THE 21ST IEEE INTERNATIONAL SYMPOSIUM ON MIXED AND AUGMENTED REALITY
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University of South Australia

Australian Research Centre for Interactive and Virtual Environments

[wcl]

Augmented Scale Models:

Presenting Multivariate Data Around Physical Scale Models in Augmented Reality

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IEEE COMPUTER SOCIETY vgtc

Motivation

- Machines in shop floors generate large amount of abstract data.
- The current workflow lacks physical and spatial context.

Illustration of the shop floor. Credit: Birulik, CC BY-SA 4.0, via Wikimedia Commons

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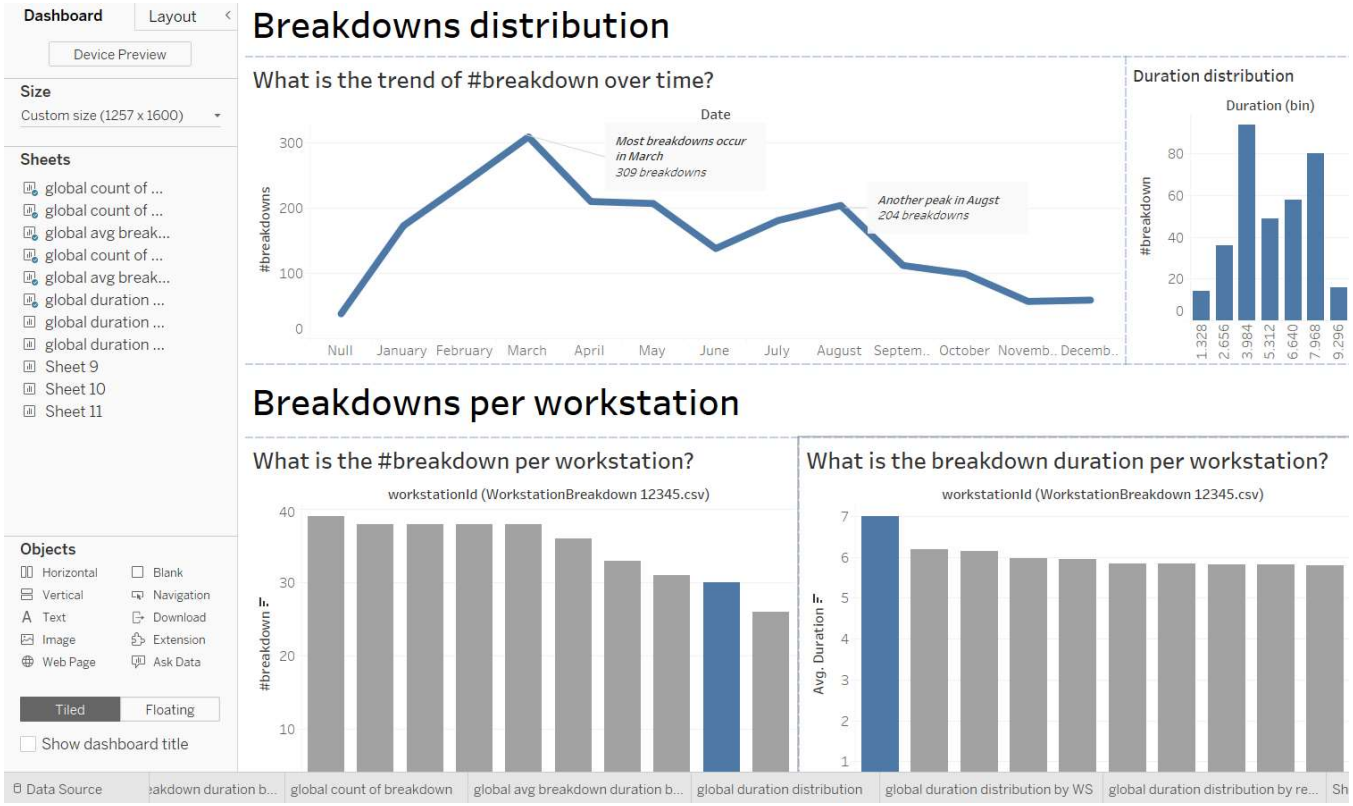
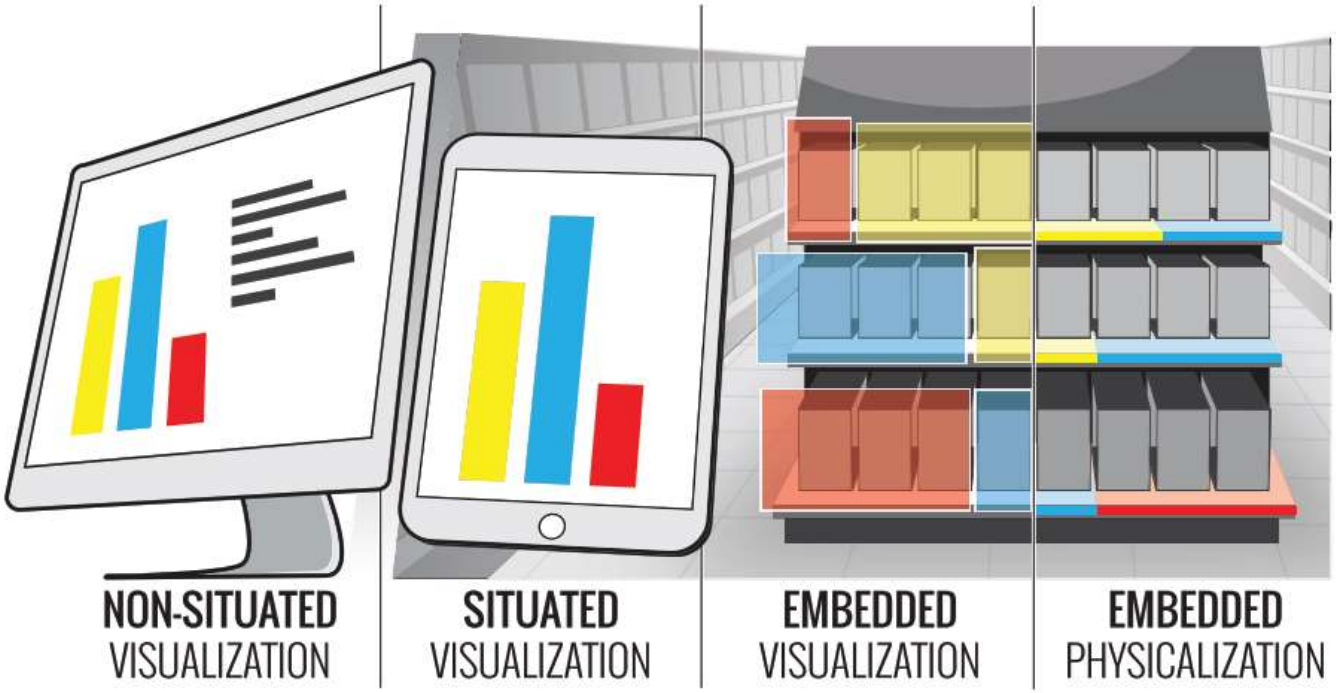


Illustration of the data analysis. Source: authors.

Related Work

- Embedded Data Representations, *Willett et al., 2016*

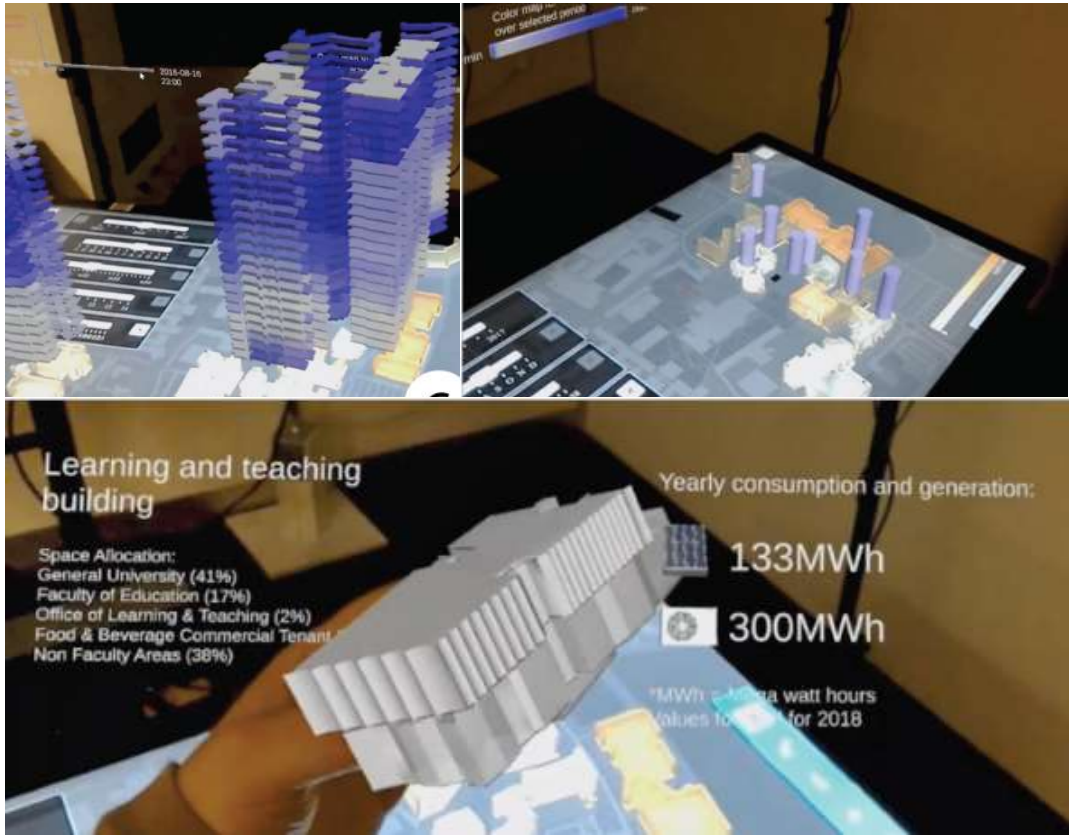


*Presenting data in the proximity of **physical referents***

Related Work

- Physical scale models + limited data attributes in AR

Uplift: A Tangible and Immersive Tabletop System for Casual Collaborative Visual Analytics
Ens et al., 2020



Our Work: Multivariate Data Representations

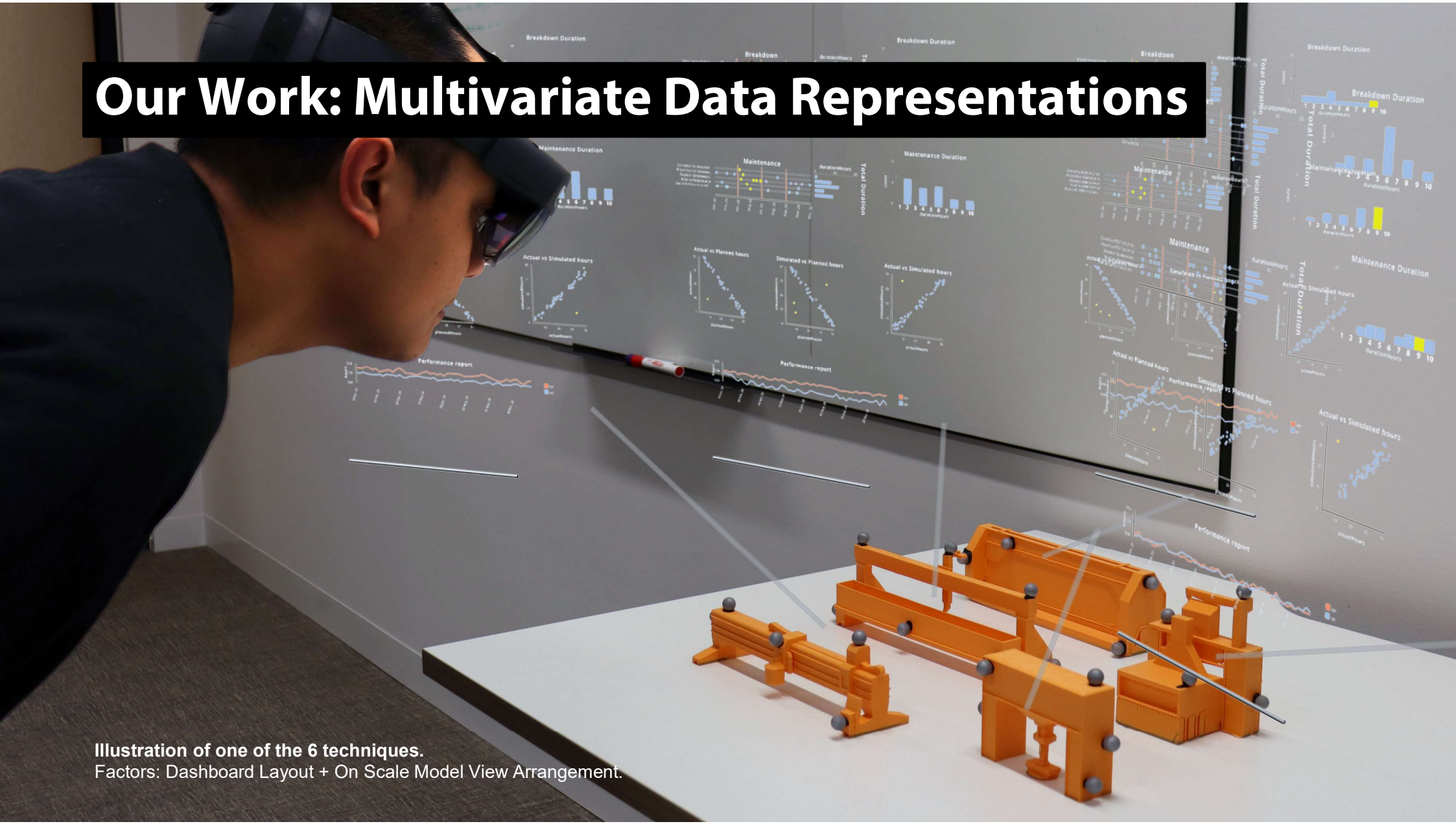


Illustration of one of the 6 techniques.
Factors: Dashboard Layout + On Scale Model View Arrangement.

Our contributions

- Augmented scale models: physical models + multivariate data visualisation.

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- Design considerations: charts layout, view arrangement.

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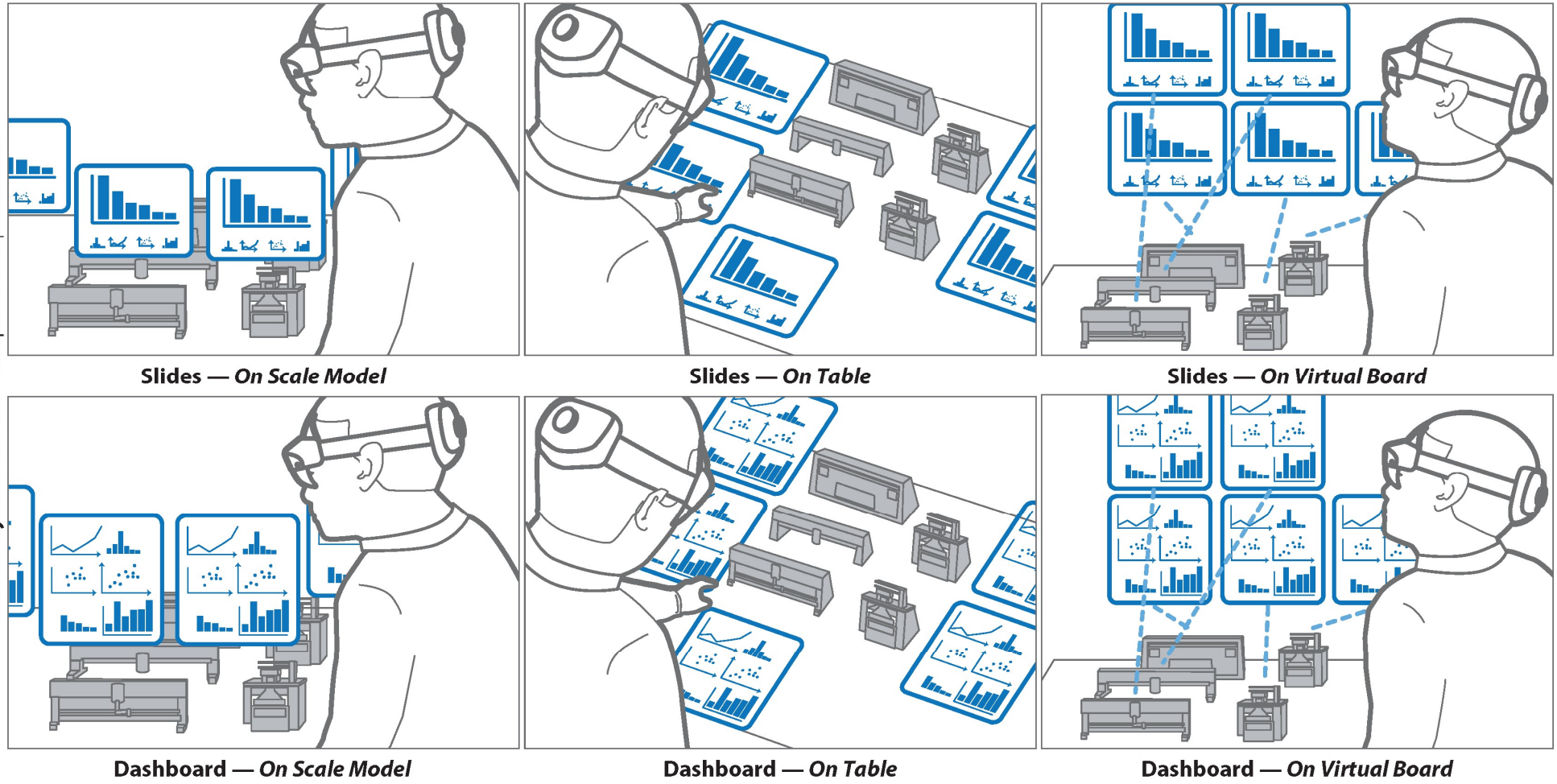
- Augmented scale models: physical models + multivariate data visualisation.
- Design considerations: charts layout, view arrangement.
- Empirical findings and design implications.

Considered Factors & Techniques

View Arrangement: How are chart views arranged around the scale models?

Charts Layout: How are multiple charts presented?



Slides — *On Scale Model*

Slides — *On Table*

Slides — *On Virtual Board*

Dashboard — *On Scale Model*

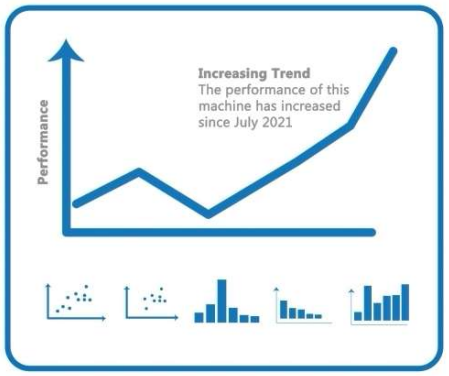
Dashboard — *On Table*

Dashboard — *On Virtual Board*

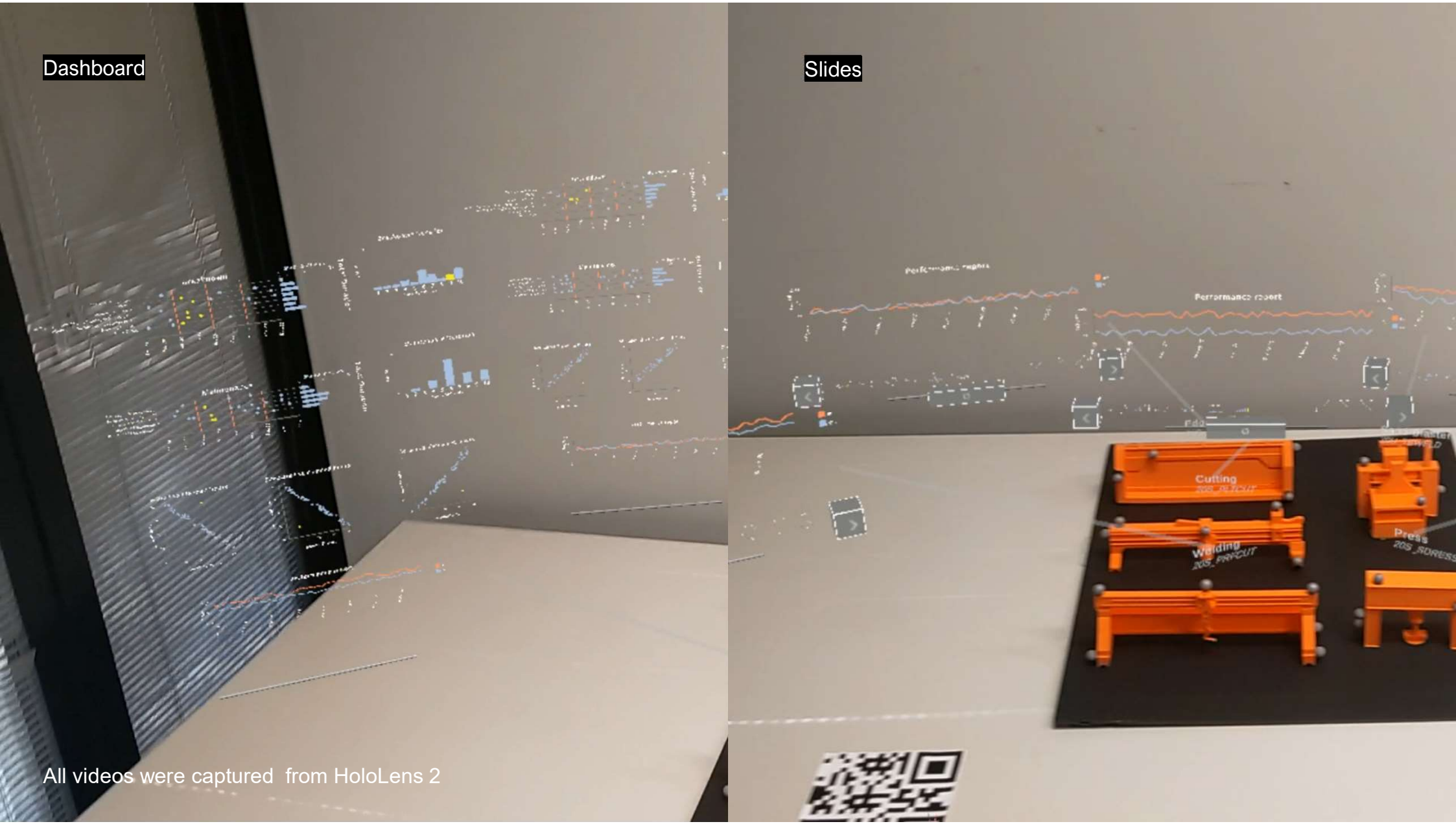
Considered Factors: Charts Layout

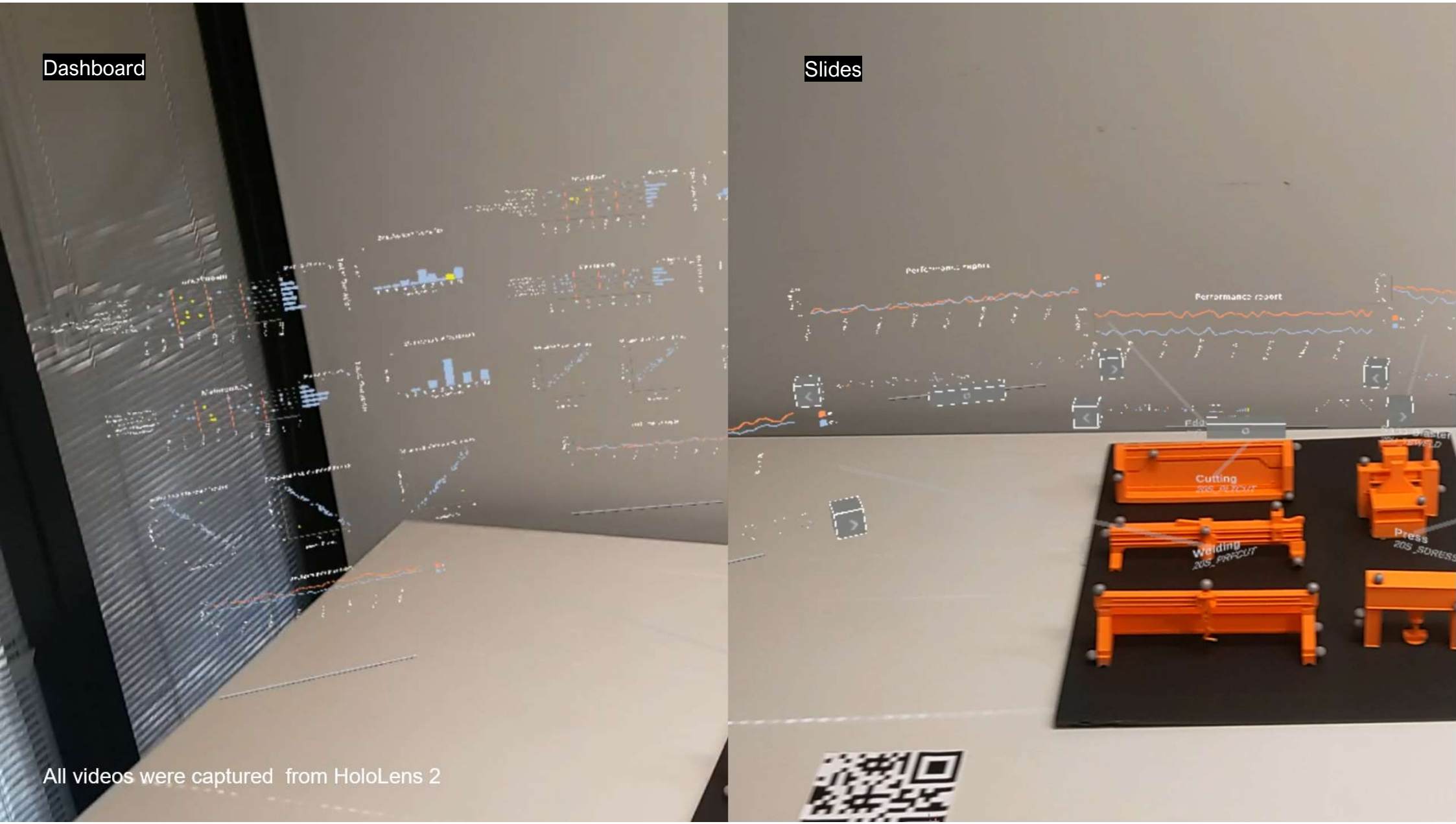
- How can we present multiple charts per scale model?

Dashboard



Slides


Dashboard
Slides
Performance report
Cutting
Welding
Press
All videos were captured from HoloLens 2


Dashboard
Slides
Performance report
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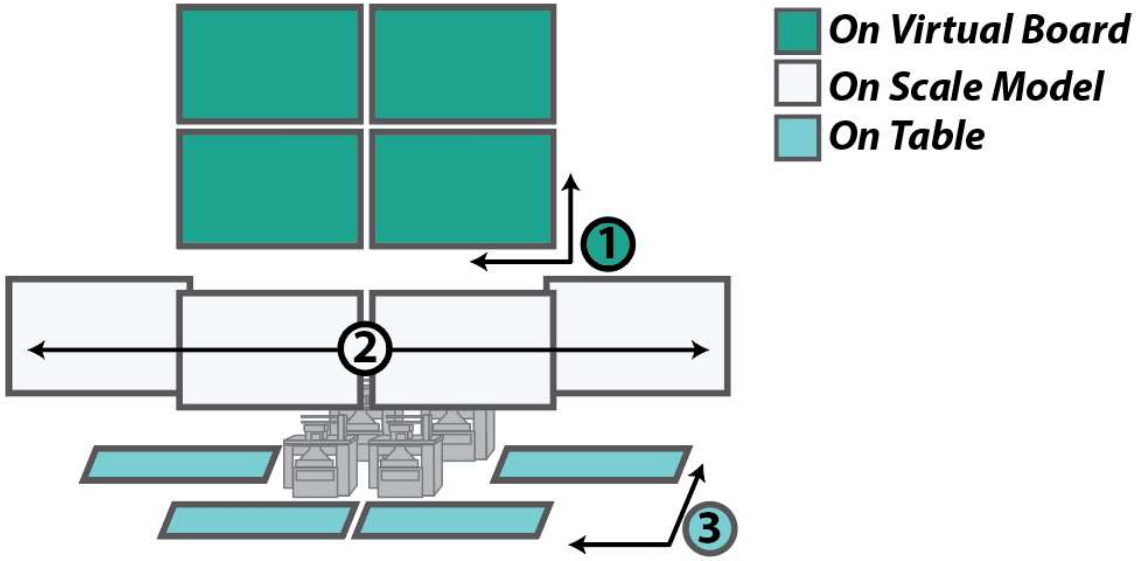
Welding
Press
All videos were captured from HoloLens 2

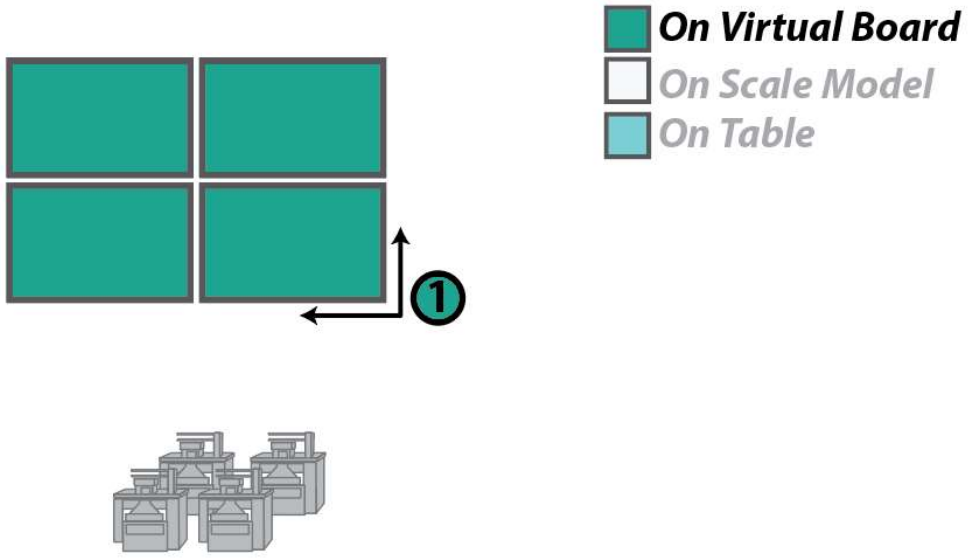
Considered Factors: View Arrangement

- How can we arrange multiple views around the scale models (with minimal occlusion)?

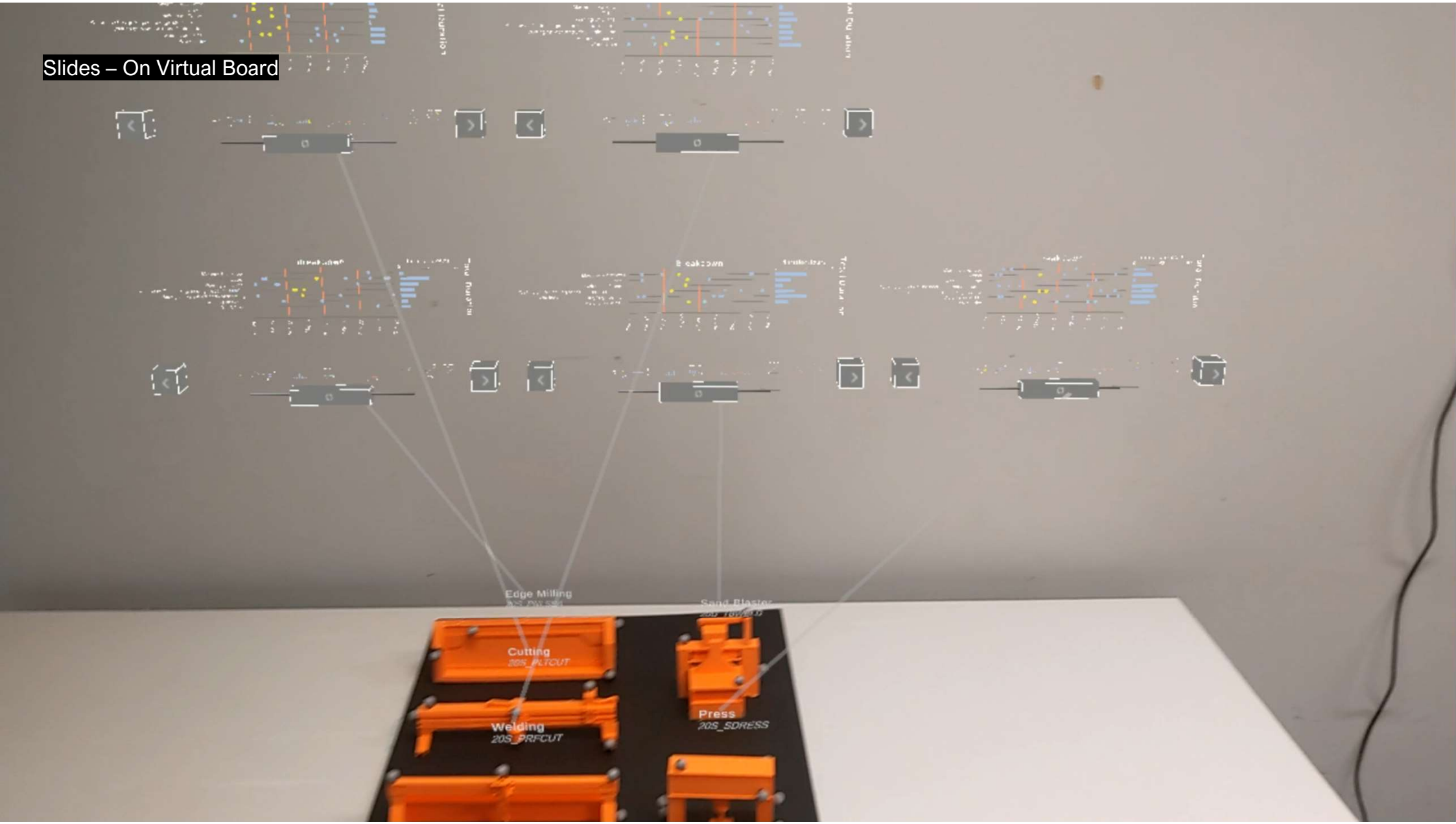


Considered Factors: View Arrangement

- On Virtual Board: orthogonal grid arrangement.

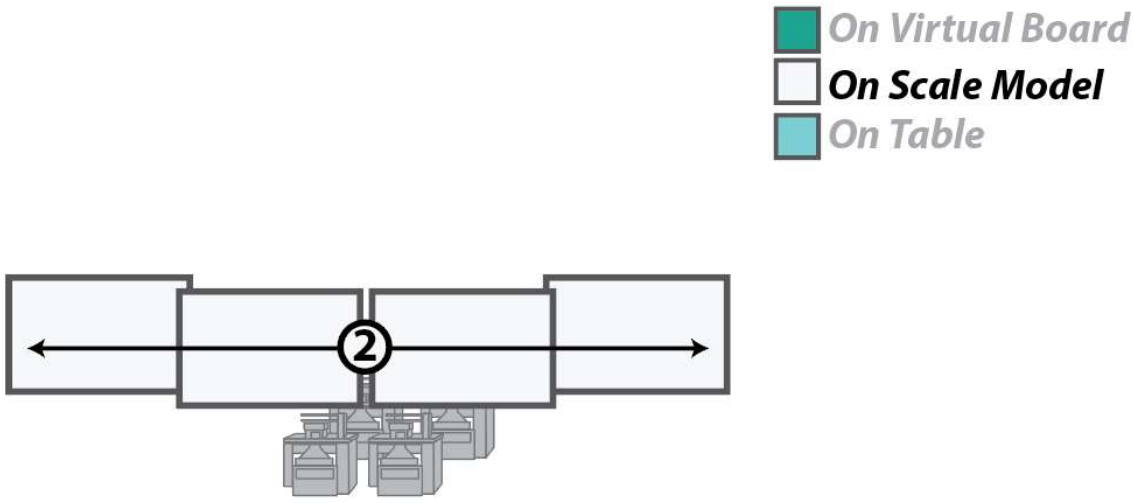


Dashboard – On Virtual Board

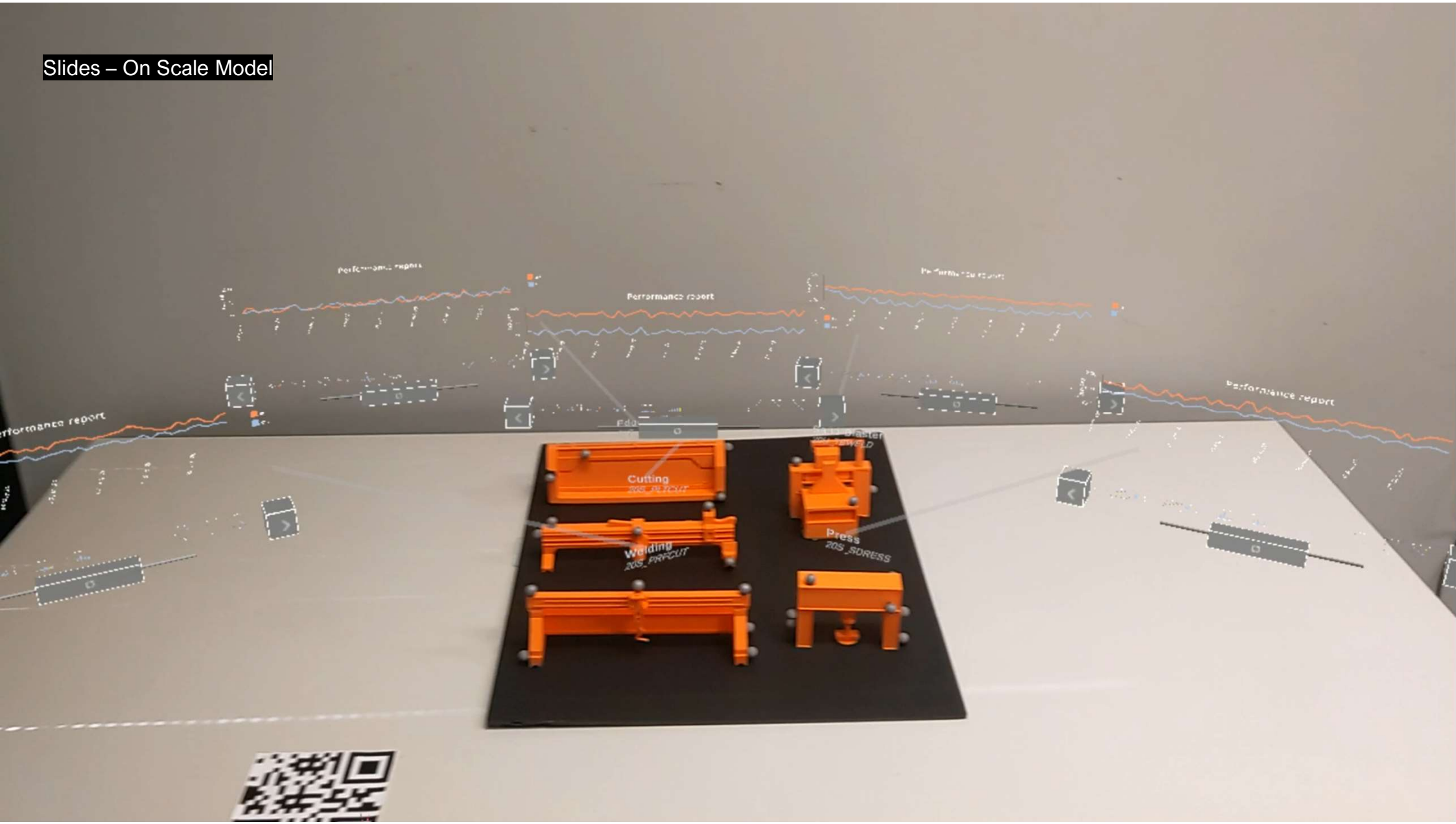

Slides – On Virtual Board
Edge Milling
Cutting
20S_PLTCUT
Welding
20S_PRFCUT
Press
20S_SDRESS

Considered Factors: View Arrangement

- On Scale Model: side-ways arrangement.

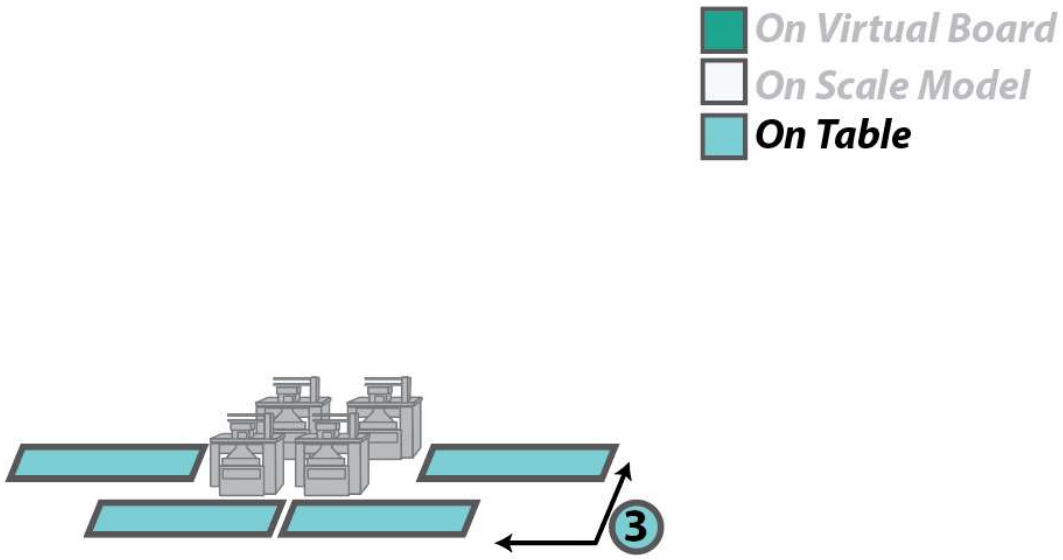


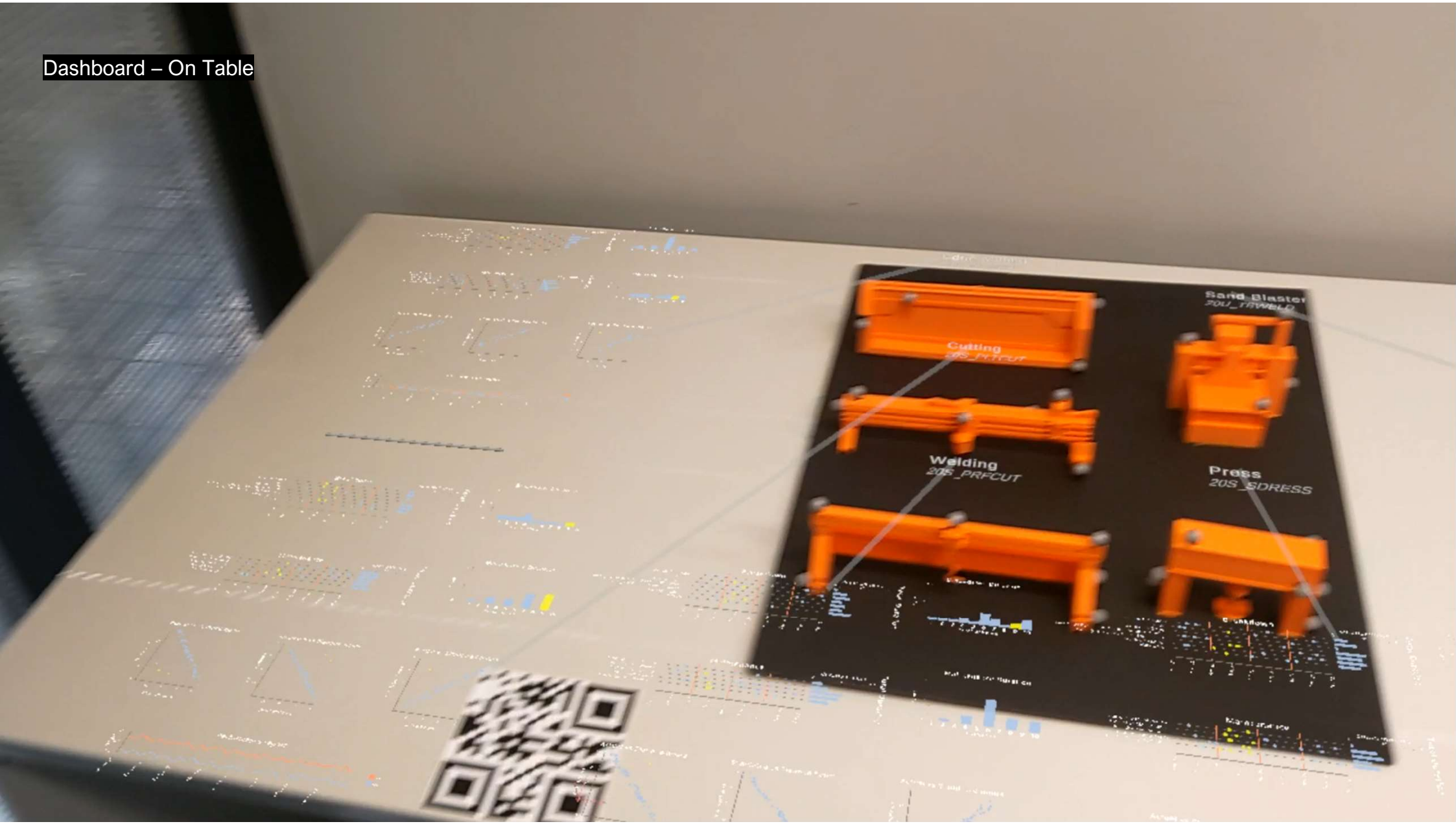

Dashboard – On Scale Model
Cutting
Welding
Press

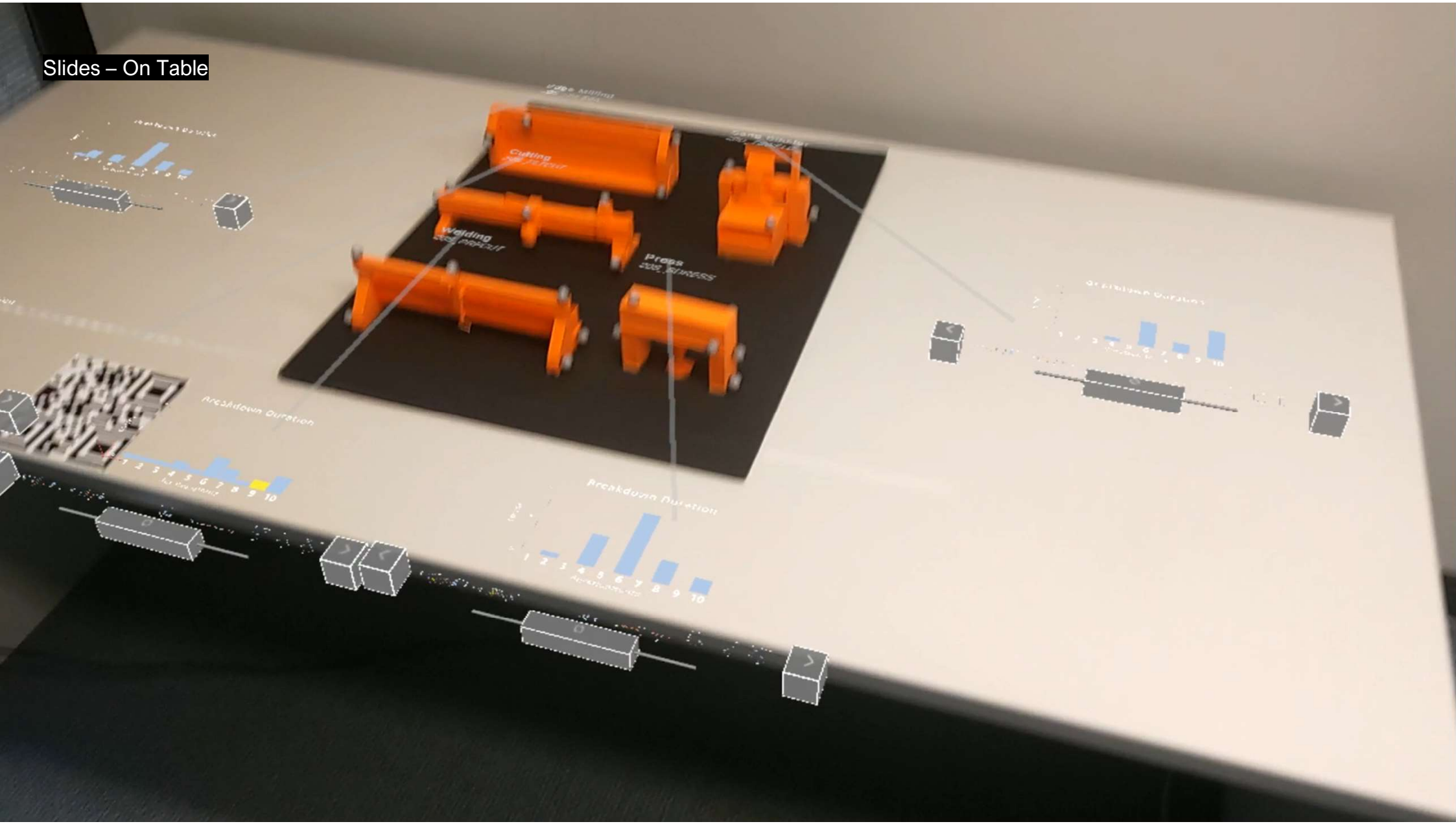

Slides – On Scale Model
Performance report
Performance report
Performance report
Performance report
Cutting
Welding
Press

Considered Factors: View Arrangement

- On Table: around scale models' boundary.




Dashboard – On Table
Cutting
Welding
20S_PRFCUT
Press
20S_SDRESS


Slides – On Table
Cutting
Welding
Press
Breakdown Duration
Breakdown Duration
Breakdown Duration

User Study

- Factors (2 x 3 x 3):
  - **Charts Layout** (Dashboard, Slides)
  - **View Arrangement** (On Virtual Board, On Scale Model, On Table)
  - **Visualisation Task** (3 types)
    - Single or multiple chart(s)?
    - Single or multiple model(s)?

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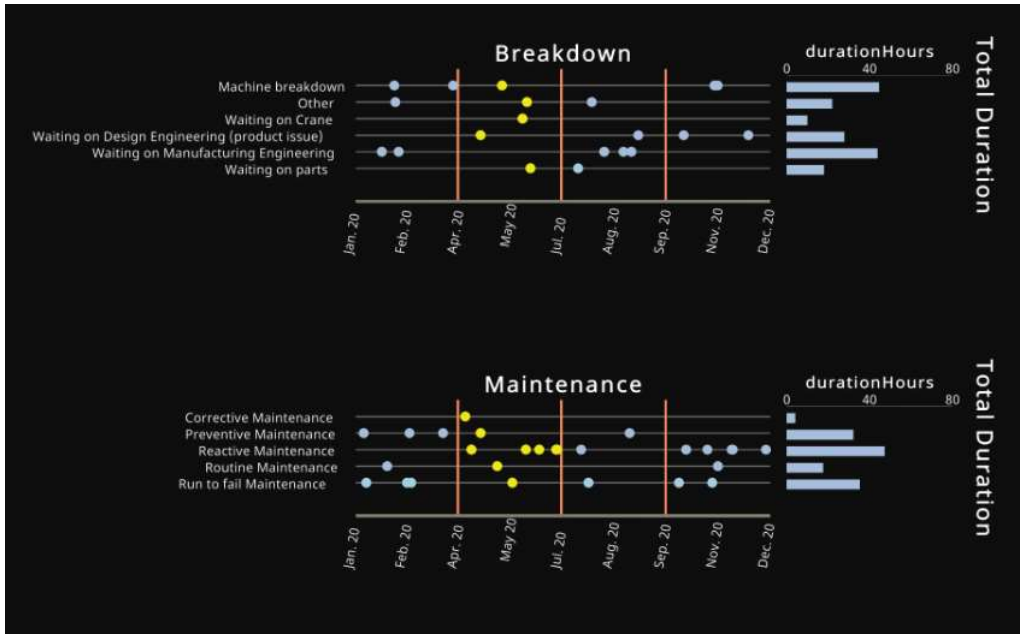
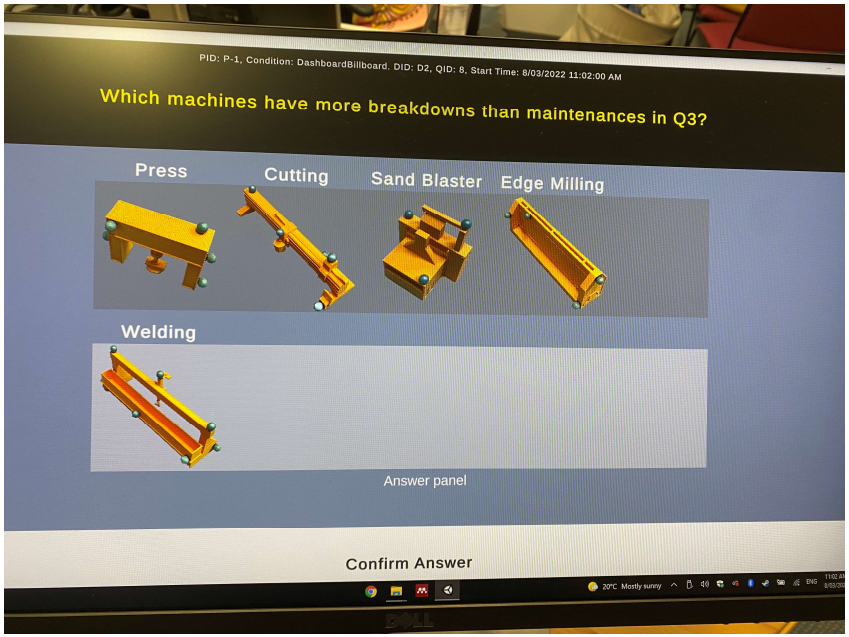
    - Single or multiple chart(s)?
    - Single or multiple model(s)?
- 5 models, 8 charts per model
- 18 participants, within subject
- Other considerations:
  - Global slide navigation (next and previous buttons)
  - Pre-attentive visual properties (highlighted bars and circles)

User Study

- Sample question: Which machines have more breakdowns than maintenances in Q2?



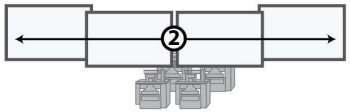
Charts to be compared (1 scale model)



User study interface

Key Findings (1/7)

- On Scale Model is the fastest, best on chart-scale model integration, and supports across scale model comparison well.



faster than

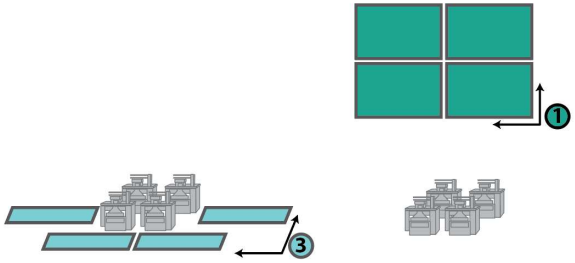


**Chart-model integration and comparing chart across models were measured using Likert's scale questionnaires (1-5)*

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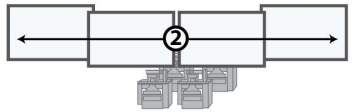

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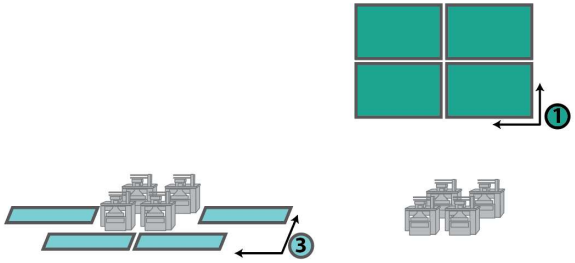
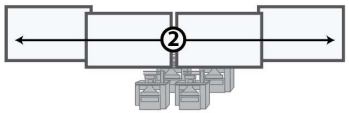
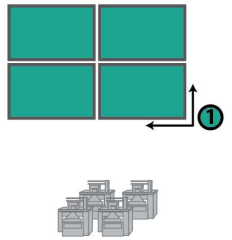




better chart-model integration than



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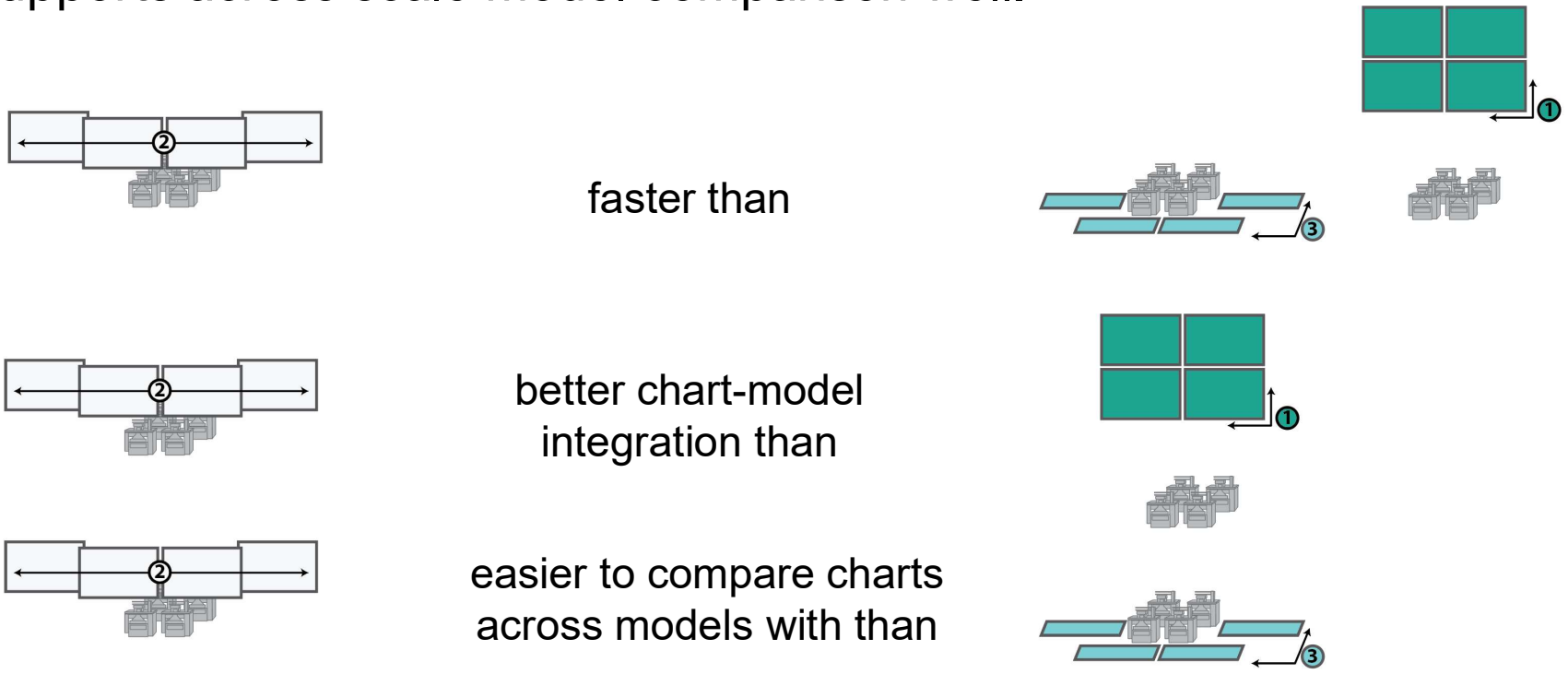
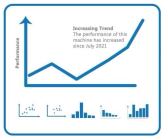


**Chart-model integration and comparing chart across models were measured using Likert's scale questionnaires (1-5)*

Key Findings (2/7)

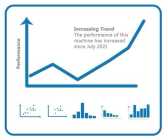
- Charts Layout impacts speed in complex tasks.

Simple tasks
single chart / model, multiple models



has the same performance as

Complex tasks
multiple charts, multiple models



slower than

Key Findings (2/7)

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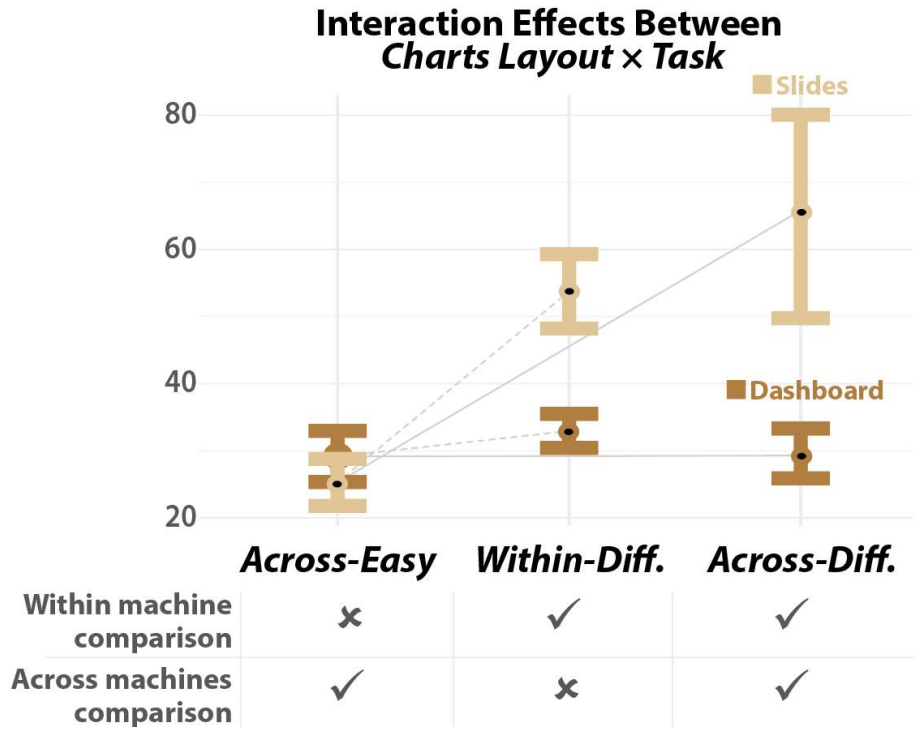
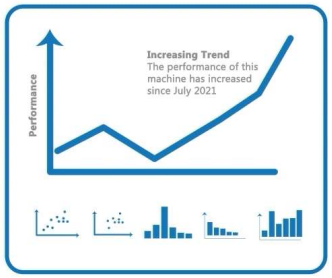


Key Findings (3/7)

- Subjective measures in favour of Dashboard.

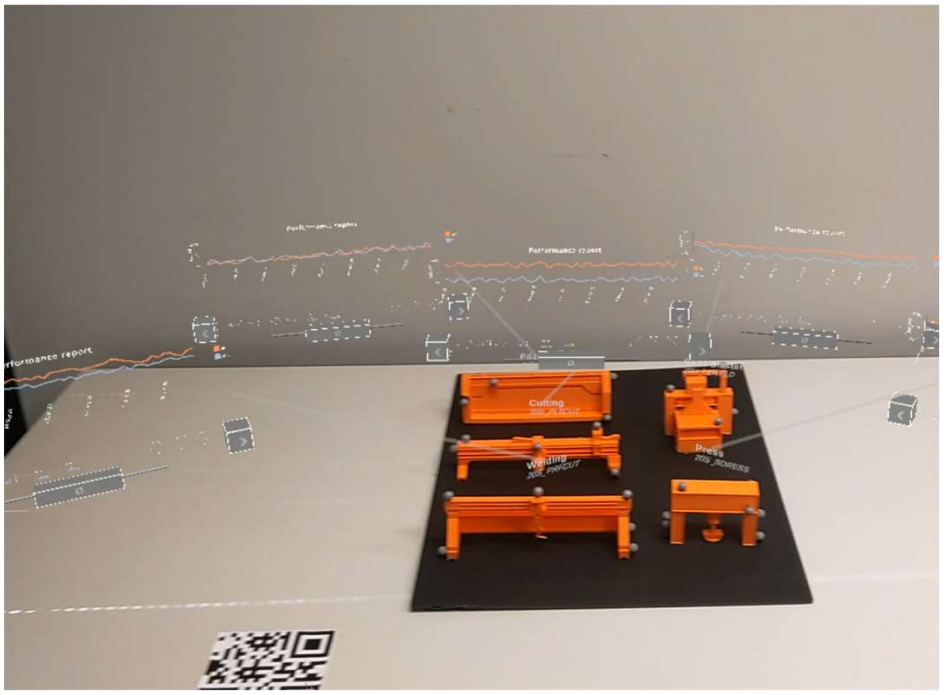


less **preferred**
higher **mental effort**
higher **physical exertion**
less **confidence** score
less **ease-of-use** score
less support for **comparison tasks**

**All factors were measured using questionnaires: mental effort (PAAS), physical exertion (Borg's RPE), the rest (Likert's scale)*

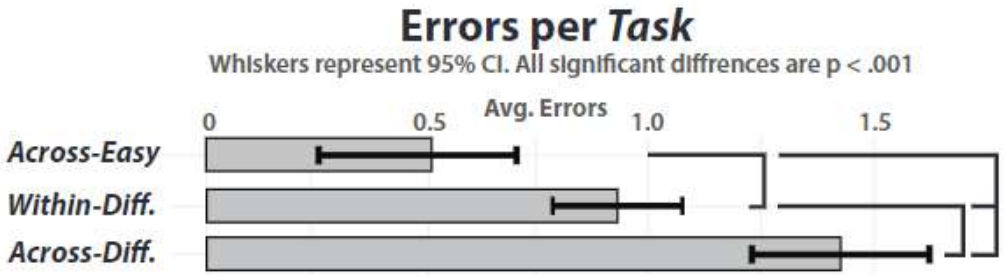
Key Findings (4/7)

- Reading small charts on Dashboard is a fair compromise over the navigation complexity of Slides layout.
  - No significant differences in Ease of Reading measure (Likert scale, 1 – 5)



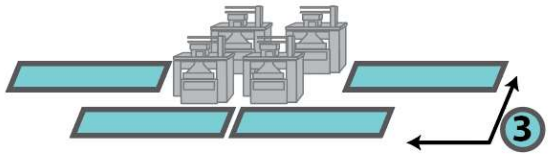
Key Findings (5/7)

- Charts Layout and View Arrangement have no effect on errors despite increasingly complex tasks.



Key Findings (6/7)

- On Table and On Virtual Board reveal a trade-off between the chart's comparison across models and the chart-scale model integration.



Better chart-model integration,
requires walking (view comparison)

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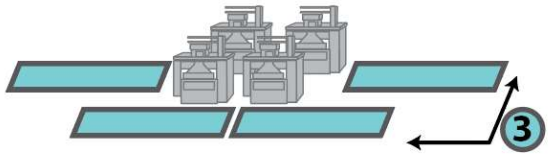

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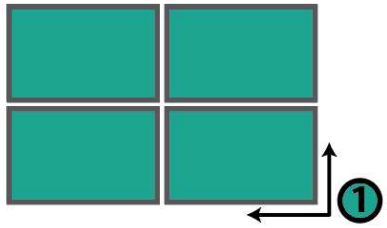

Better views comparison,
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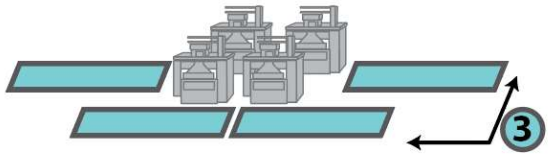

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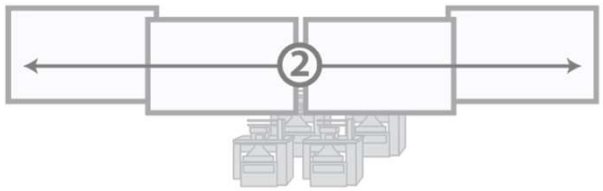
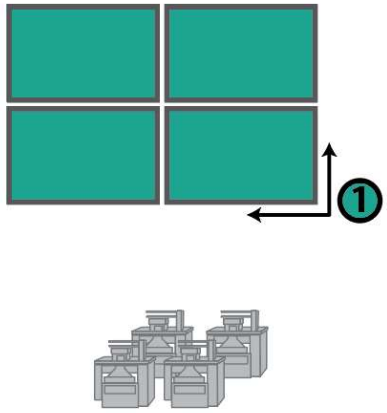


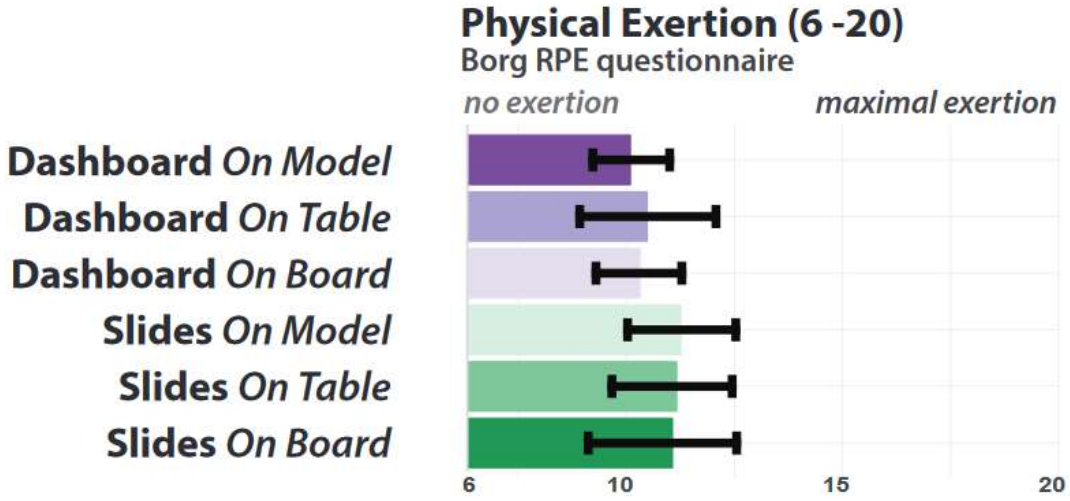
Compromise



Better views comparison,
lower chart-model integration

Key Findings (7/7)

- Data analysis with augmented scale models causes very light to light physical exertion.
  - Measured using Borg's RPE (subjective measure, range 6 – 20)



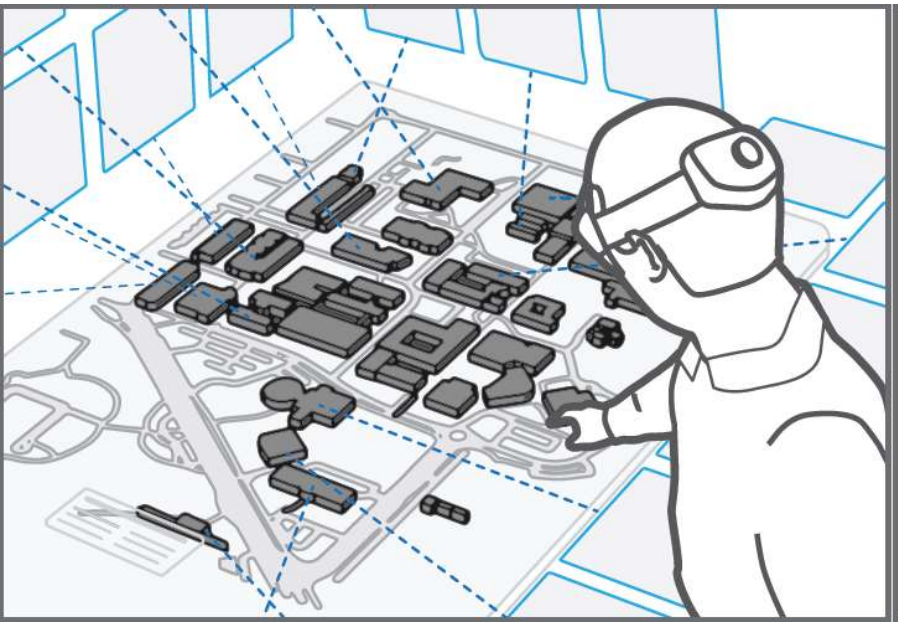
Future work

Study different tasks

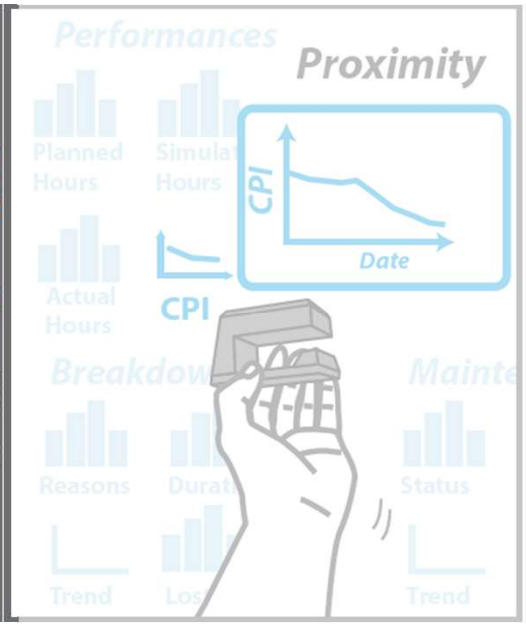
- **Known data pattern, unknown model**:
  what is the trend of attribute x of model 1, 2, and 3?
- **Purely visual exploration**:
  unknown data pattern, unknown model

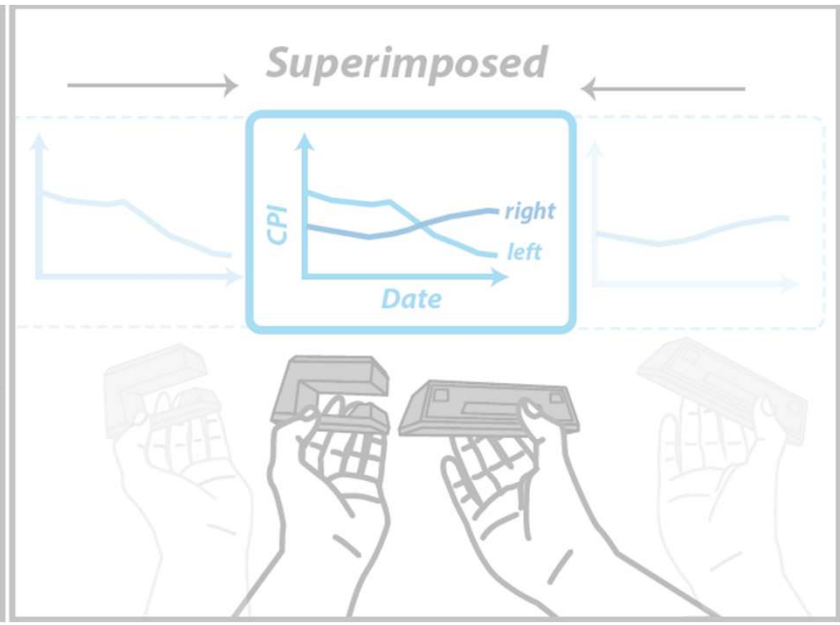
Future work

Study different tasks and …



More complex scenarios

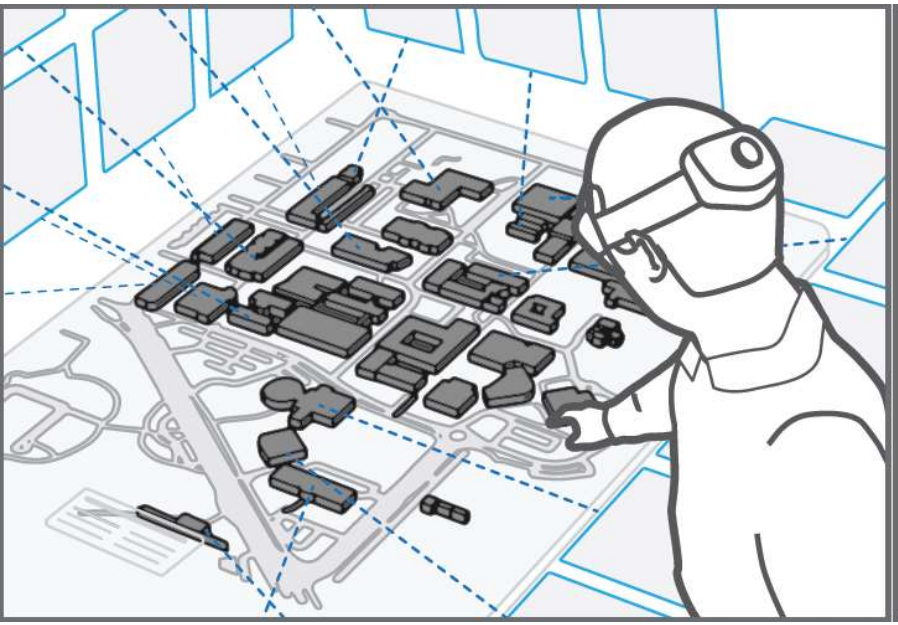




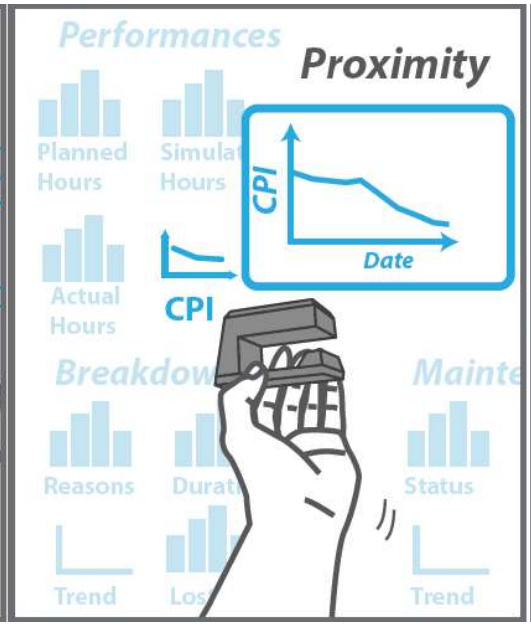
More tangible-driven user interactions

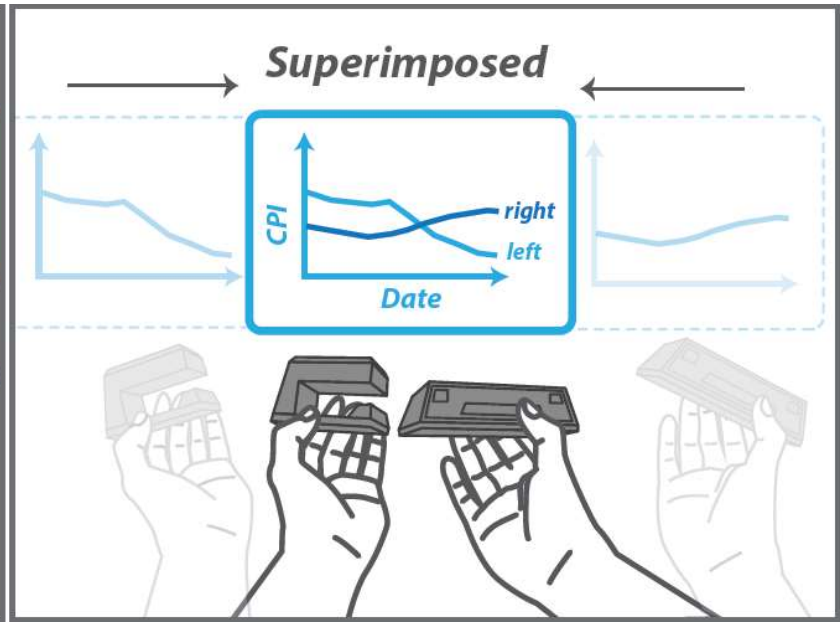
Future work

Study different tasks and …



More complex scenarios





More tangible-driven user interactions

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