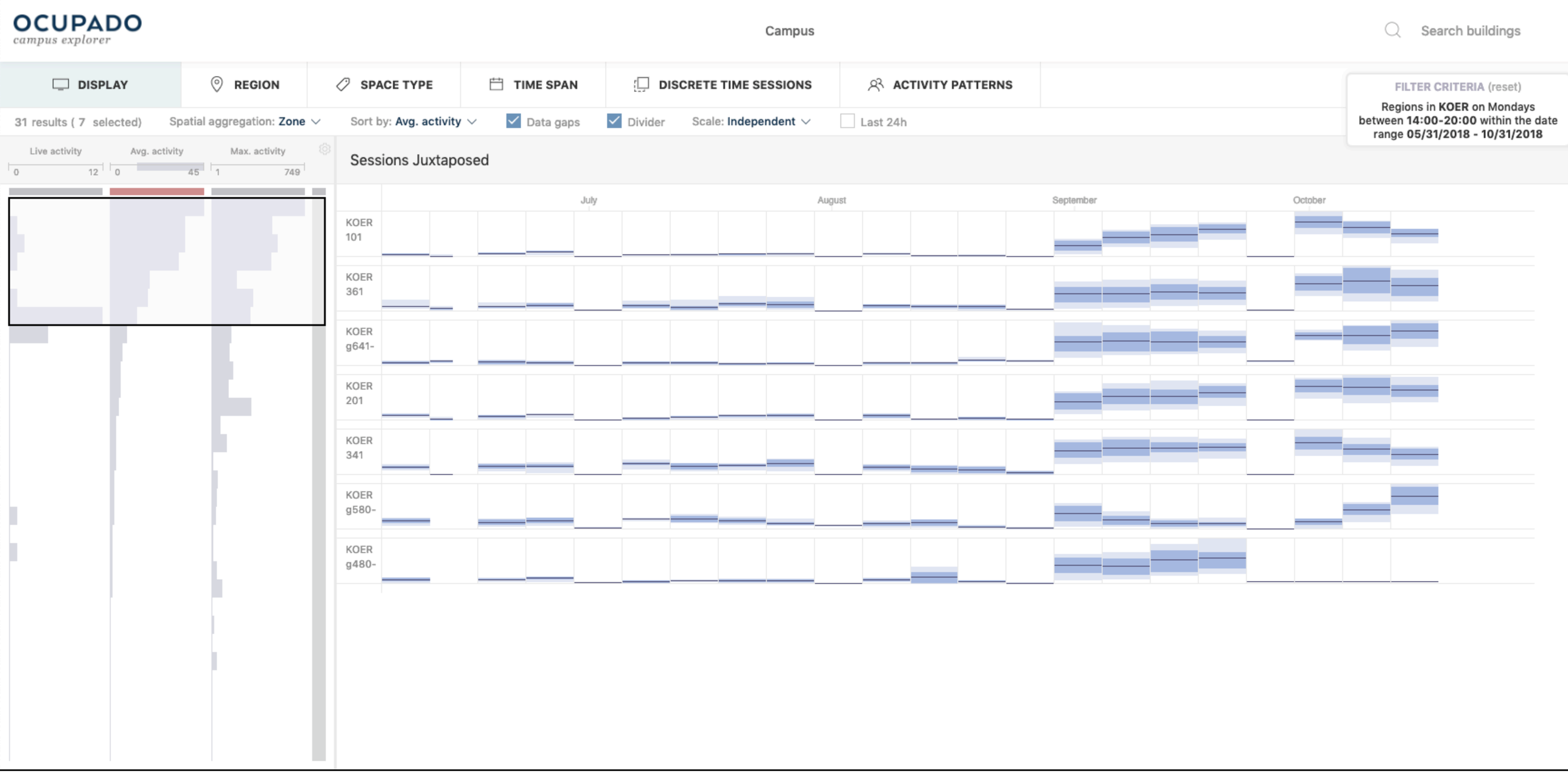



**Campus explorer, control panel.** Activity patterns provide one-click shortcuts to complex combinations of actions. They can control spatial and temporal filter criteria, the visual encoding of the region subset view, and the selection window in the region overview.

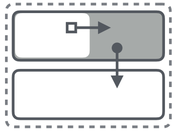


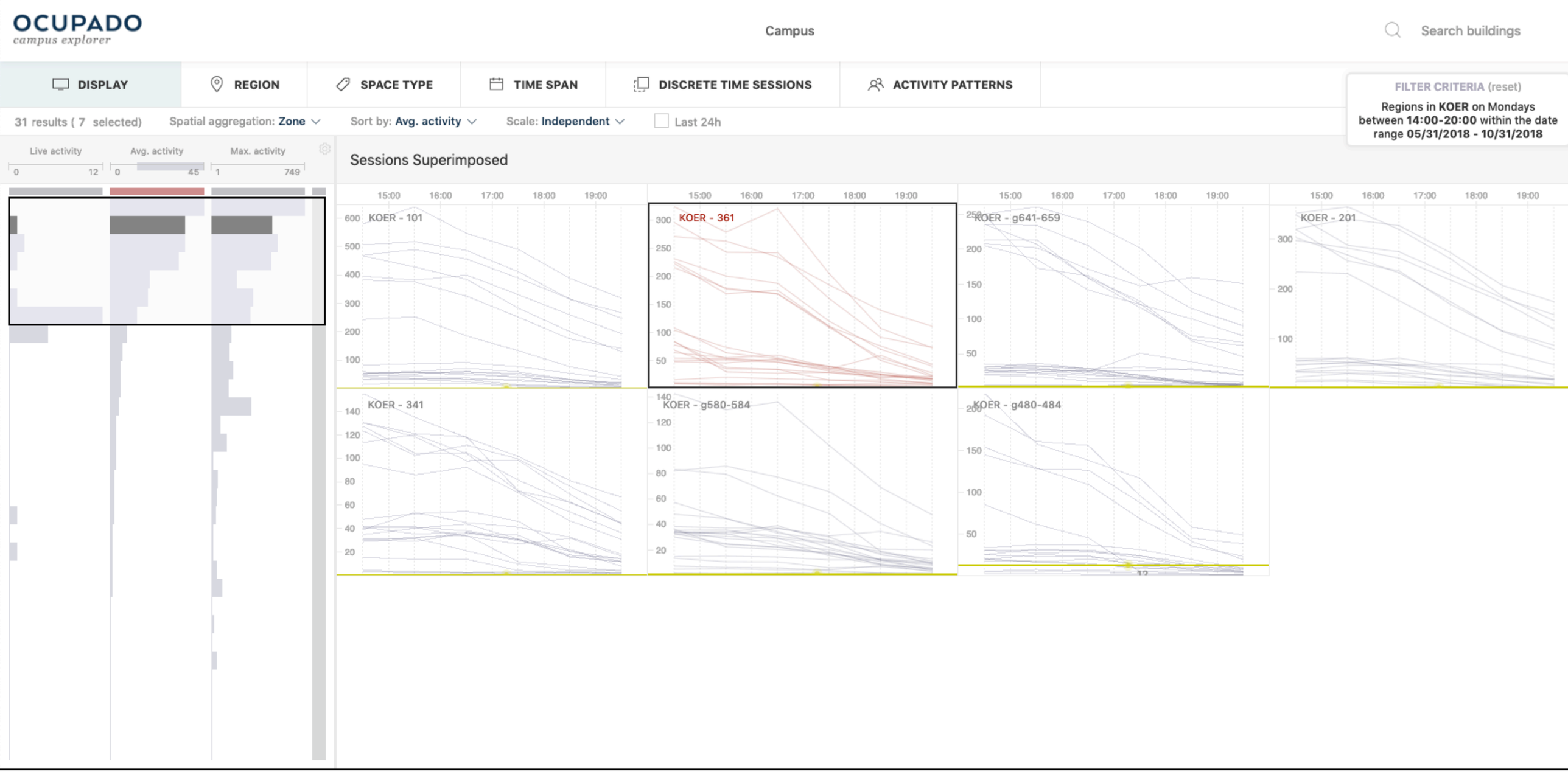

**Campus explorer, control panel.** We integrated a small widget that shows a textual summary of all active filters because custom selections would not be immediately visible due to the many different options that are hidden in dropdown menus.






**Campus explorer, region subset view.** Box-plot-bars for discrete time intervals, such as Mondays between 2-8pm. ZB-Few:LA

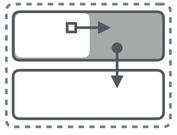


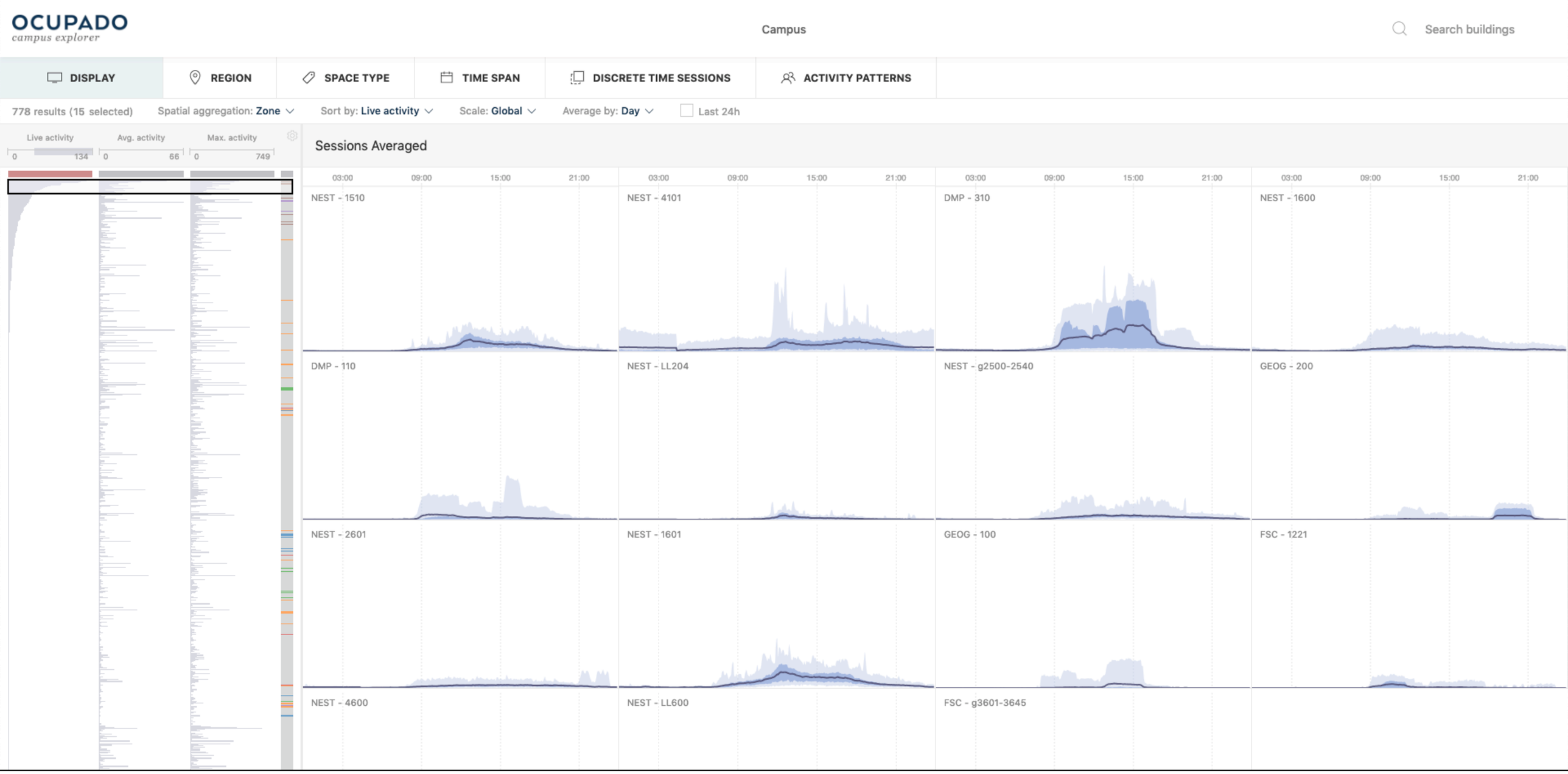



**Campus explorer, region subset view.** Discrete time intervals visualized as superimposed line charts. A region gets automatically highlighted in both views when we hover over it. ZC-Few:LI

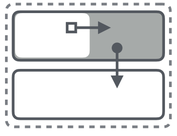

**Campus explorer, region subset view.** Many discrete time sessions, such as all weekdays during a long recording period, are displayed as superimposed line charts. Different temporal filter options help users in narrowing down the search space. ZB-Few:LI

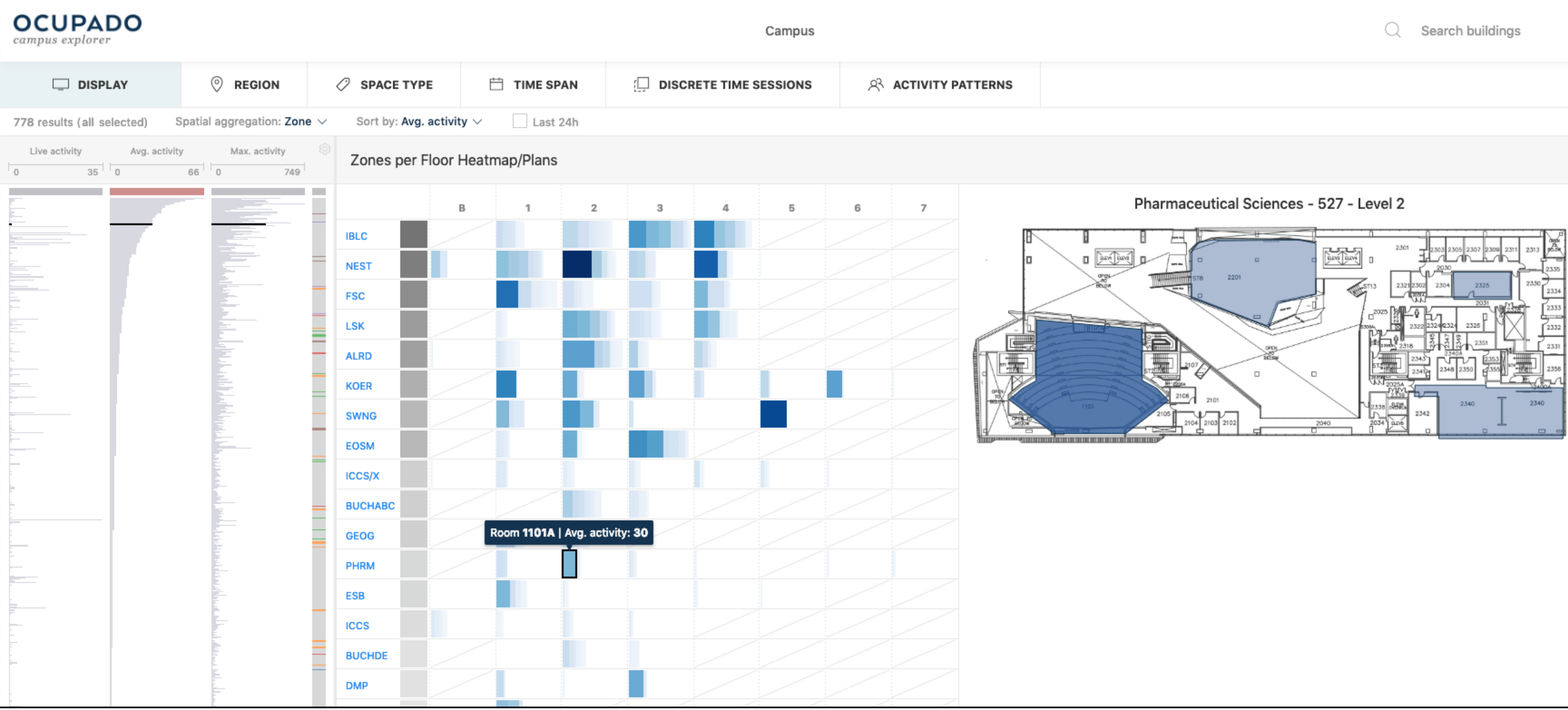

**Campus explorer, region subset view.** Aggregated sessions are presented as line charts with confidence bands to answer questions such as *When do people usually leave on weekday evenings?* ZC-Few:LA



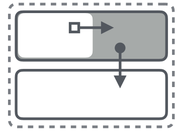


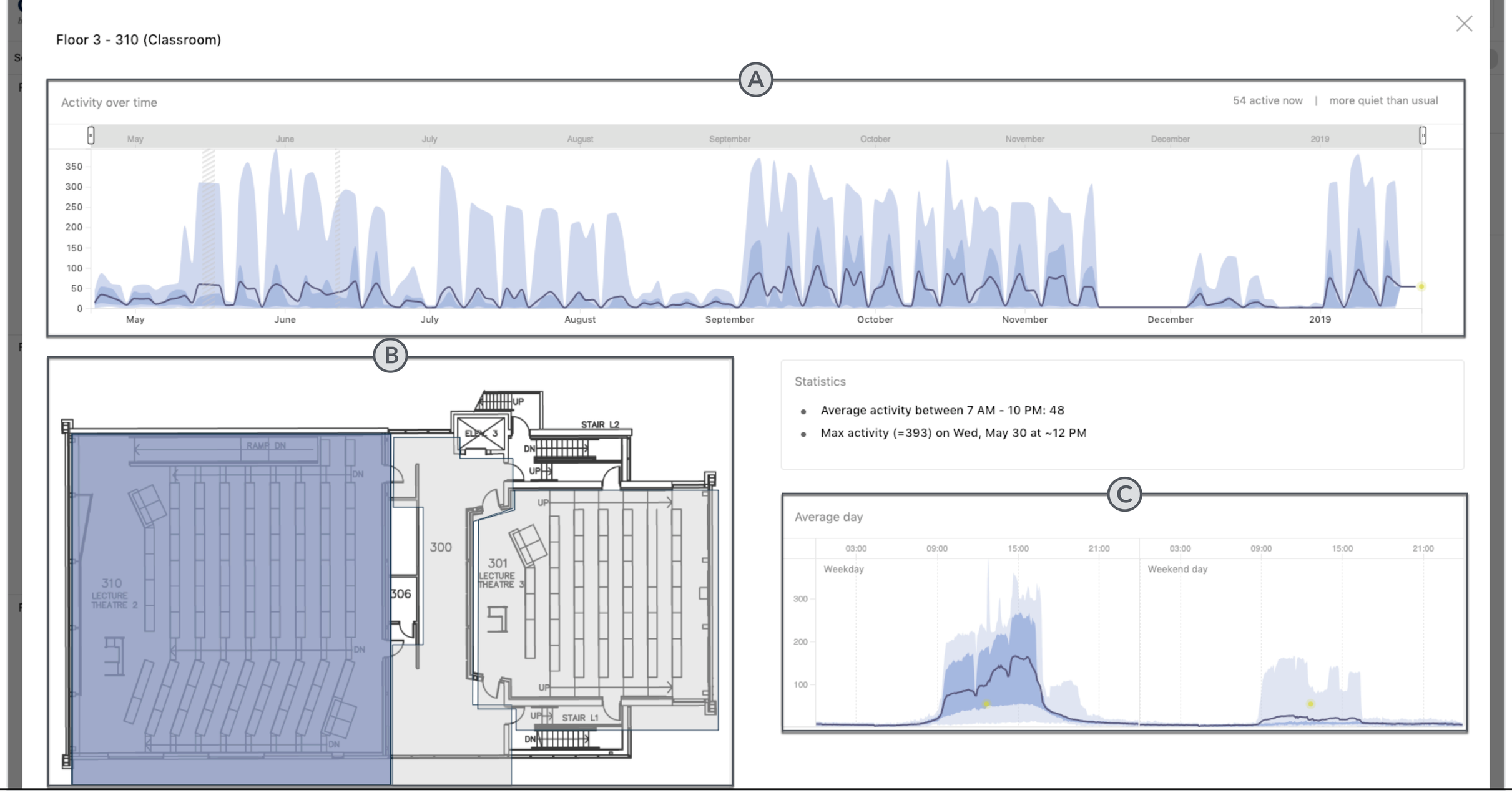

**Campus explorer, region subset view.** Absolute scales ensure consistent axes and enable direct comparisons of device counts between regions. Users can globally choose between independent and absolute y-scales that are applied to all temporal visualizations (sparklines, box-plot-bars, superimposed line charts). ZC-Few:LA



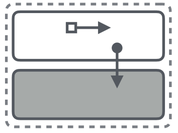



**Campus explorer, region subset view.** The spatial heatmap provides a campus-level view on device counts. Each row in the grid represents a building and each column indicates a floor. A cell is composed of one or more subcells, one for each zone, where its size and color depends on the number of devices. We decided to encode the same variable with two channels (size and color) to increase saliency. Users can hover over subcells to see more details or click on it to open the floor plan. This visualization approach provides a way to locate regions with certain characteristics and to investigate spatial relationships. ZC-AII:*





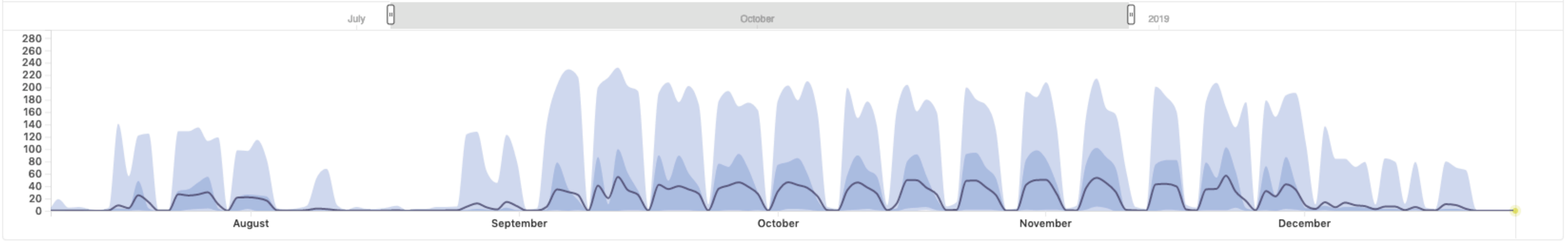

**Campus explorer, region detail view.** (a) Zoomable binned time series chart with confidence bands ( ZF-One:LI ). (b) Interactive floor plan to provide a spatial context and to navigate between close regions. (c) Typical day profiles show aggregated device counts ( ZF-One:LA ).

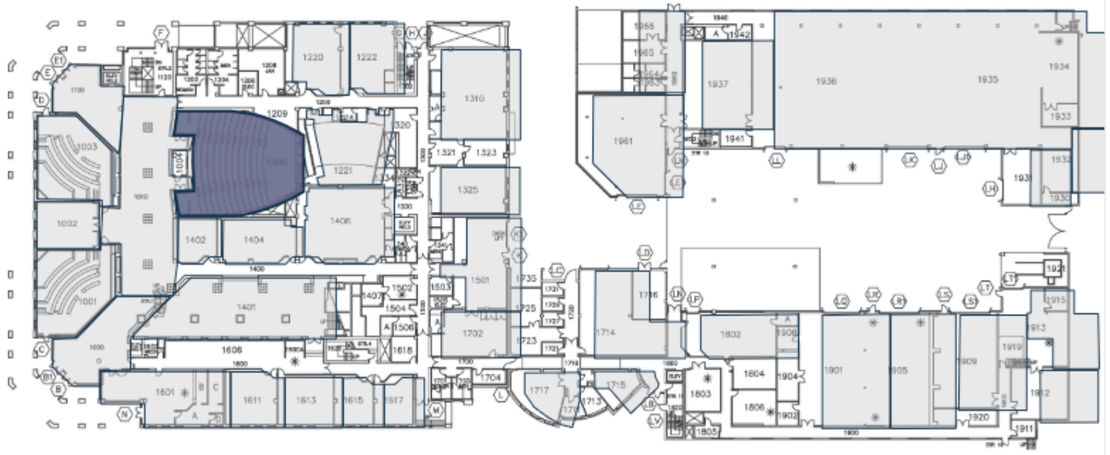


Floor 1 - 1005 (Classroom)

Activity over time

0 active now | normal activity

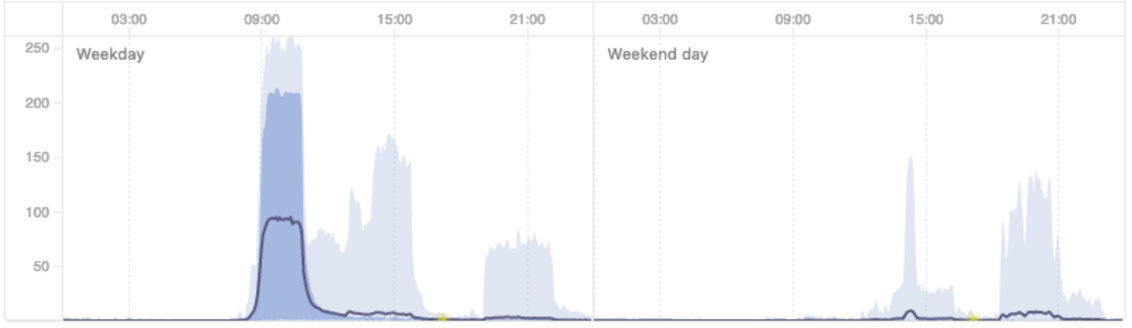


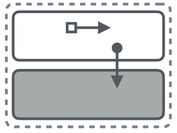
Statistics

- Average activity between 7 AM - 10 PM: 23
- Max activity (=293) on Thu, Mar 21 at ~09 AM

Average day




**Campus explorer, region detail view.** Example for another zone. ZF-One:L*



OCUPADO

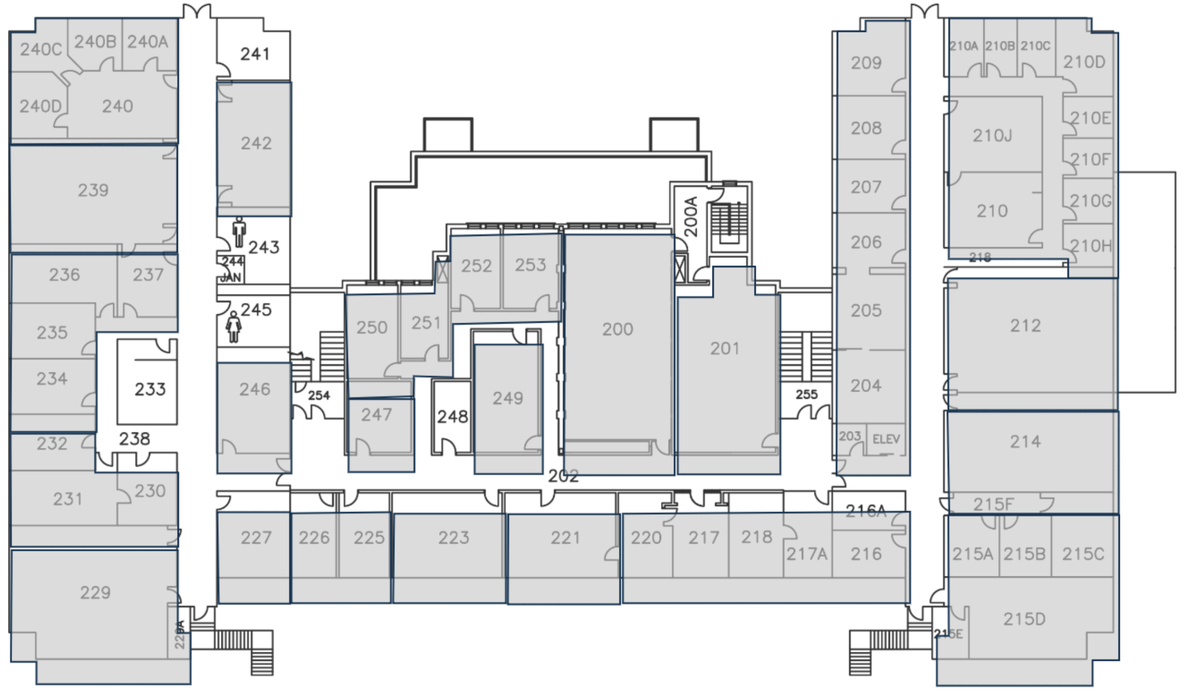
Campus / **Building Y**

Search buildings

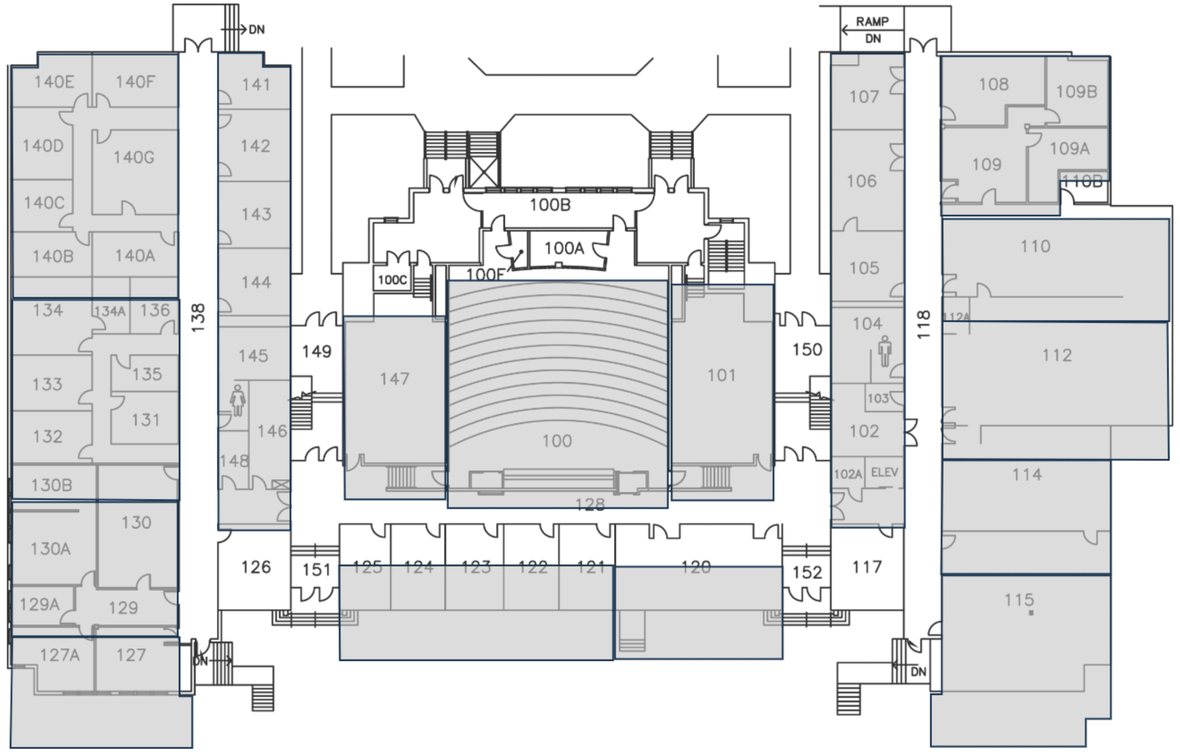
Floors | Activity

Meeting room | Research lab | Undergrad lab | Informal learning | Office | Classroom | Non-assigned

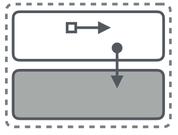
Level 2

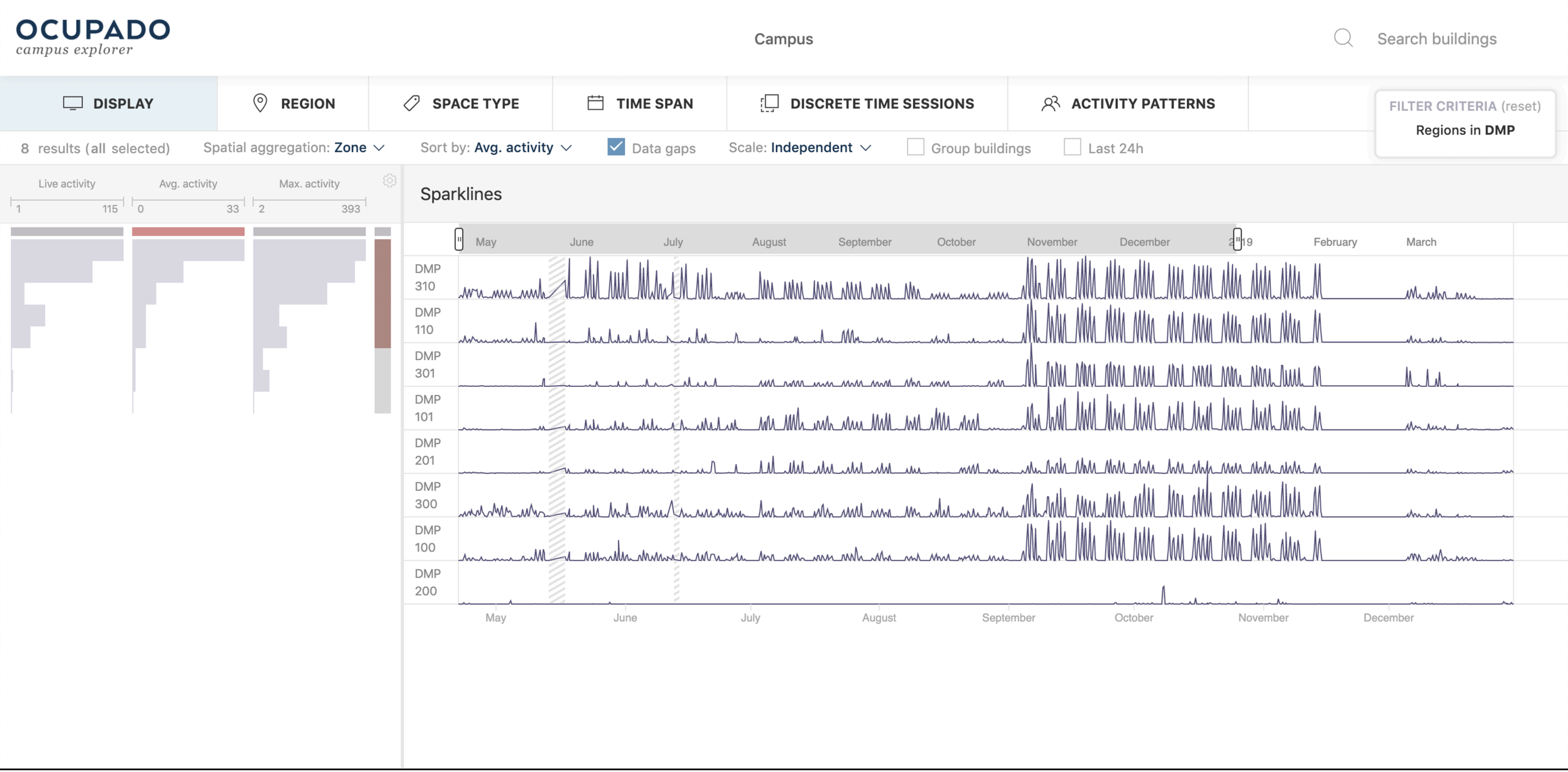



Level 1

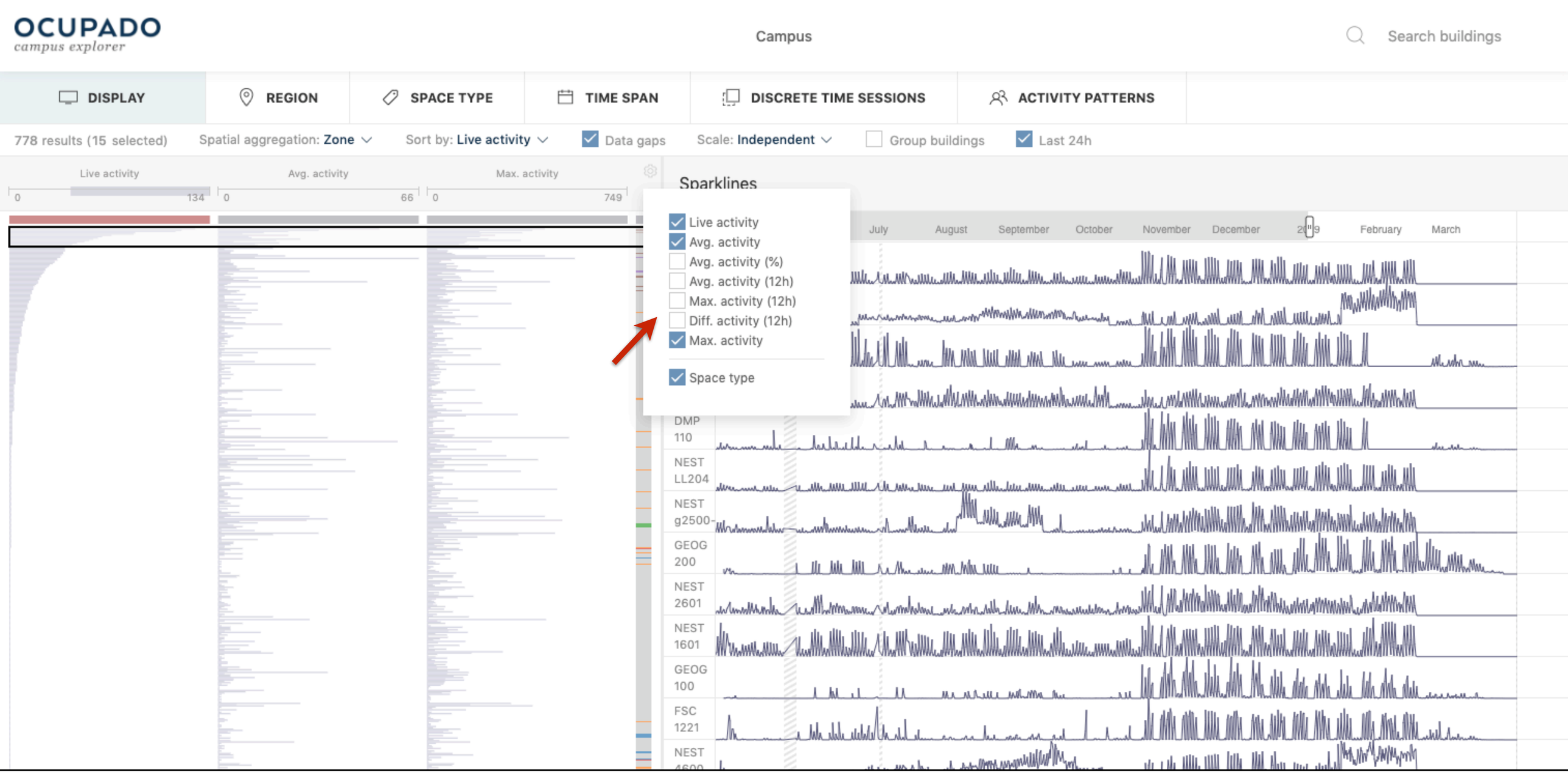



**Campus explorer, region detail view.** The detail view of a building is divided into two tabs: the first tab shows all floor plans ( [ZB,FB]-All ) and the second tab contains a binned time series chart and typical day profiles, similar to *floor* or *zone* detail views.





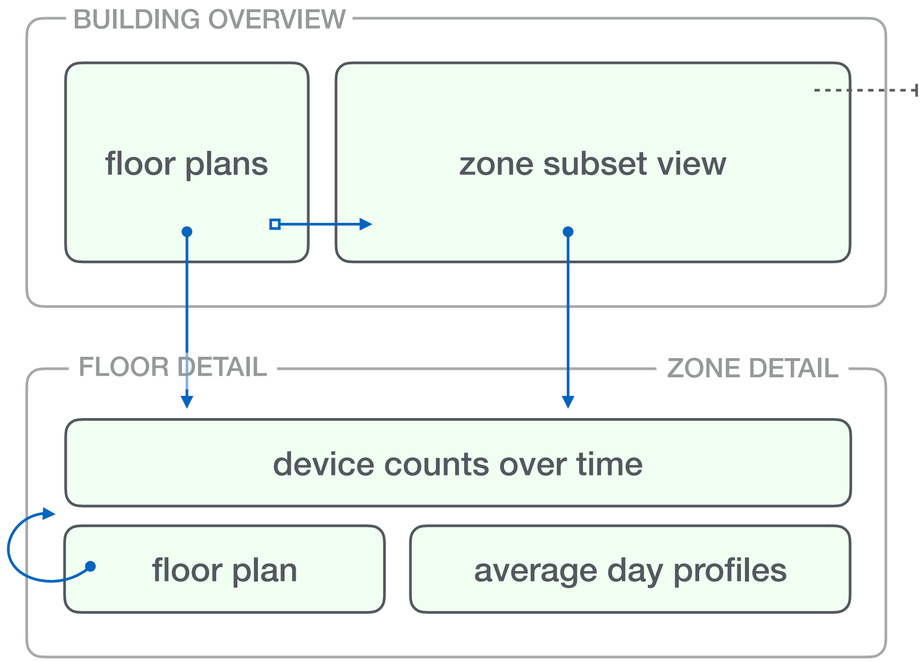

**Campus explorer, region subset view.** Regions are filtered by building (DMP) and displayed as sparklines ( ZB-AII:LI ).




**Campus explorer, region selector.** The width of the data stripes ( ZC-AII:*A ) is adjustable and users can enable or disable variables.

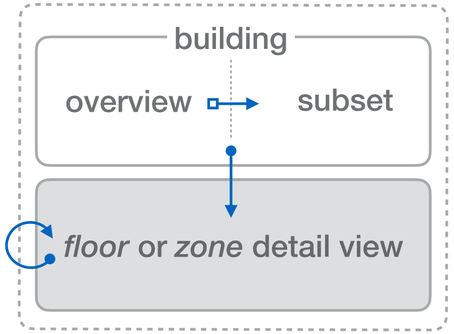
# 4.3 Building Long-Term Interface

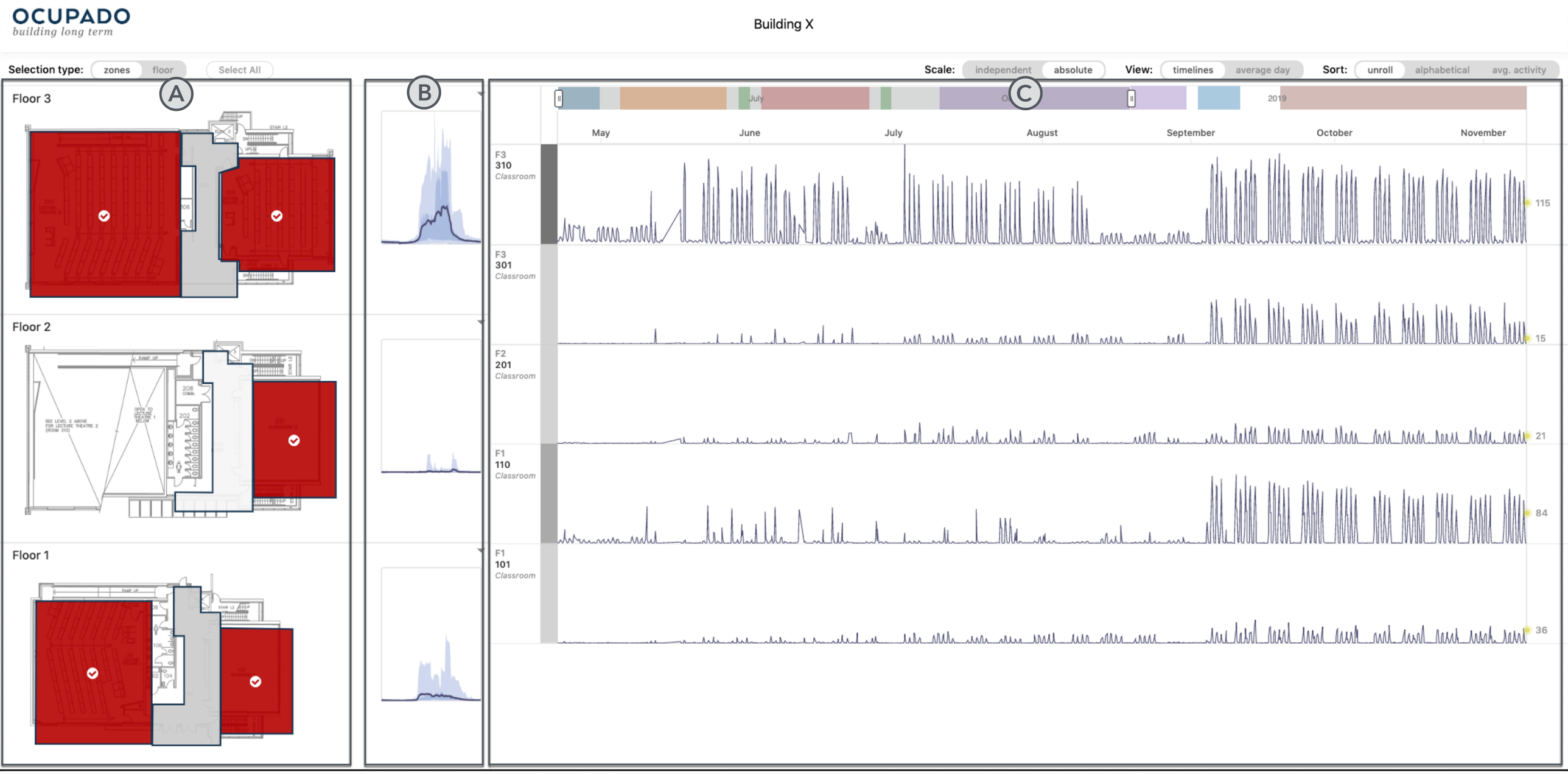
# Building Long-Term Interface: View Coordination & Layout



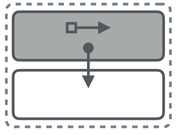

(a) sparklines
(b) average day profiles per zone (confidence-band line charts)

*Compact summary:*



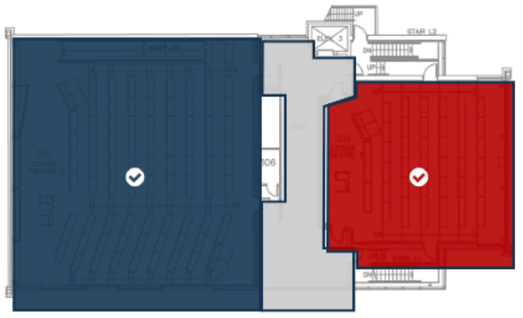



**Building Long-Term Interface.** (a) Interactive floor plans for selecting regions of interest ( ZB-All ). (b) Per-floor rollups showing average utilization ( FB-All:LA ). (c) Each selected zone shown as sparklines ( ZB-Few:LI ).

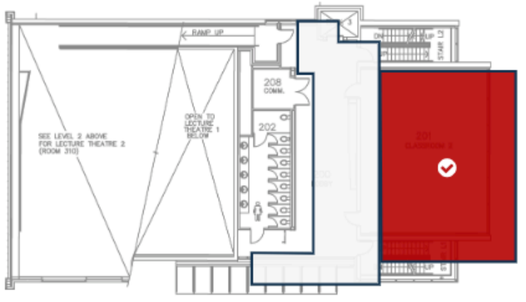


Selection type: zones floor | Select All | Scale: independent absolute | View: timelines average day | Sort: unroll alphabetical avg. activity

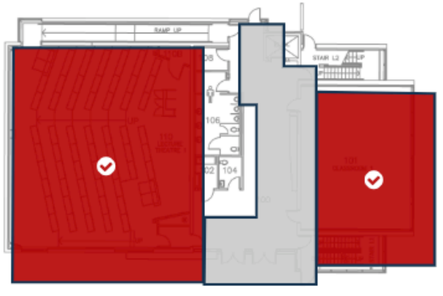
Floor 3



Floor 2

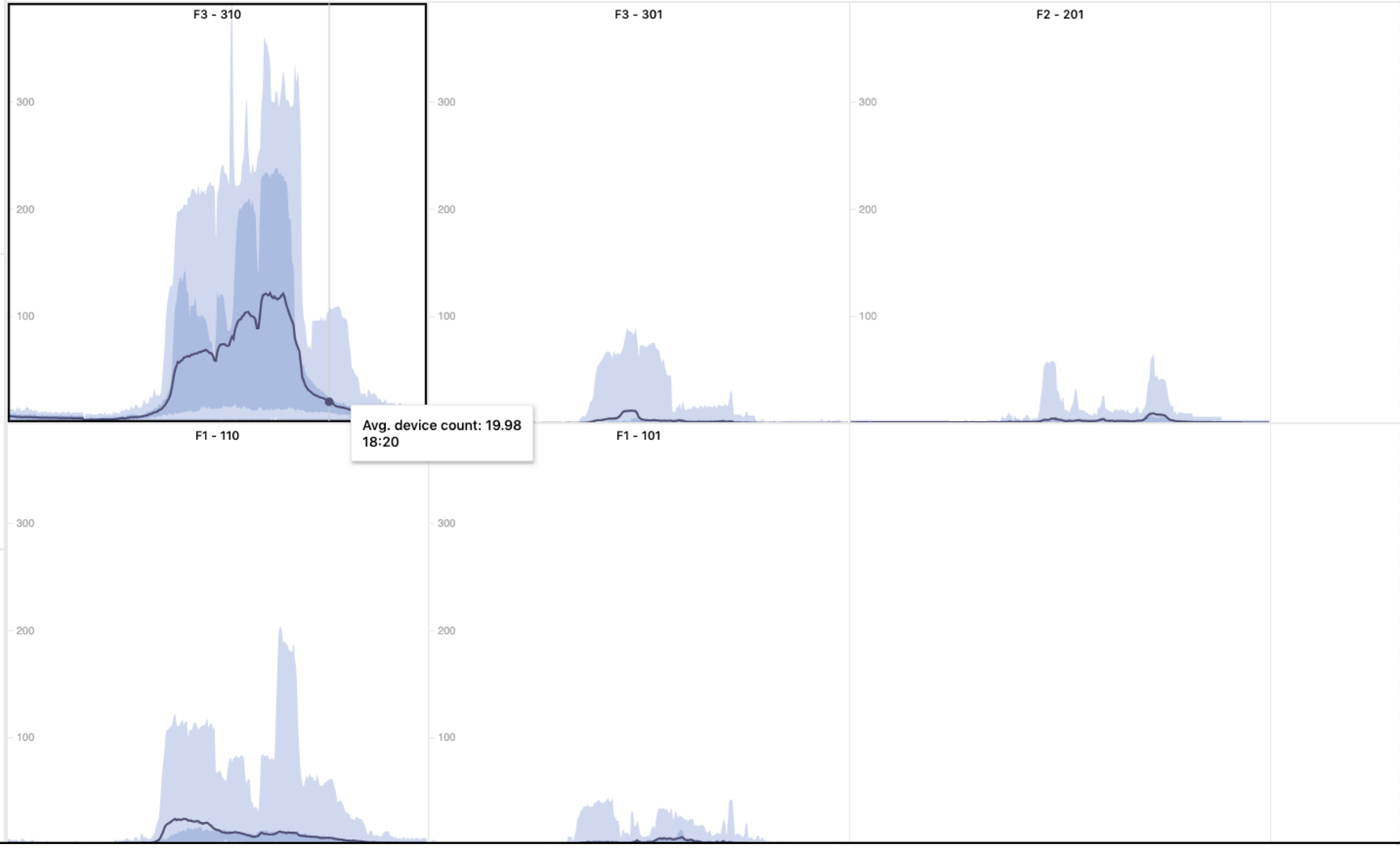


Floor 1

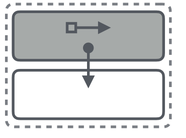


Typical daily device count

average | middle 50% of distribution | min/max




**Building Long-Term Interface.** Selected zones are shown as typical day profiles. ZB-Few:LA



OCUPADO
*building long term*

Building X

Selection type: zones floor | Scale: independent absolute | View: timelines average day | Sort: unroll alphabetical avg. activity

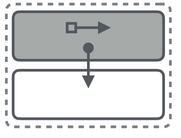
Floor 4
Floor 3
Floor 2
Floor 1
Floor -1

Typical daily device count

average | middle 50% of distribution | min/max

F2 - g2020-2051 | F2 - g2211-2215 | F2 - 2204 | F2 - 2201 | F2 - 2402 | F2 - 2401 | F2 - 2435
F2 - 2430 | F2 - 2237 | F2 - 2239 | F2 - 2232 | F2 - 2233 | F2 - 2231 | F2 - g2220-2229
F2 - 2330 | F2 - 2310 | F2 - 2965 | F2 - 2964 | F2 - 2942 | F2 - 2916 | F2 - 2910
F2 - 2333 | F2 - 2501 | F2 - g2600-2653_2700-2721 | F2 - g2002-2005

**Building Long-Term Interface.** Typical day profiles for many zones, automatically sized to fit onscreen. ZF-AII:LA

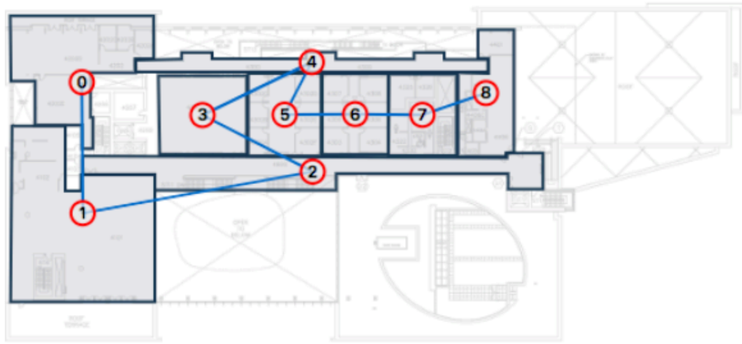


# Linearized Floor-Plan Ordering for Regions

We use a shortest path algorithm to create a linearized order for the per-zones displays of sparklines or line charts in the region subset view of the Building Long-term interface, based on spatial contiguity within the floor plans.

- In the outer loop, traverse each floor in order from top to bottom floor.
- Within each floor, the start position is at the top left corner (x=0; y=0).
- Compute the bounding box for all shapes/zones.
- Calculate the distance to the nearest bounding box centroid (nearest zone). Save the zone ID that is assigned to a shape in an ordered list and label the shape as visited. Repeat this step until all shapes are visited.

Examples:

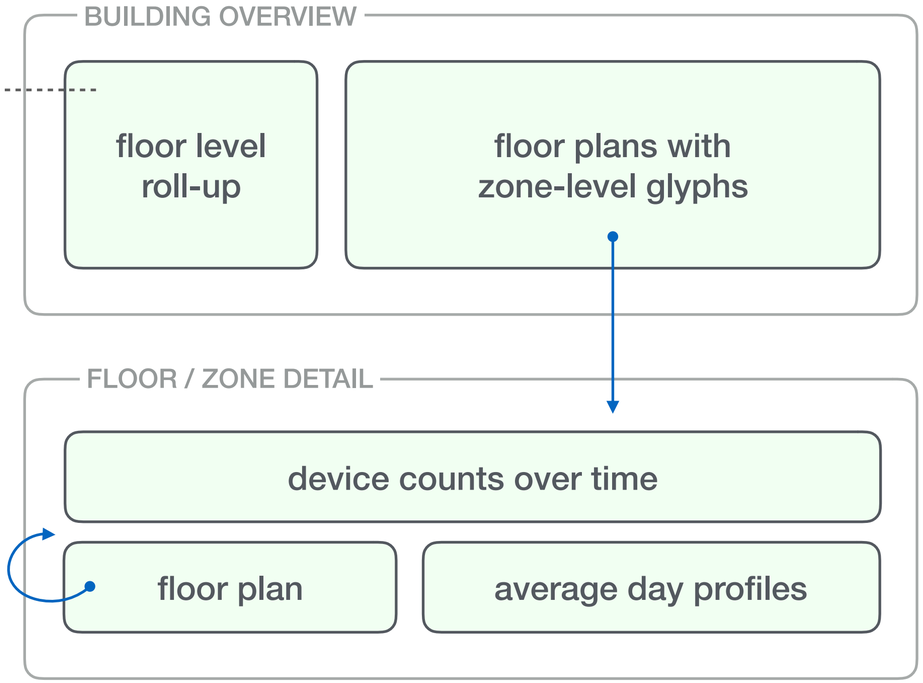




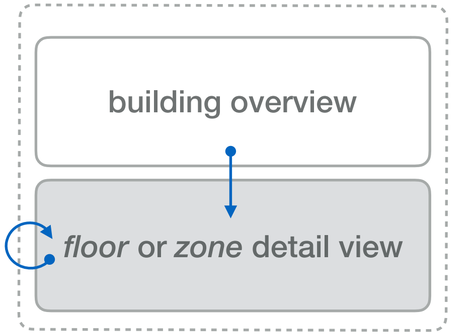
# 4.4 Building Recent Interface

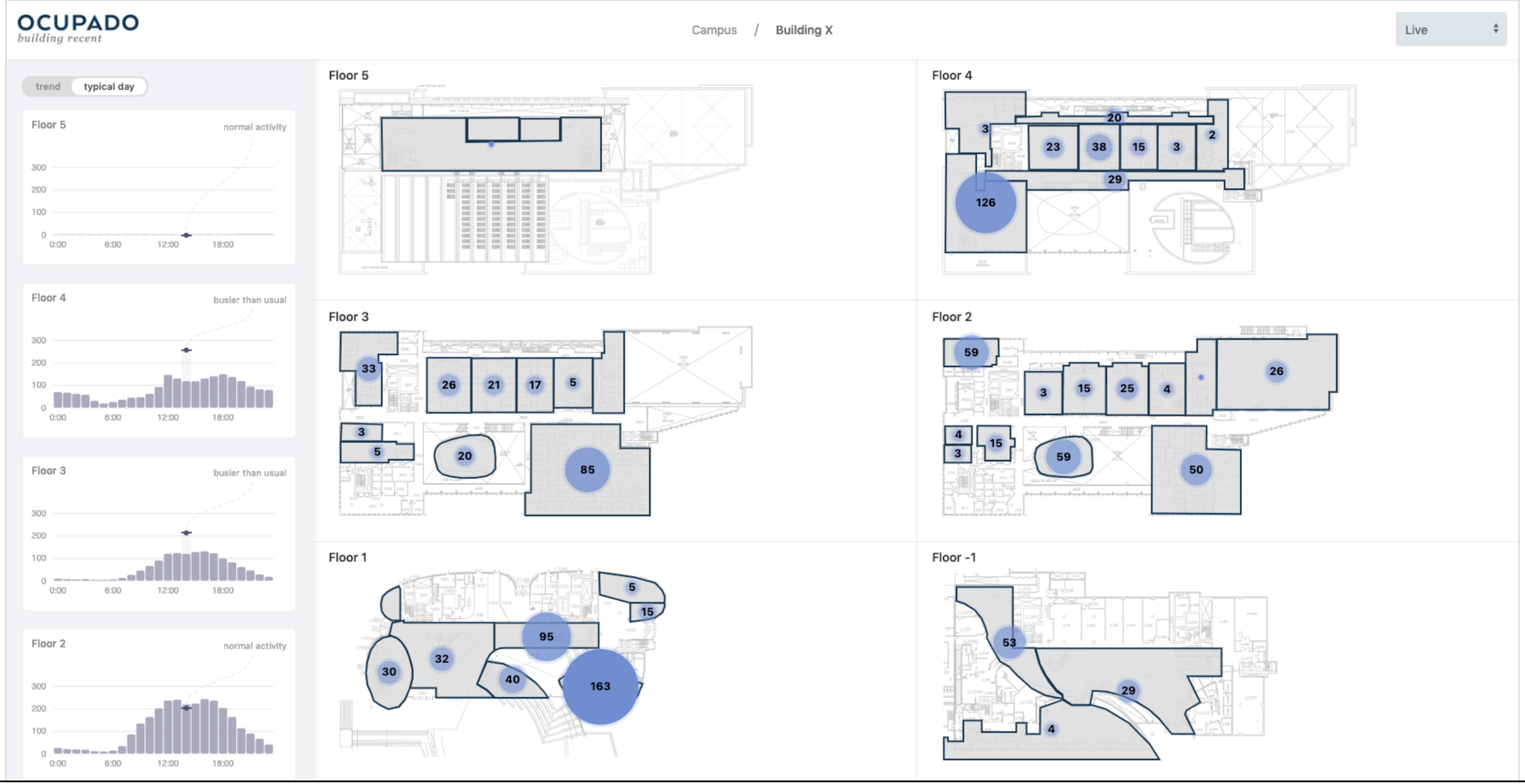
# Building Recent Interface: View Coordination & Layout

(a) last 12h and next 3h (line charts)
(b) average day per floor (histograms)

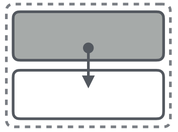



*Compact summary:*

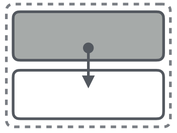


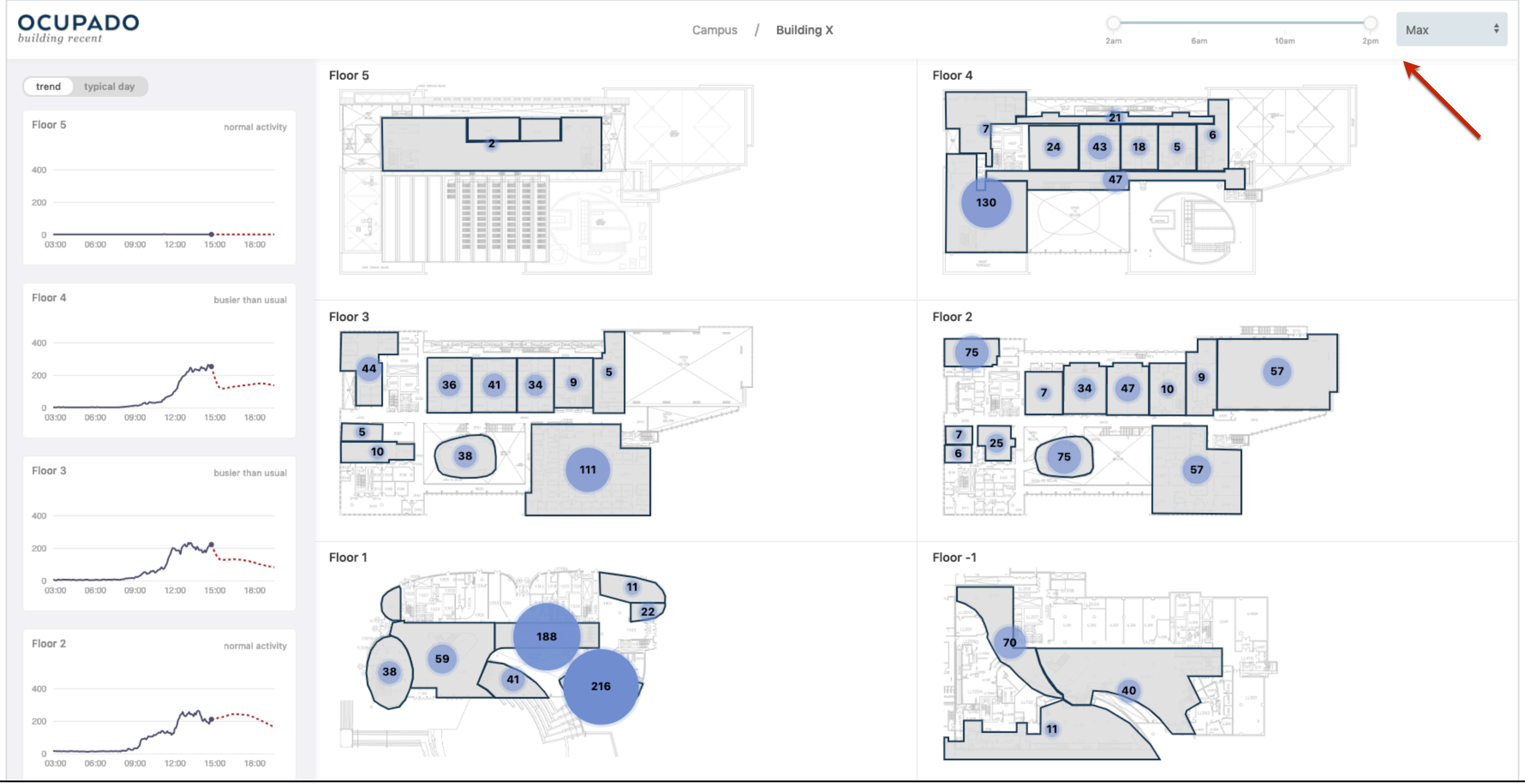



**Building Recent Interface.** Floor plans are arranged in a grid layout to fit on screen and live device counts are displayed as superimposed circle symbols ( [ZF,ZB]-AII:S* ). The left sidebar shows the aggregated per-floor usage for a typical day compared to the current device count ( FB-AII:LA ).

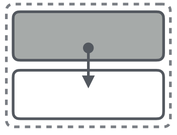


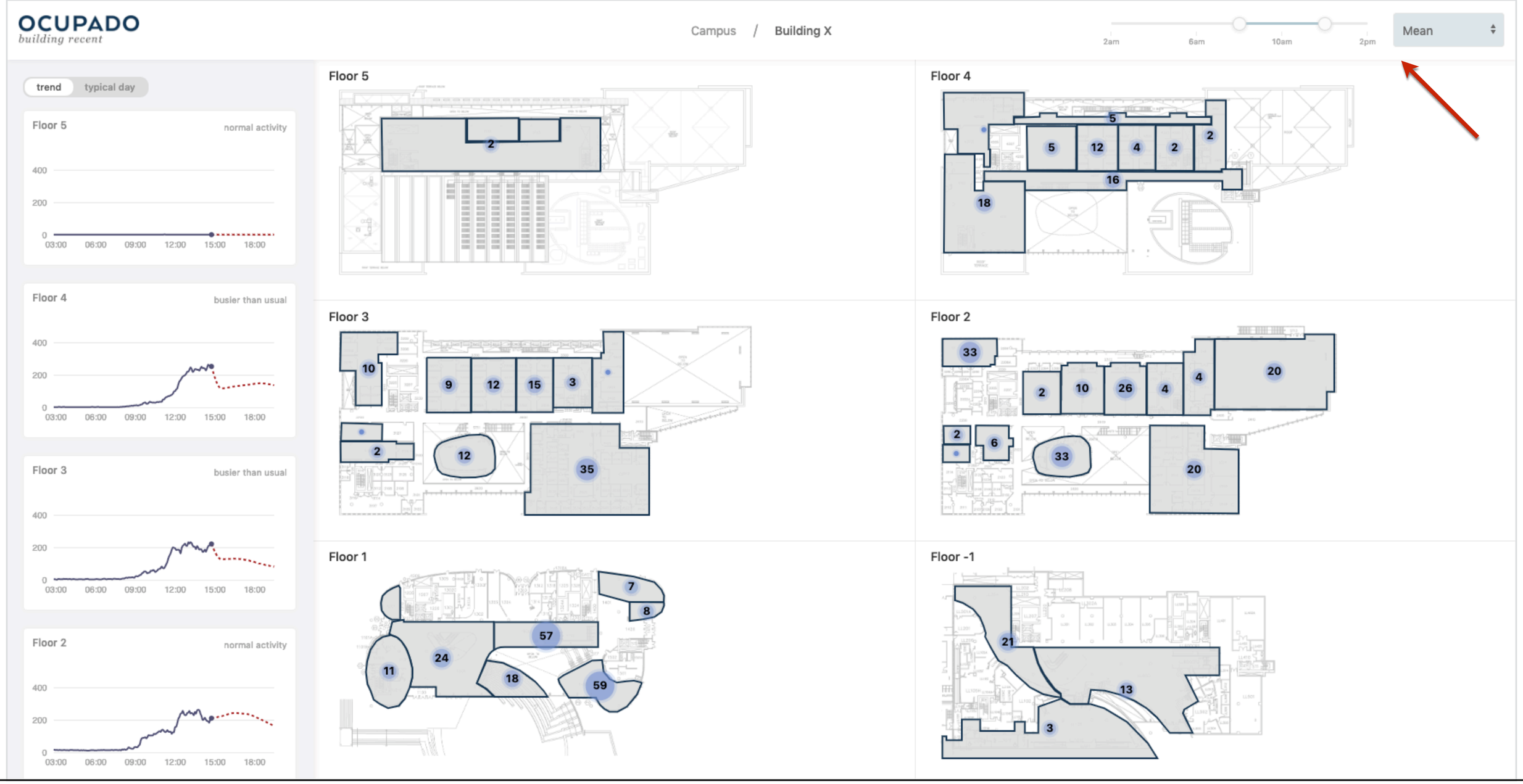

**Building Recent Interface.** Users can switch between histograms and line charts in the left sidebar. This screenshot shows per-floor aggregate trend charts with device counts over past 12 hours ( FB-AII:SI ) and prediction for the next 3 hours (red dashed line).



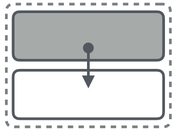


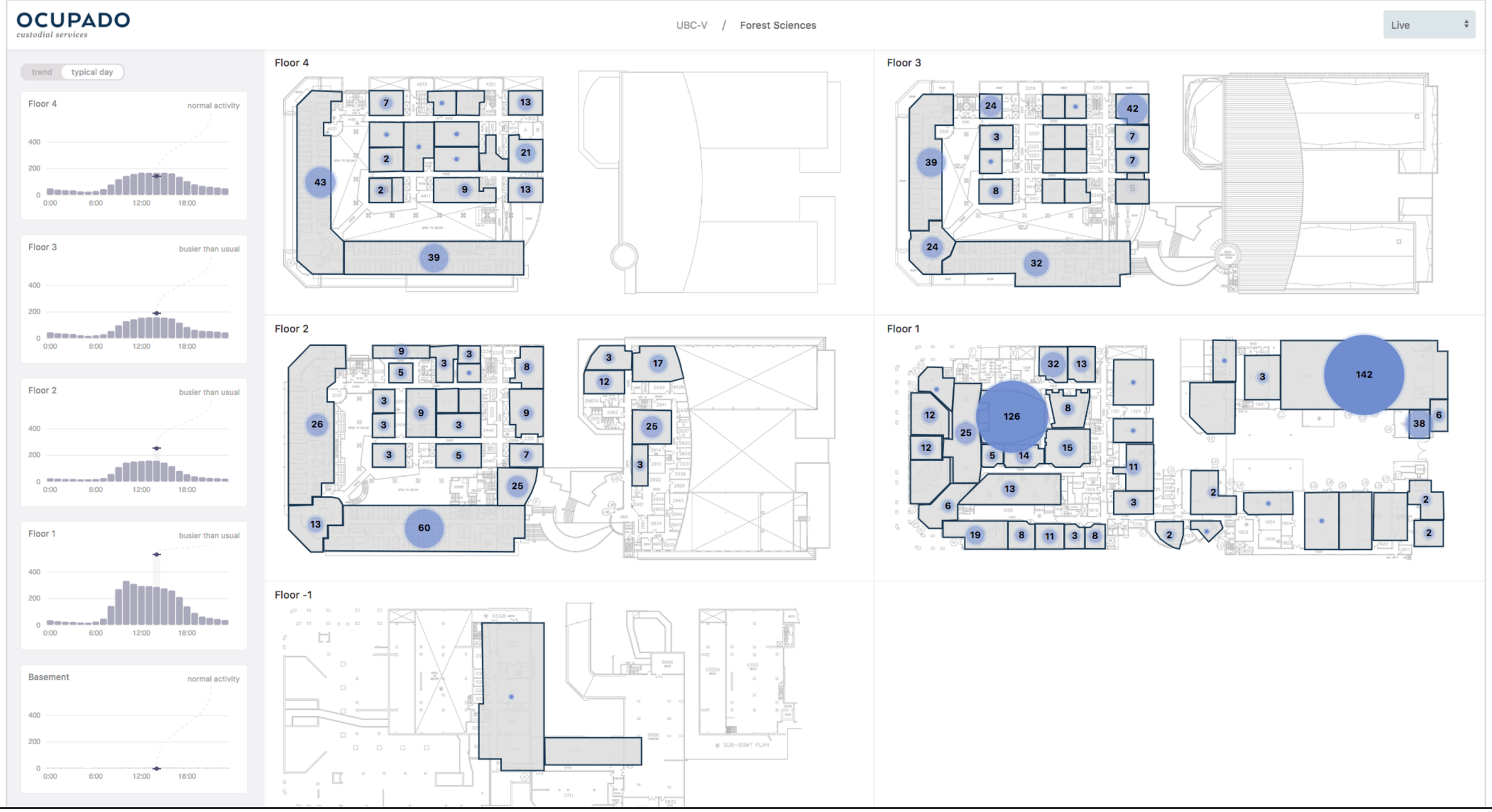

**Building Recent Interface.** The underlying variable for the glyphs can be changed in the control panel. For example, analysts can choose to show the maximum device count during the last 12 hours instead of the live device count. Average device count is the third option. [ZF,ZB]-AII:SA



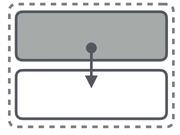


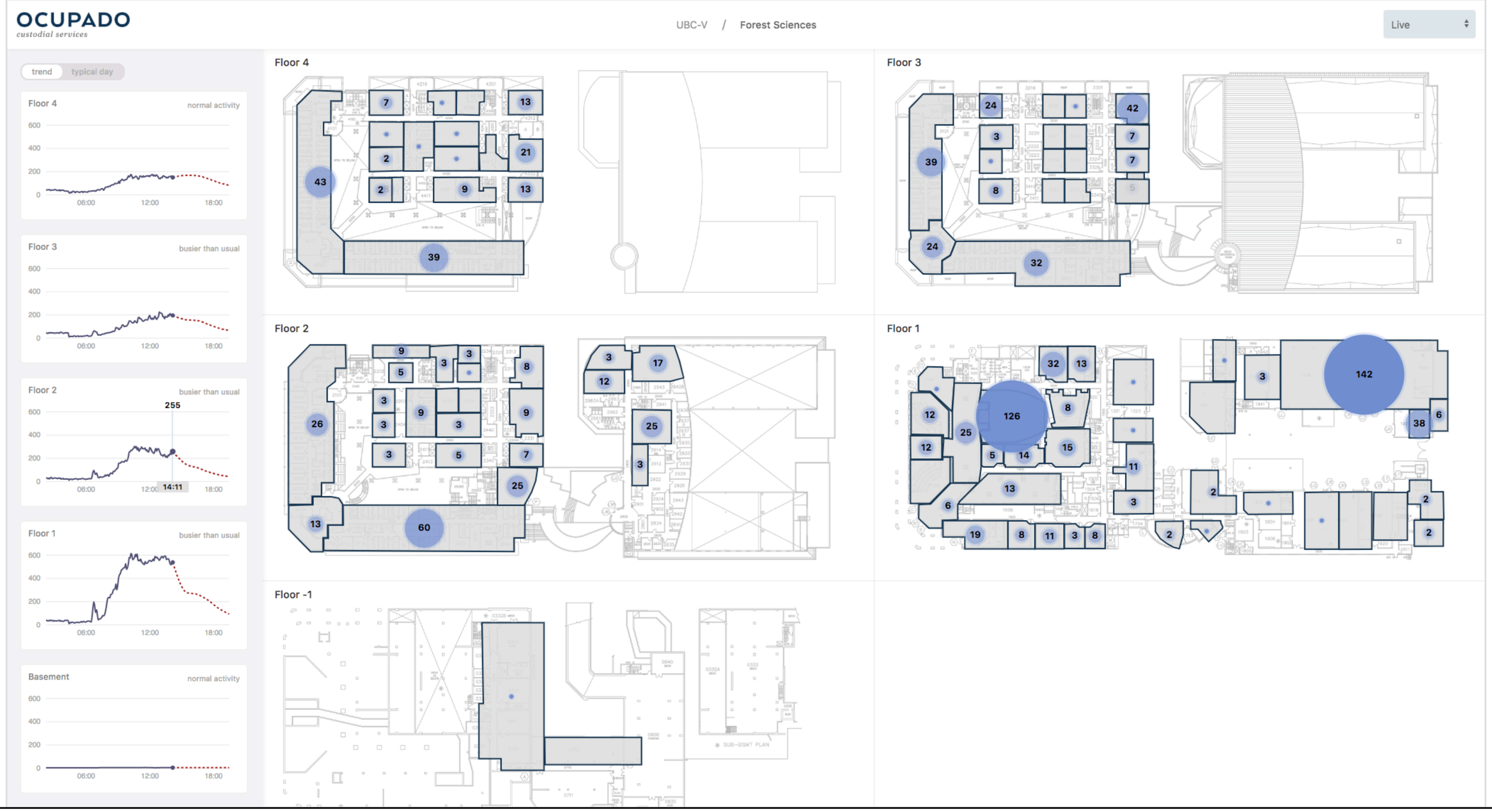

**Building Recent Interface.** The range slider in the top right corner can be used to select a shorter time window; for example, to select the average device count between 8am - 12pm today. [ZF,ZB]-AII:SA



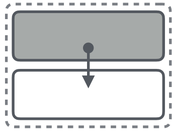


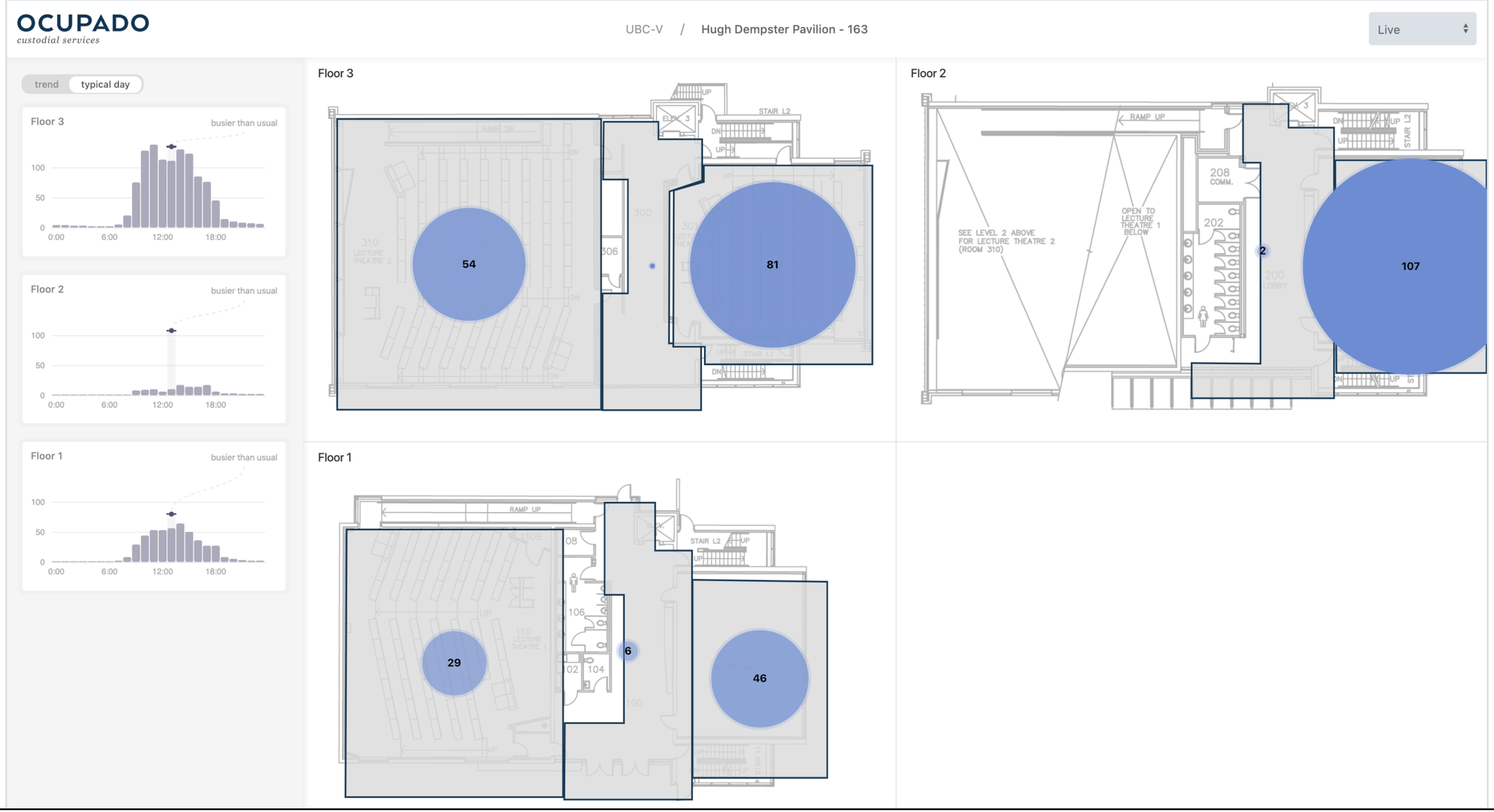

**Building Recent Interface.** Example for another building with aggregated per-floor usage in the left column ( FB-AII:LA ) and live device counts superimposed on floor plans in the right column ( ZB-AII:SI ).






**Building Recent Interface.** Example for another building with per-floor trend charts in the left column ( FB-AII:SI ) and live device counts in the right column ( ZB-AII:SI ).

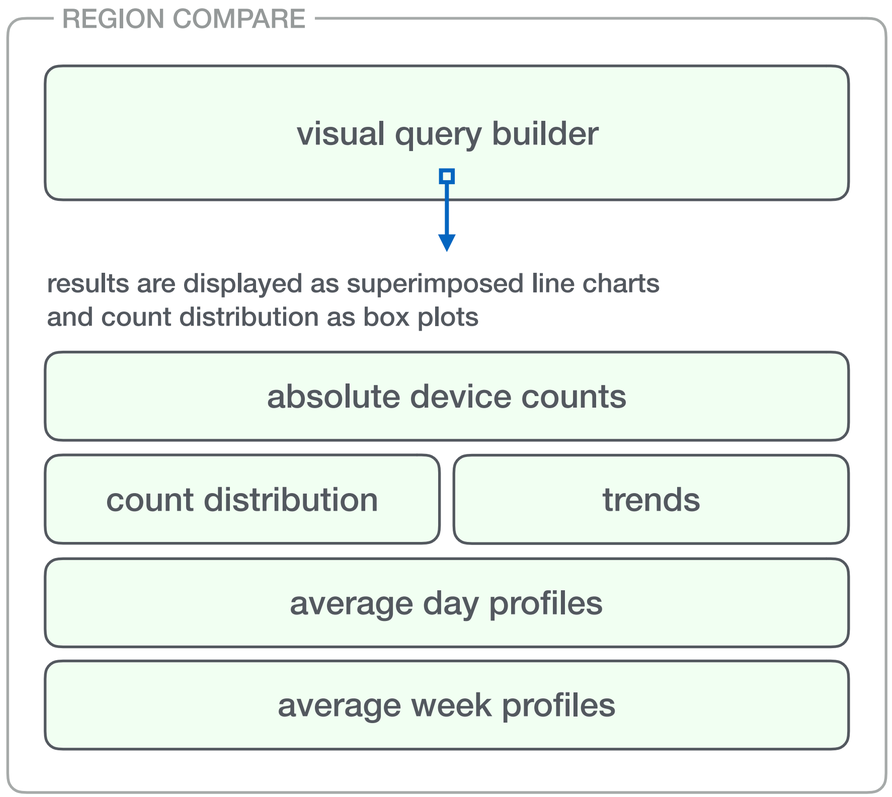




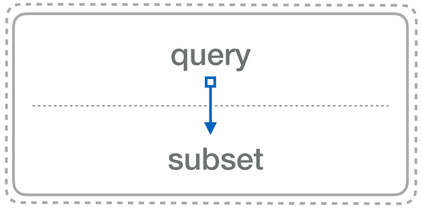

**Building Recent Interface.** Example for another building (left column: FB-AII:LA ; right column: ZB-AII:SI ).

# 4.5 Region Comparison Interface

# Region Comparison Interface: View Coordination & Layout



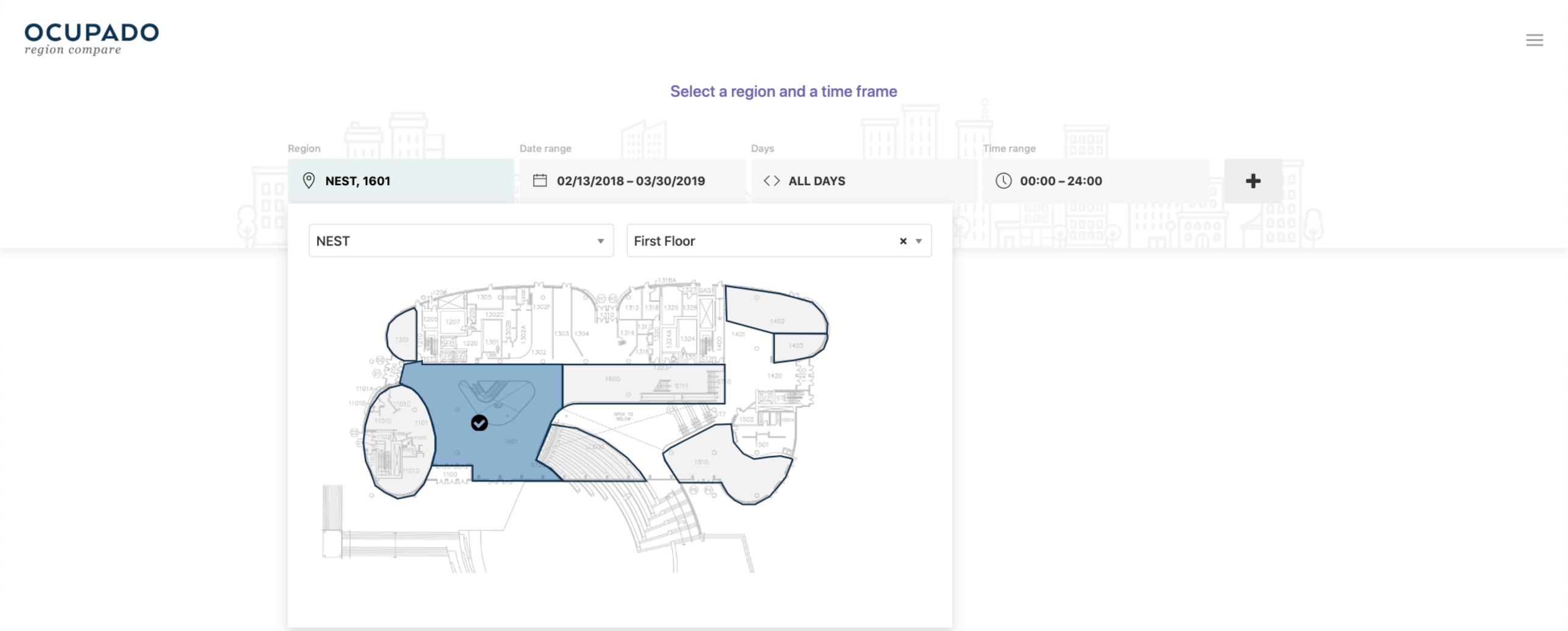

*Compact summary:*



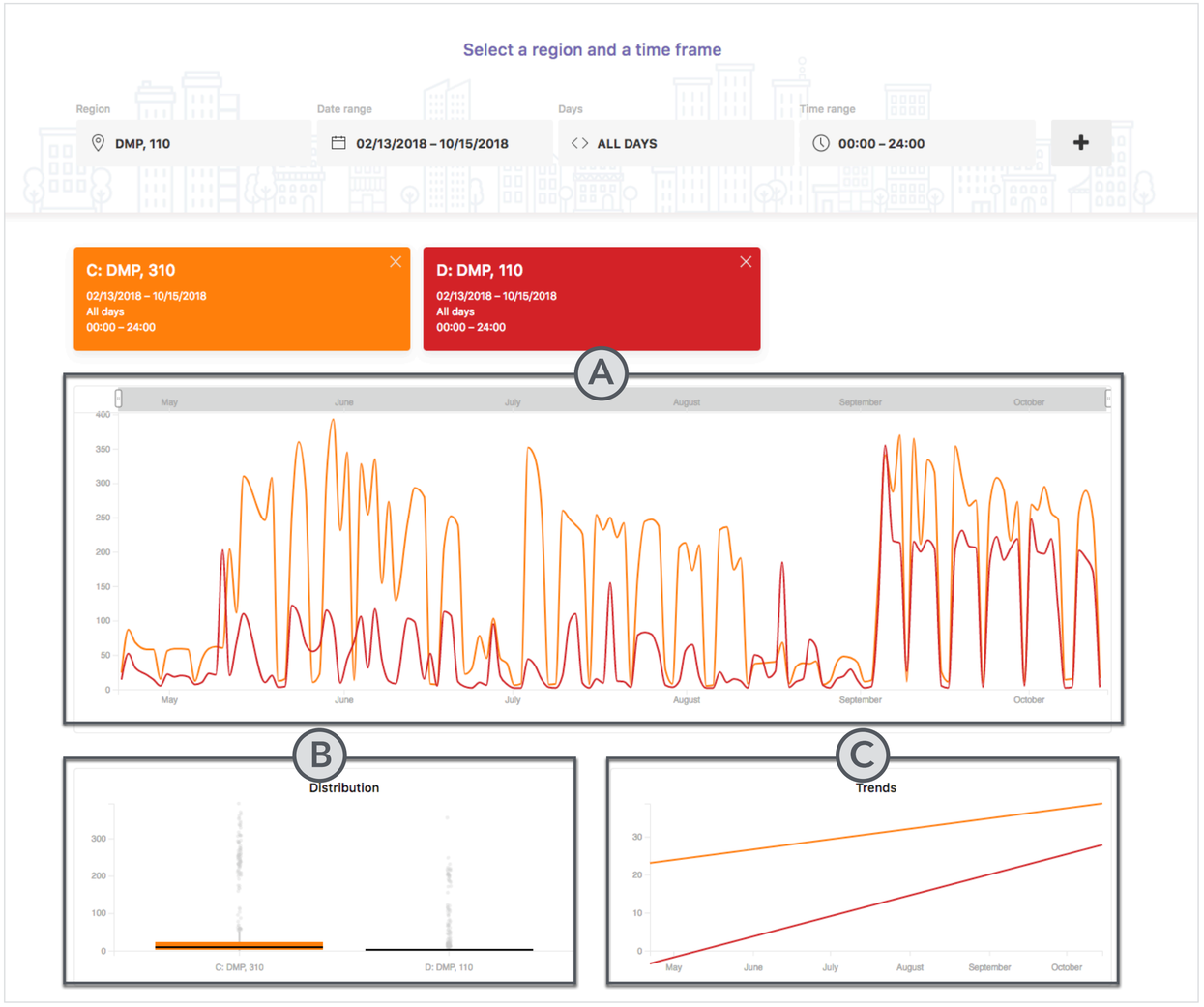
# Region Comparison Interface

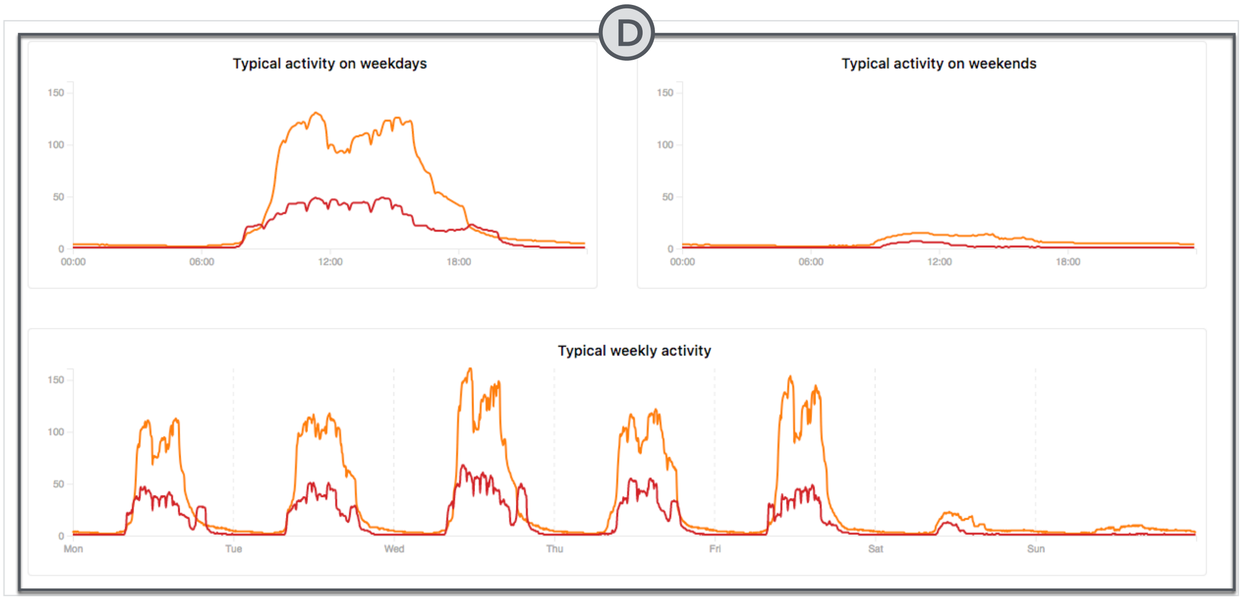
This interface allows users to compare a small subset of regions or time periods. A recurring task (T6), for instance, to analyze the impact of space upgrades, to compare summer vs. winter use, or to help assess the custodial workload of different floors.

The *Campus Explorer* and the *Building Long-Term Interface* support this task only to a limited extent. In these tools, we use juxtaposition to provide overviews of many regions but this faceting approach can hinder direct local comparison [Javed, 2010]. In the *Region Comparison Interface*, we display data from multiple regions in the same space, superimposed.




**Region Compare Interface.** The visual query builder is the key component that aids comparisons along two dimensions: space and time. For each query, users can select a building, floor or zone and a specific time period. FB-Few




**Region Compare Interface.** The results are displayed in multiple views: (a) Interactive zoomable line chart to show the raw device counts over time ( ZB-Few:LI ); (b) boxplots to summarize the distribution of counts ( ZB-Few:LA ); (c) trend charts to facilitate a high-level comparison ( ZB-Few:LA ); and (d) line charts with aggregated counts to illustrate the average daily and weekly utilization ( ZB-Few:LA ). We allow a maximum of five time series or regions to avoid visual clutter. Queries can be added and removed dynamically and all views are updated accordingly.

# 5. Analysis Scenarios

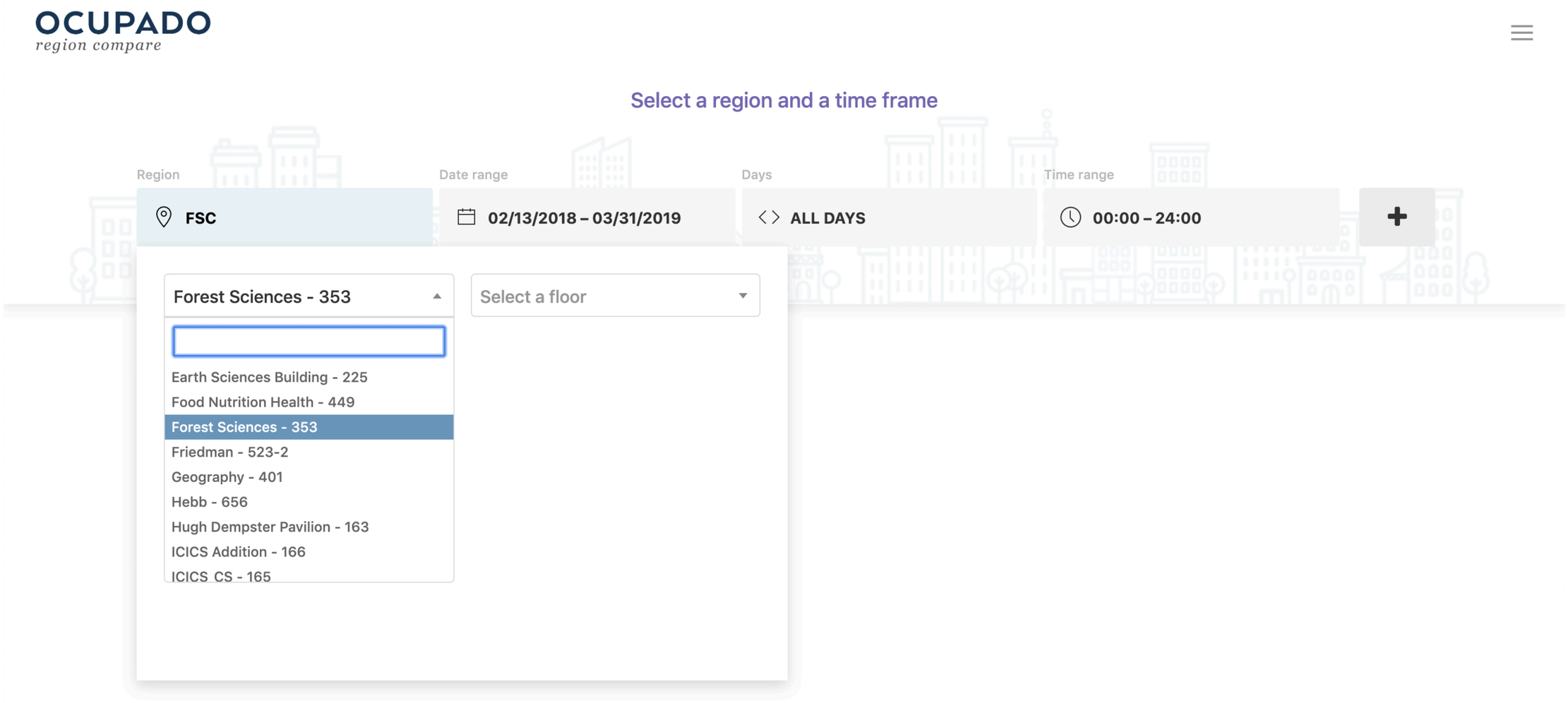
# 5.1 Analysis Scenario: **Compare Usage Patterns**

# Compare Usage Patterns

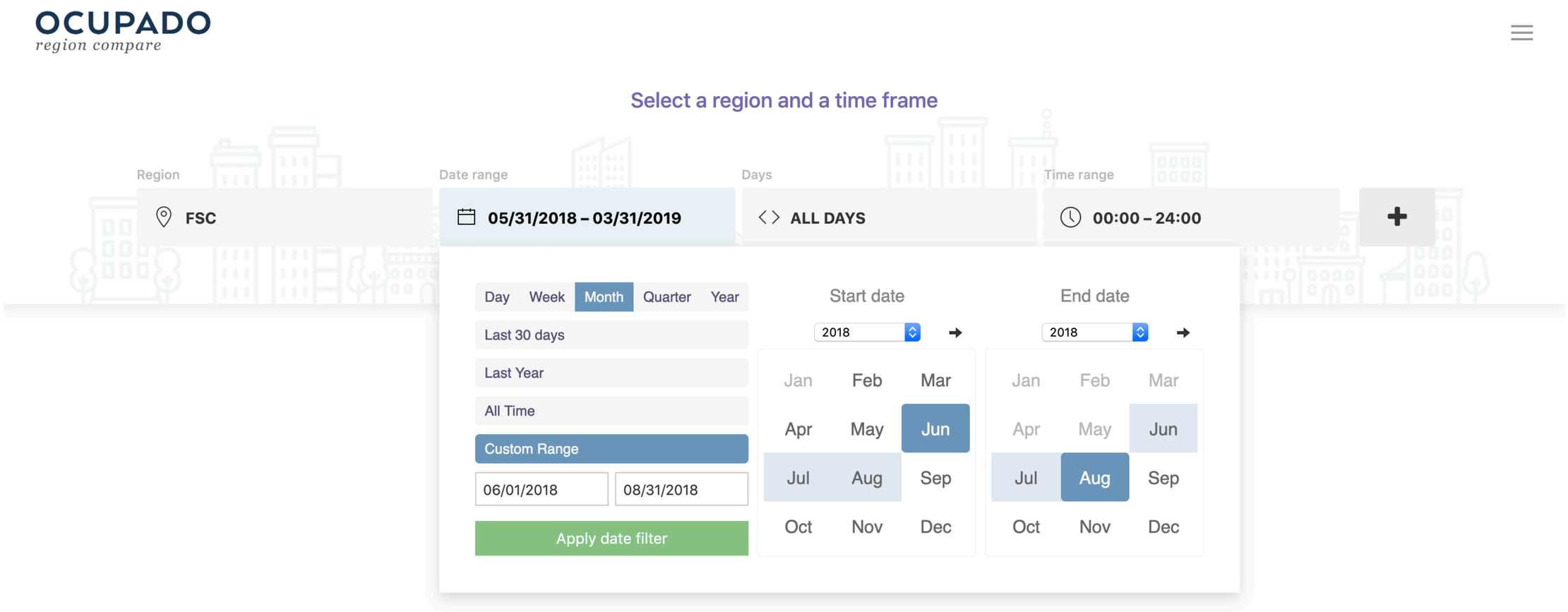
The motivating question for this analysis scenario is:
*How do renovations or space improvements affect the usage pattern of a region?*

A building manager and a senior planner for informal learning spaces posed this question several times. It is an important but infrequent task that requires a substantial amount of recorded data before and after conducting the upgrades.

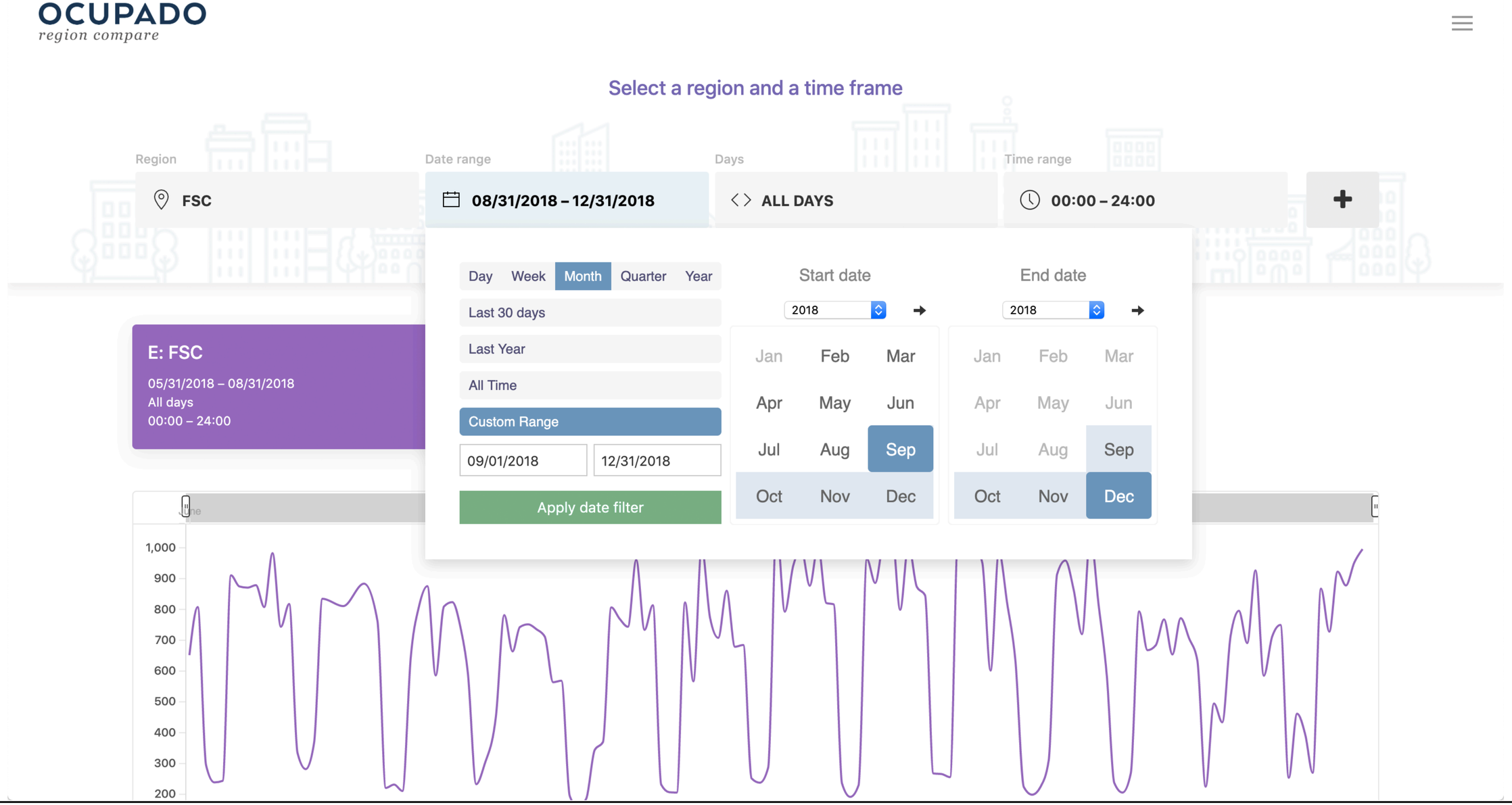
We describe this analysis based on winter vs. summer usage because of insufficient available data that can be linked to current renovations.



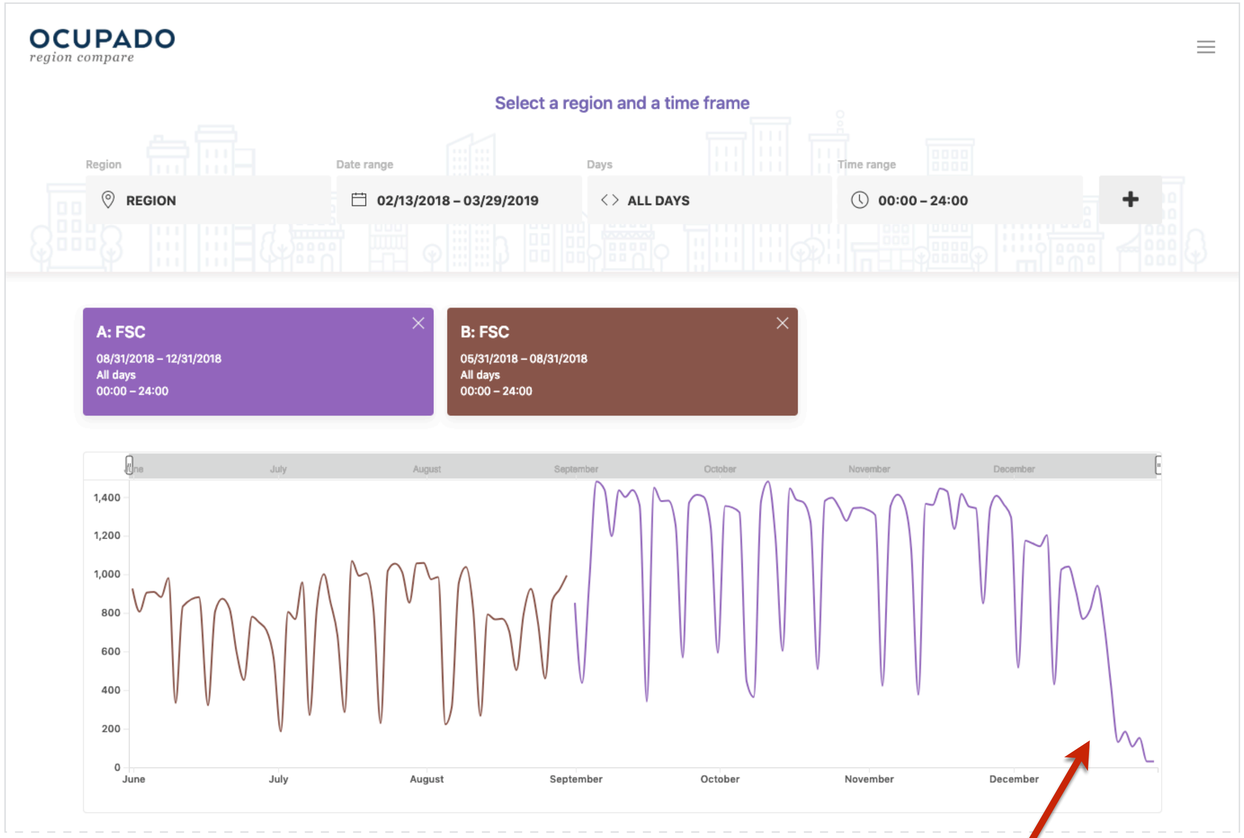

**Region Comparison Interface.** Analysts select the Forest Sciences building.

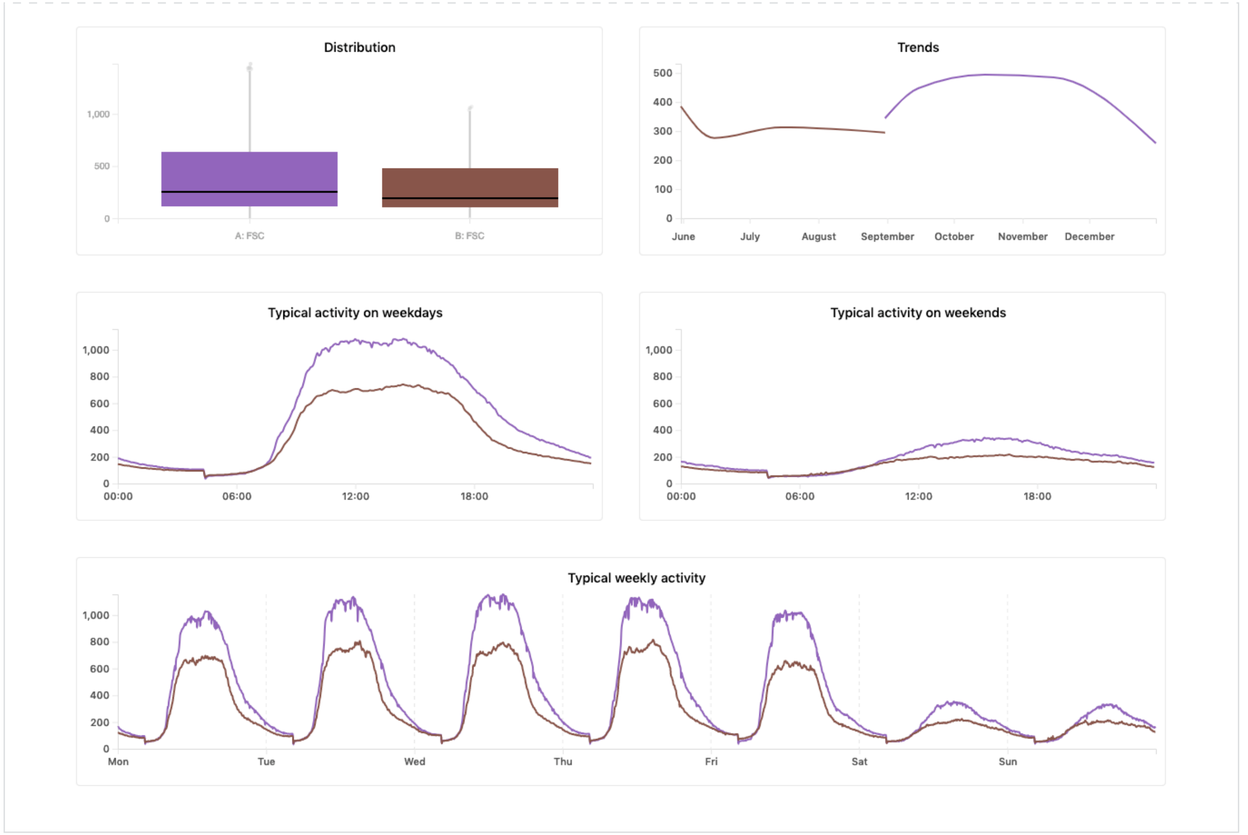



**Region Comparison Interface.** Select date range (Jun-Aug) and submit the query.




**Region Comparison Interface.** The result of the query, the device count over time and the typical daily and weekly activity, is displayed directly below. The building remains selected and the analysts pick Sep-Dec for the second query.




**Region Comparison Interface.** The two time series are now displayed in all views and enable direct comparisons. The maximum device count during the fall is around 1400 and in the summer not substantially lower. The analysts can observe generally very similar patterns and a major decline on Dec 20th, after the term officially ended. BC-One:L*

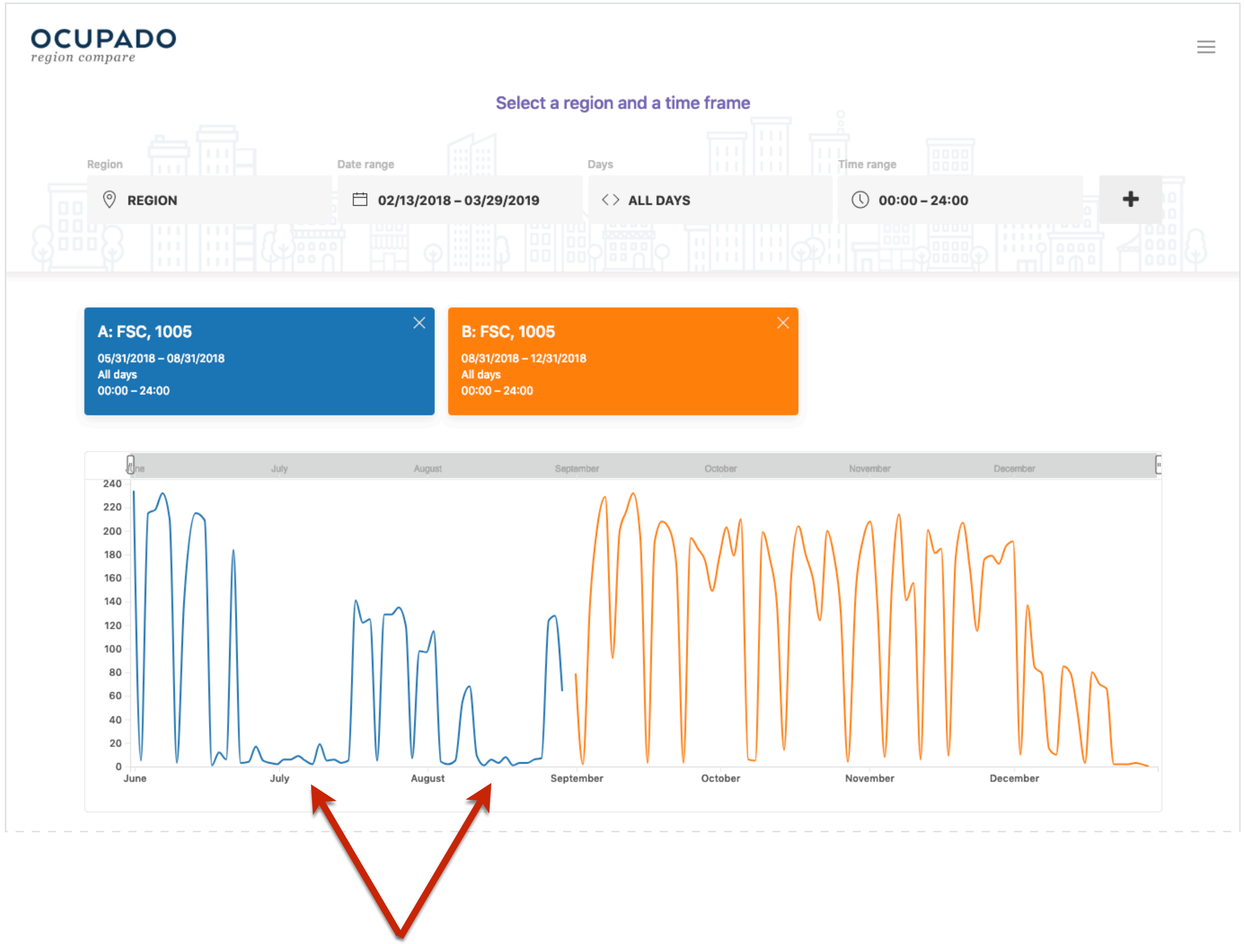
OCUPADO
region compare

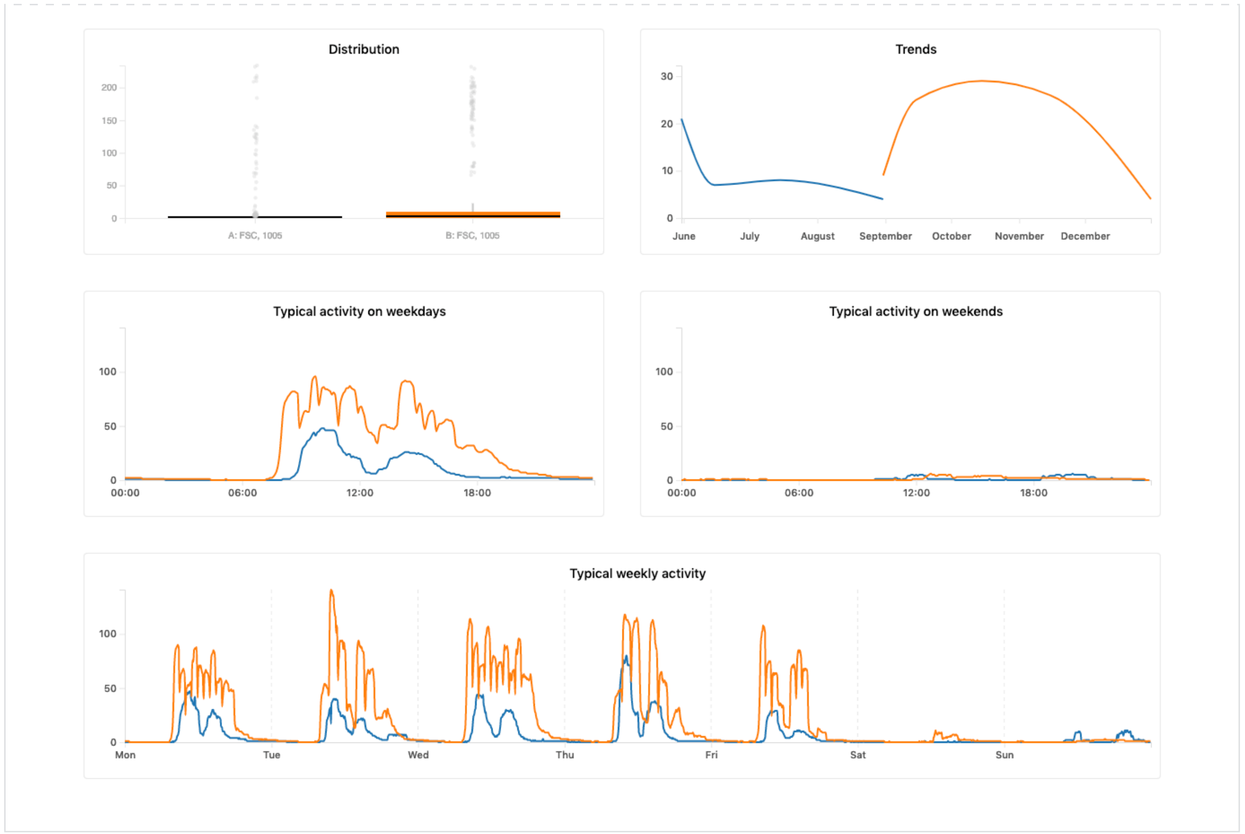
Select a region and a time frame

Region: FSC, 1005 | Date range: 08/31/2018 – 12/31/2018 | Days: ALL DAYS | Time range: 00:00 – 24:00

Forest Sciences - 353 | Main Floor

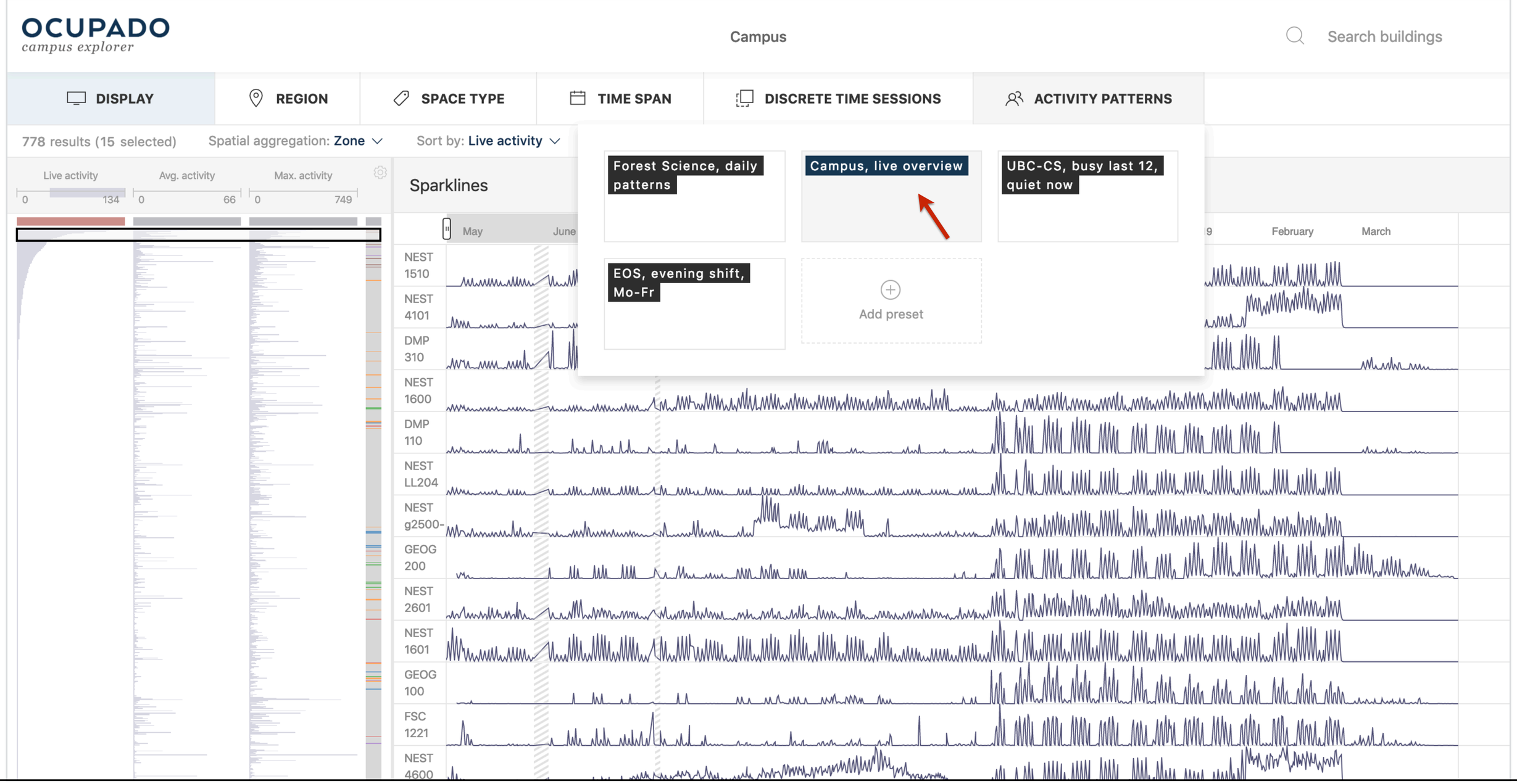
**Region Comparison Interface.** To investigate a specific classroom in the building, the analysts remove the two active queries and select the main floor in the query builder. An interactive floor plan is displayed that lets them pick a specific zone. The analysts send a second query by just changing the time frame to compare summer vs. winter usage. ZB-One:L*



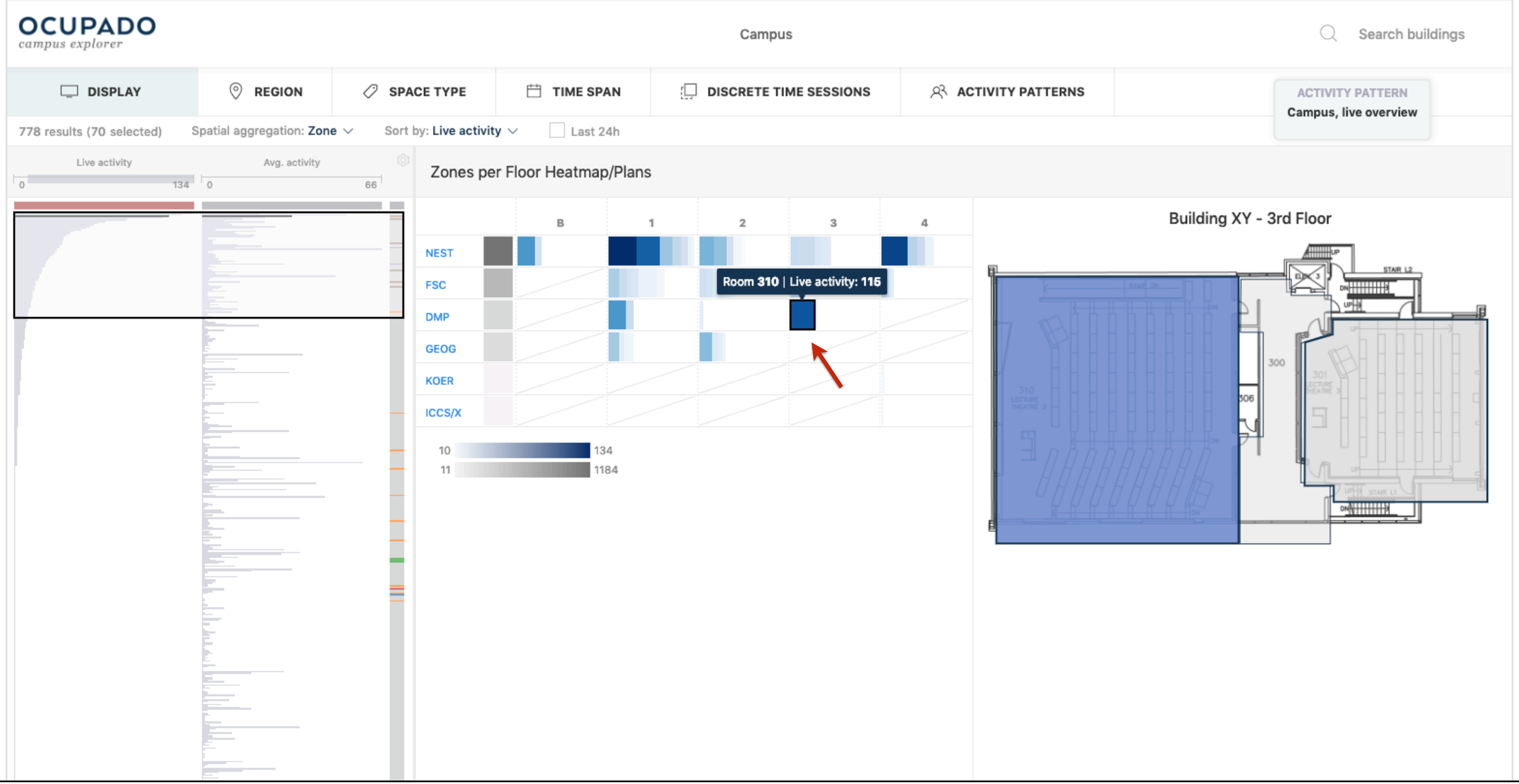




**Region Comparison Interface.** The two time series for summer and winter terms are visualized in multiple views. The room was used in the summer but the timeline also reveals two week-long gaps. The average activity on weekends is slightly higher during the summer than in the winter which is caused by a few outliers. ZB-One:L*

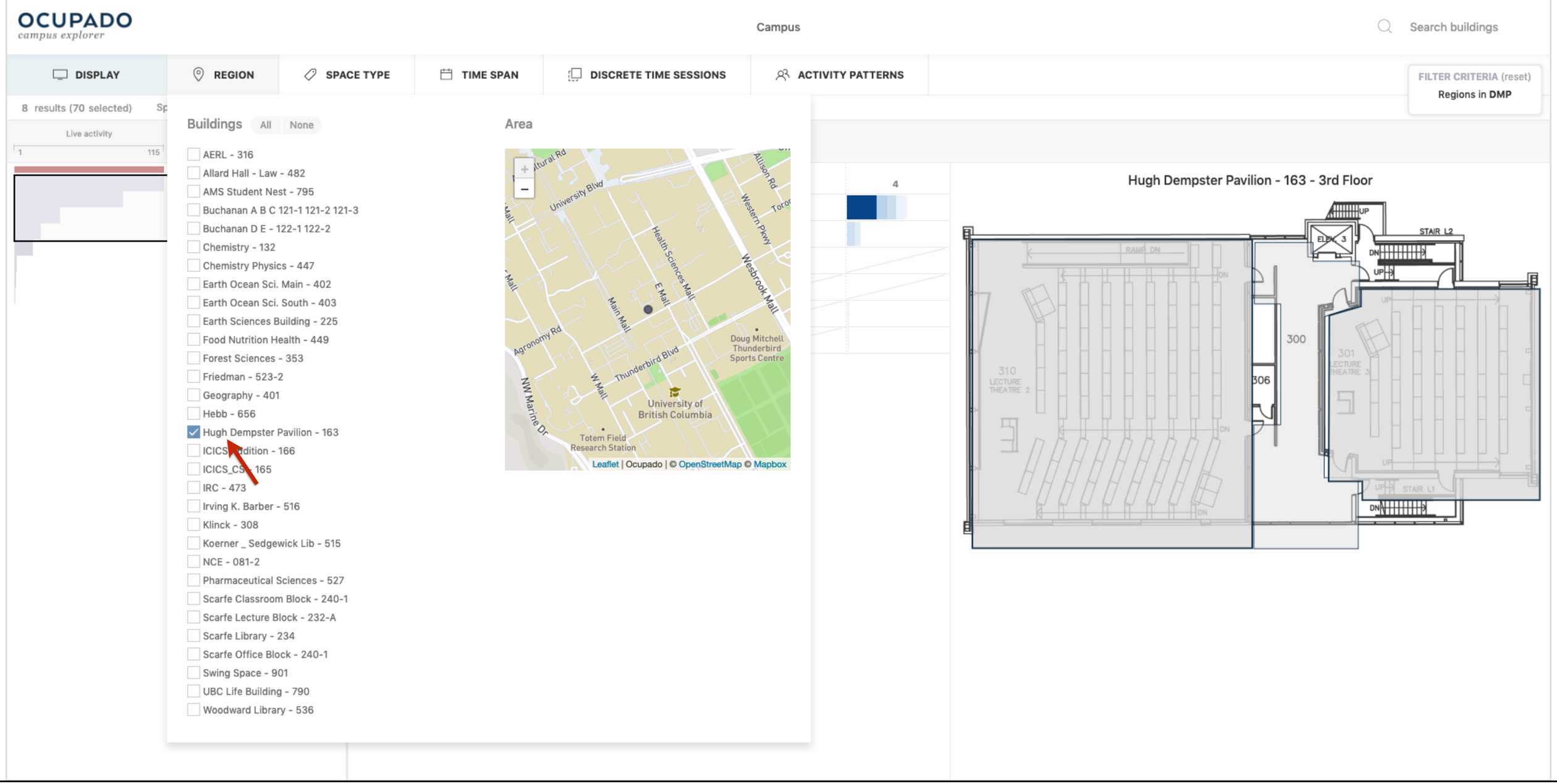
# 5.2 Analysis Scenario: **Campus-Wide Situational Awareness**



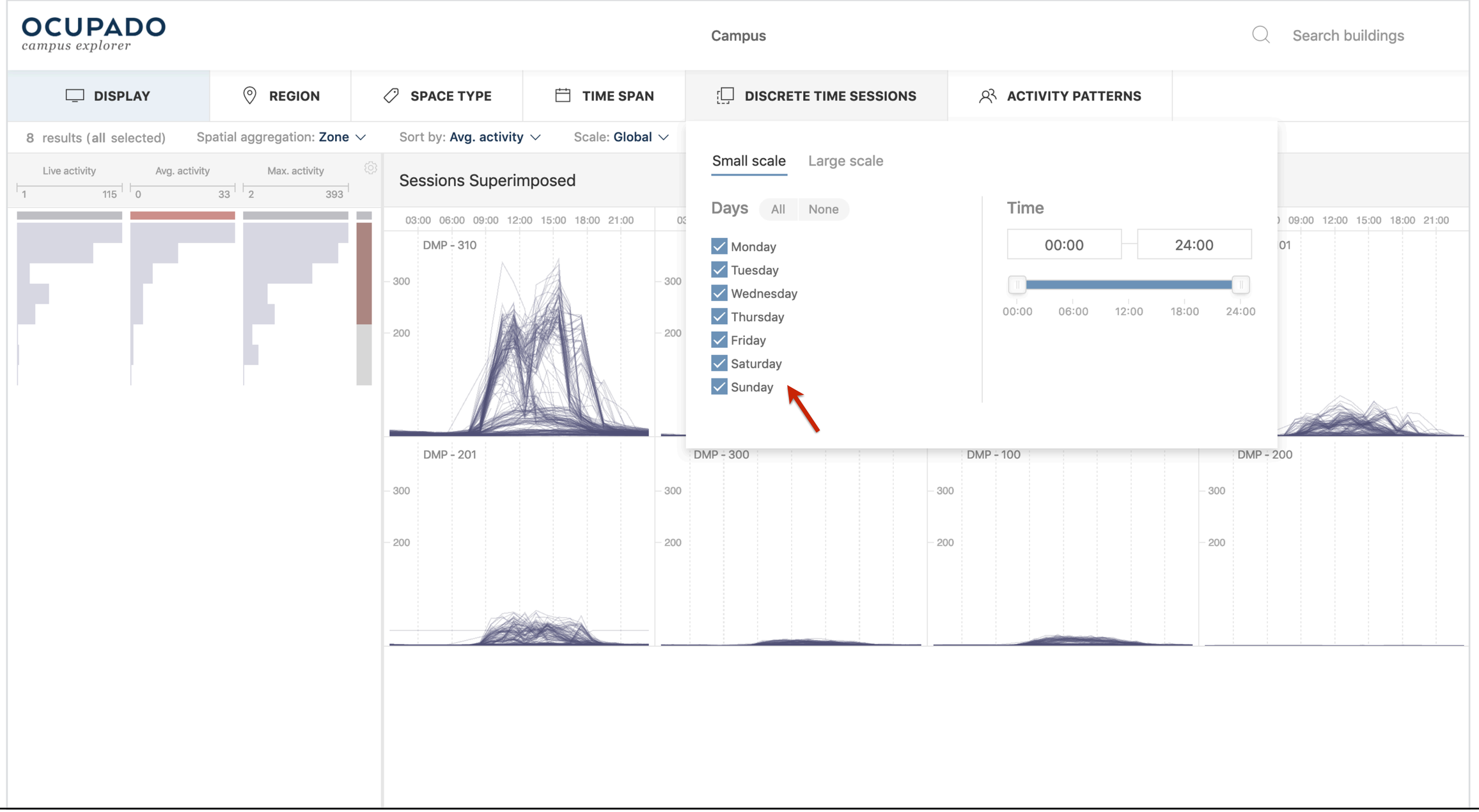

**Campus Explorer.** The analysts select the *Campus, live overview* activity pattern from the control panel. (Activity patterns provide single-click shortcuts for complex combinations of actions to simplify the sometimes-overwhelming interface)



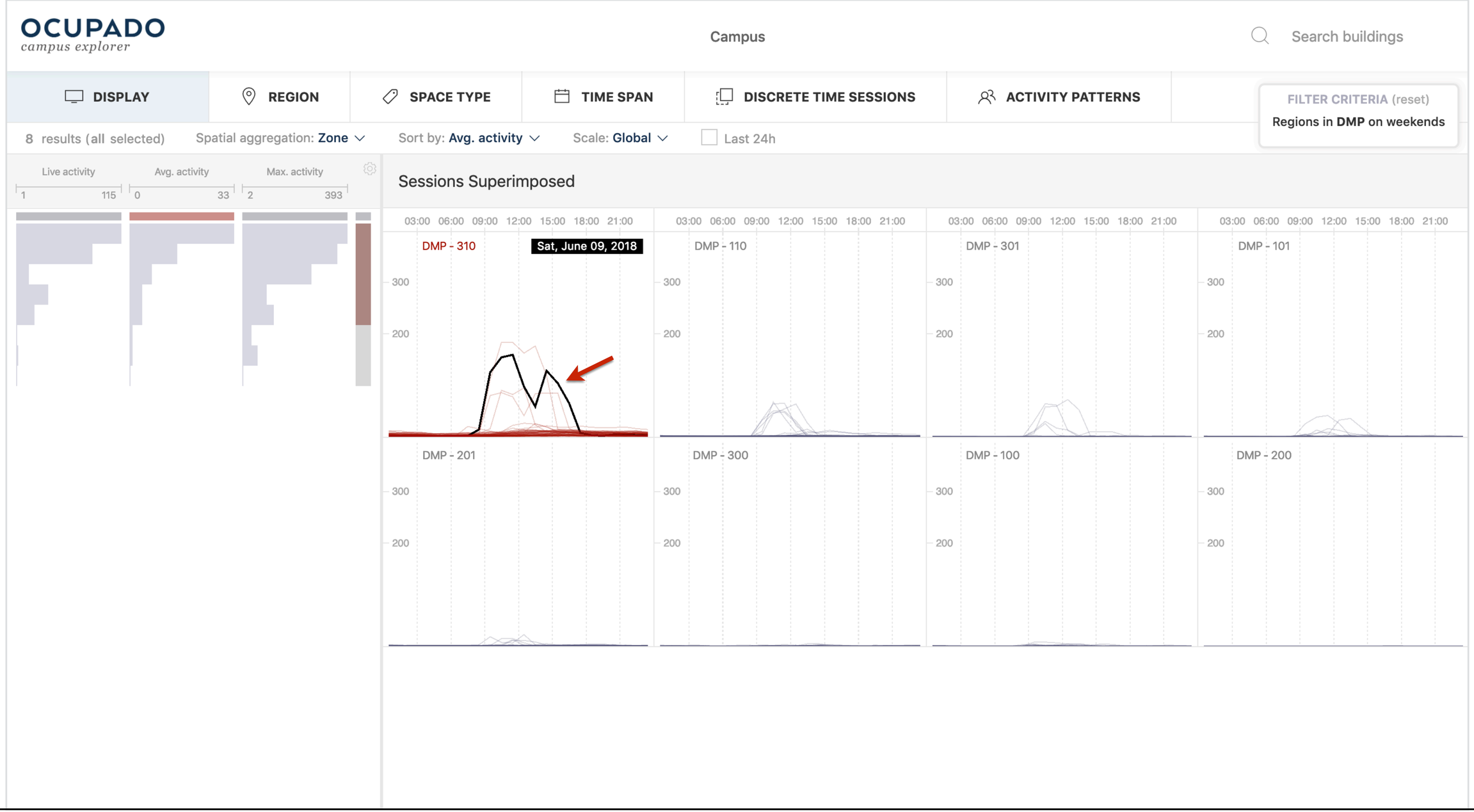

**Campus Explorer.** The interface automatically sorts zones based on *live activity* in descending order, selects the top 70, and visualizes them in a spatial heatmap ( ZC-Few:SI ). The analysts are running this query on the weekend, and are unsurprised to see high activity in *NEST*, a student union building. However, the high device counts in *DMP* are surprising in a building primarily used for lectures.




**Campus Explorer.** In the control panel, the analysts filter on DMP to exclude all other buildings.

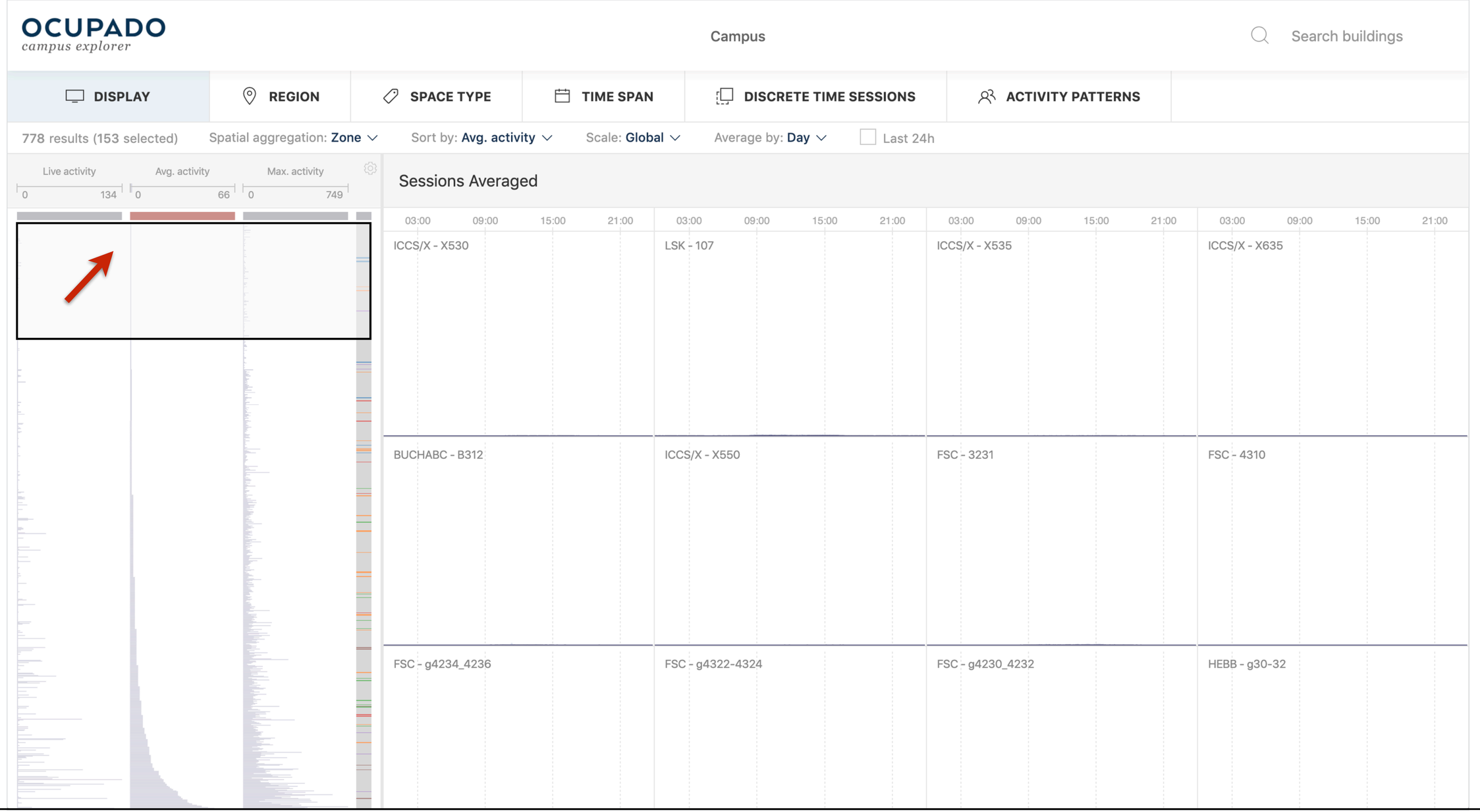



**Campus Explorer.** The analysts use the control panel to change the view to superimposed line charts. Since each line denotes one day, clear patterns are not discernible due to the long (8-month) recording period. They select only weekends with the discrete time sessions menu. ZB-Few:LI




**Campus Explorer.** The analysts see five outlier days stand out from the other near-zero lines; they have learned that occasional after-hours use does occur. ZB-Few:LI

# 5.3 Analysis Scenario: **Data Quality Control**




**Campus Explorer.** The data stripes can be used to rank zones based on average device count in order to locate constantly empty regions ( ZC-AII:LA ).