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Cartographic Visualization for Indoor Semantic Wayfinding

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Master Thesis - Final Presentation

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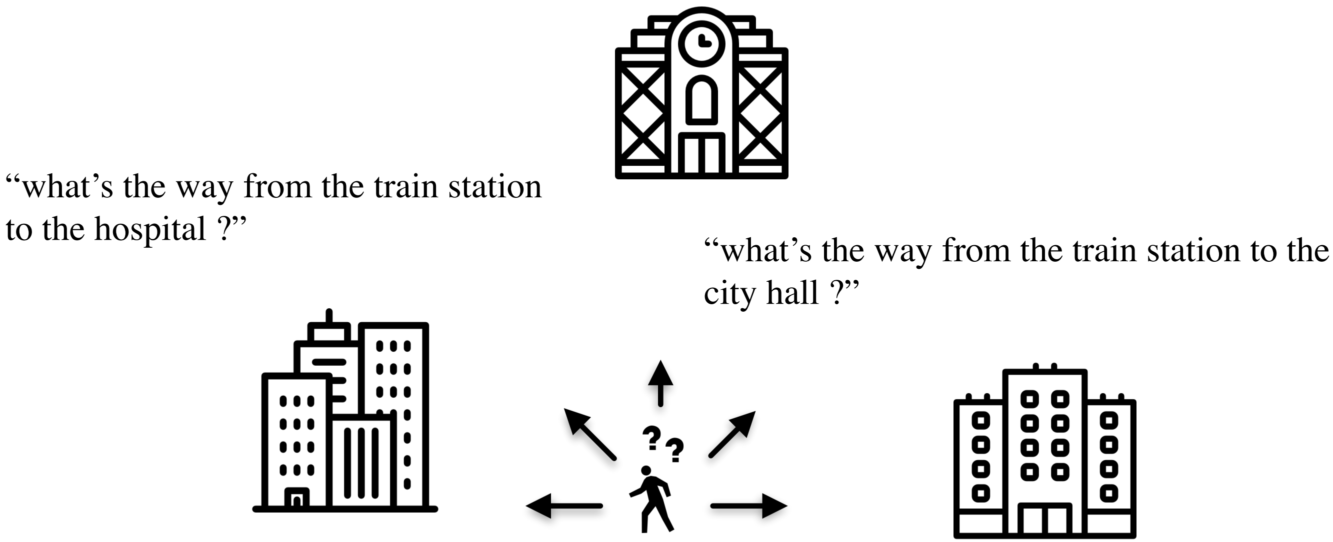
Overview

- Motivation
- Objective
- Indoor Landmark Navigation Model (ILNM)
- Concept implementation
- Data analysis
- Conclusion
- Future work

Motivation

Motivation

- Navigation assistance aids — major part of our everyday life
- Often, people encounter navigation problems when visiting a new place



Motivation

- People tend to lose orientation a lot easier within complex buildings (e.g universities, hospitals)
- Efficient navigational performance using unambiguous routing instructions
- Including **landmarks** to routing instructions can improve navigational performance

Objective

Objective

- Investigating the feasibility of the Indoor Landmark Navigation Model (ILNM) proposed by (Fellner et al., 2017)
  - Combining ILNM with indoor route maps
  - Wayfinding experiment with human participants

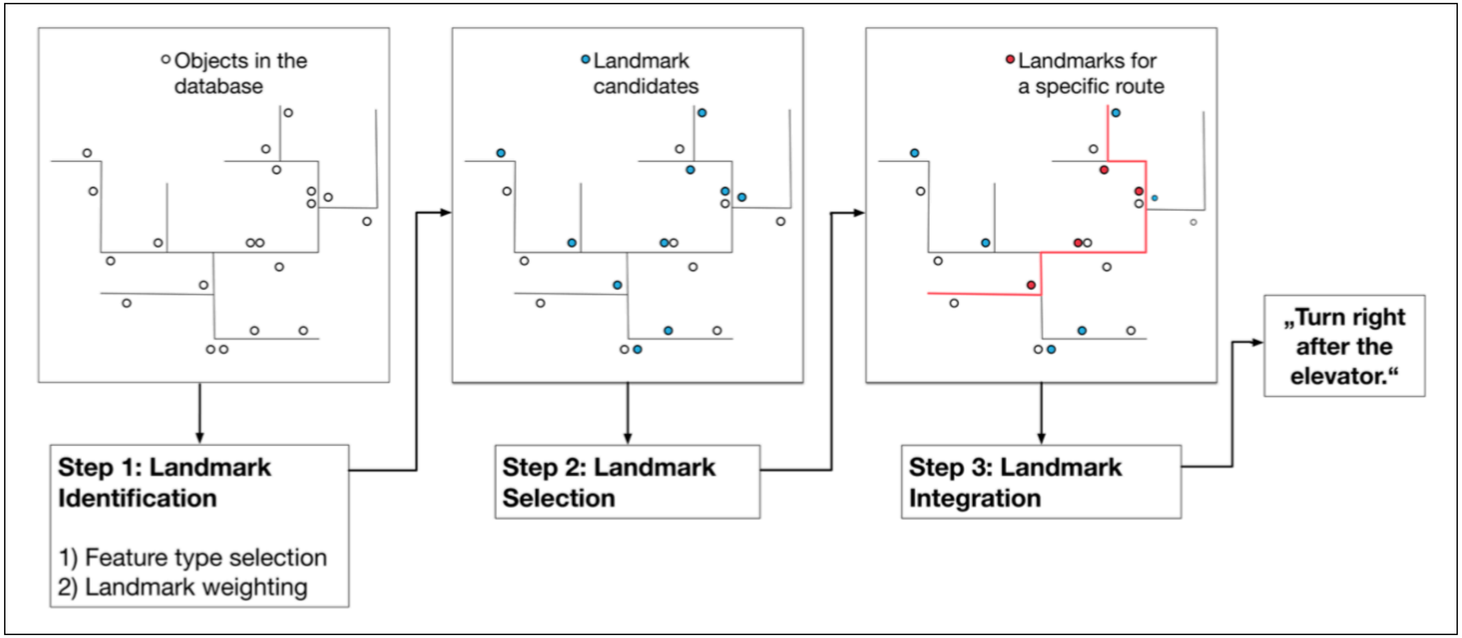
- Generate and evaluate two different landmark cartographic visualization approaches

Indoor Landmark Navigation Model (ILNM)

ILNM Algorithm

- Method for generating landmark-based route instructions for indoor navigation

Overview of the indoor landmark navigation model (ILNM)



(Fellner et.al., 2017)

ILNM Algorithm

- Step 1: **Landmark identification**
  - Identify categories of indoor spatial features that may be basically suitable as landmarks (based on recognizability and availability)
  - Scoring the suitability of each feature category as landmarks (semantic, visual and structural characteristics)

ILNM Algorithm

- Step 2: **Landmark selection**
  - Categorization of candidate landmarks that lie along the path route based on their location:
    - In-leg landmarks
    - Crossed landmarks
    - Landmarks at DPs (decision points)
  - Increase or decrease the weight of each landmark based on the category they belong

ILNM Algorithm

- Step 3: **Landmark integration**
  - The set of selected landmarks for DPs and route legs of a specific route will be integrated to generate landmark-based instructions for this route
  - Based on the characteristics of indoor route we adjust the routing instruction (e.g "*use the stairs to go to the D floor*")

Concept implementation

Concept implementation

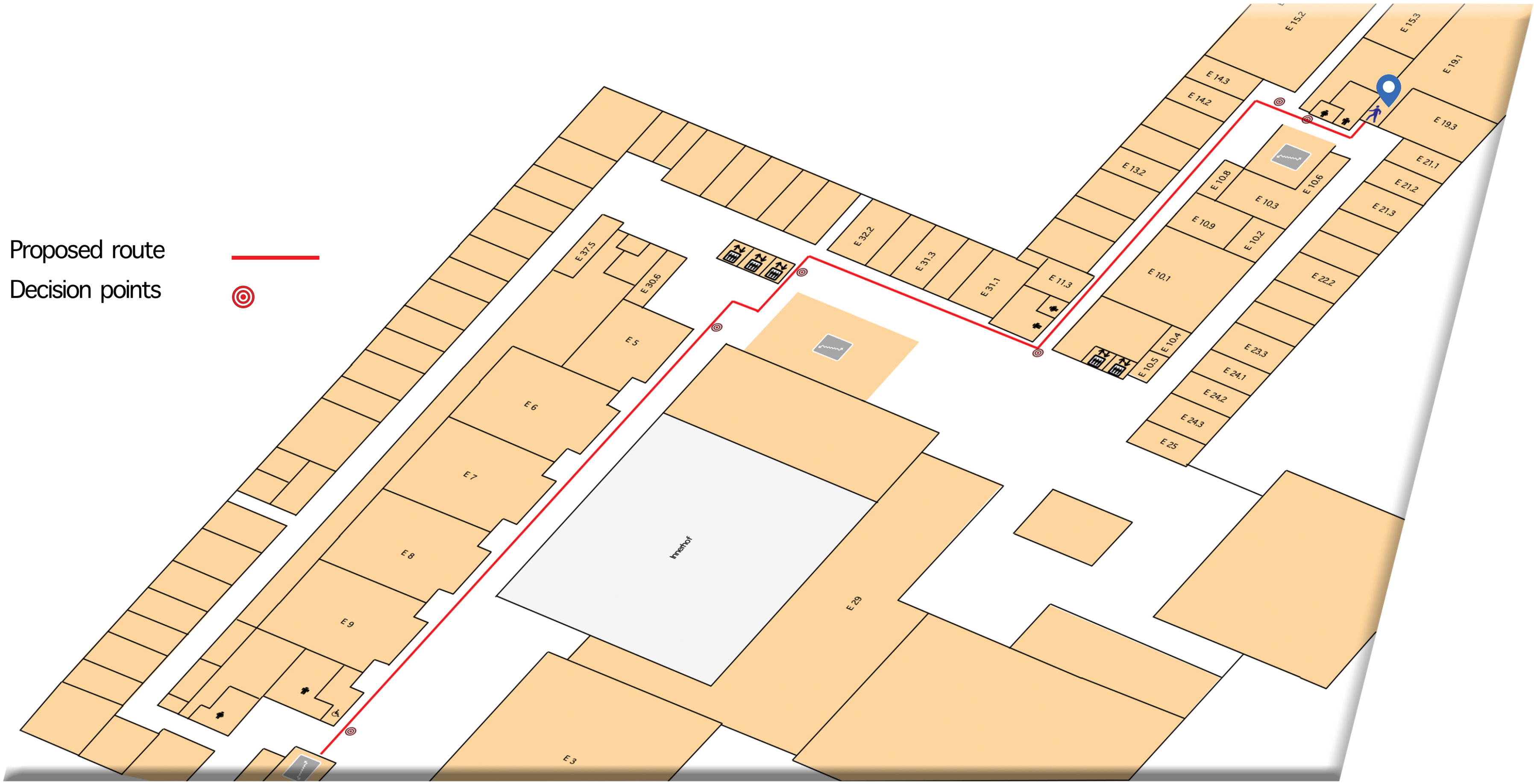
- Conduct of a wayfinding experiment
  - Applying ILNM on a certain test area
  - 3 different cartographic visualization scenarios
  - Visualize landmarks based on two design approaches
  - Development of 3 custom made android routing applications

Route selection

ETH Hönggerberg, HIL Building, **Room E 19.1**

Proposed route

Decision points



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Route selection

ETH Hönggerberg, HIL Building, **Room D 55.2**

Proposed route

Decision points

Landmark identification

"Candidate Landmarks"	
1. Elevator	9. Lockers
2. Toilet	10. Uncategorised Room
3. Door	11. Organic waste can
4. Scanner/printer	12. Closets
5. Stairs	13. Meeting Room
6. Auditorium	14. Trash and Recycle Can
7. Seminar Room	15. Notice Board
8. PC Room	

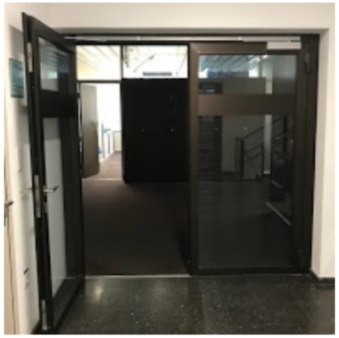
Categories of indoor spatial features that may potentially serve as landmarks

Landmark weighting / selection

- A group of experts was asked to give 5-point-liker with respect to the following two dimensions:
  - how **suitable** a typical instance of this category is as a landmark (from “Ideal” to “Never suitable”)
  - how **likely** it is that a particular instance of this category is typical (from “All typical” to “Few”).

Landmark weighting / selection

- Questionnaire (google forms)
  - 7 participants
    - 4 men and 3 women
    - employees and students



Door (typicality)

	Few	Some	Many	Most	All
Physical size	○	○	○	○	○
Prominence	○	○	○	○	○
Difference from surroundings	○	○	○	○	○
Availability of a unique label	○	○	○	○	○
Ubiquity and familiarity	○	○	○	○	○
Length of description	○	○	○	○	○
Spatial extents	○	○	○	○	○
Permanence	○	○	○	○	○

Door (suitability)

	Never suitable	Somewhat suitable	Suitable	Highly suitable	Ideal
Physical size	○	○	○	○	○
Prominence	○	○	○	○	○
Difference from surroundings	○	○	○	○	○
Availability of a unique label	○	○	○	○	○
Ubiquity and familiarity	○	○	○	○	○
Length of description	○	○	○	○	○
Spatial extents	○	○	○	○	○
Permanence	○	○	○	○	○

Landmark weighting / selection

Example ratings for the feature category "Elevator"

	SUITABILITY	TYPICALITY
Physical size	Ideal	All
Prominence	Highly suitable	Most
Difference from surroundings	Highly suitable	Most
Availability of a unique label	Never suitable	All
Ubiquity and familiarity	Ideal	All
Length of description	Ideal	All
Spatial extents	Highly suitable	Most
Permanence	Ideal	All

Landmark scoring system based on spatial feature categories

Suitability	Typicality				
	All	Most	Many	Some	Few
Ideal	8	4	2	1	0
Highly suitable	4	4	2	1	0
Suitable	2	2	2	1	0
Somewhere suitable	1	1	1	1	0
Never suitable	0	0	0	0	0

(Duckham et.al., 2010)

Overall score: 8+4+4+0+8+8+4+8 = **44**

Landmark weighting / selection

Python script for scoring the suitability of spatial features

```
# ratings in terms of suitability
suitNeverSuitable = 1
suitSomewhatSuitable = 2
suitSuitable = 3
suitHighSuitable = 45

suitIdeal = 5

#ratings in terms of typicality
typFew = 1
typSome = 2
typMany = 3
typMost = 4
typAll = 5

overallScore=0 # for overallscore
################################
score1=0 # for physical size
score2=0 # for prominence
score3=0 # for difference from surroundings
score4=0 # for availability of a unique label
score5=0 # for Ubiquity and familiarity
score6=0 # for Length of description
score7=0 # for Spatial extents
score8=0 # for permanence

# in terms of PHYSICAL SIZE
suitSize = int(input('enter your suitability evaluation in terms of physical size: '))
typSize = int(input('enter your typicality evaluation in terms of physical size: '))

if suitSize == 5 and typSize==5:
    score1 = 8
if suitSize == 5 and typSize==4:
    score1 = 4
if suitSize == 5 and typSize==3:
    score1 = 2
if suitSize == 5 and typSize==2:
    score1 = 1
if suitSize == 5 and typSize==1:
    score1 = 0
```

Landmarks	Suitability score	Normalised weight
Elevator	35	1.00
Toilet	26	0.67
Door	22	0.55
Scanner/printer	15	0.27
Stairs	29	0.80
Auditorium	30	0.81
Seminar Room	24	0.59
PC Room	18	0.38
Lockers	23	0.56
Uncategorised Room	7	0.00
Organic waste can	14	0.26
Closets	11	0.14
Meeting Room	15	0.28
Trash and Recycle Can	17	0.37
Notice Board	13	0.22

Landmark weighting / selection

Final selected landmarks and their corresponding normalised weights

Landmarks	Suitability score	Initial weight	Final weight
Elevator	35	1.00	**1.00**
Toilet	26	0.67 (**+0.2**)	**0.87**
Door	22	0.55 (**+0.2**)	**0.75**
Scanner/printer	15	0.27 (**+0.2**)	**0.47**
Stairs	29	0.80	**0.80**
Auditorium	30	0.81-[**(5-1)*0.2/4**]	**0.61**

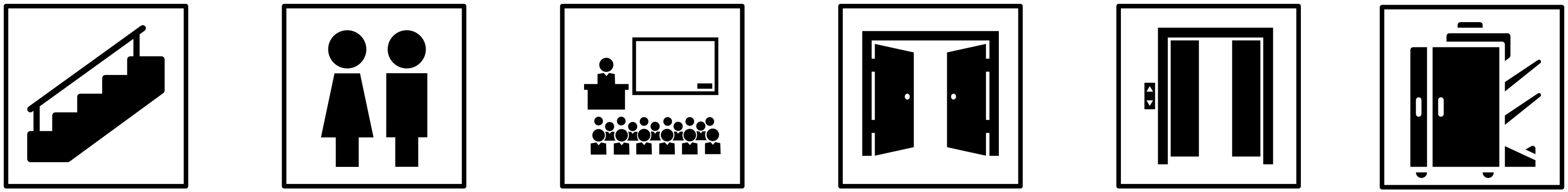
- **adjustment unit (au) = 0.2**
- **(n-1)*au/4**

Landmark integration

Metric-based instructions		**Landmark-based** instructions
“After 2.5m turn right”	→	***“Turn right and pass through the door”***
“Go along the path. After 33 meters turn right”	→	***“Go along the path. You will pass through one door”*** ***“After the men’s toilet E 11.2 turn right”***

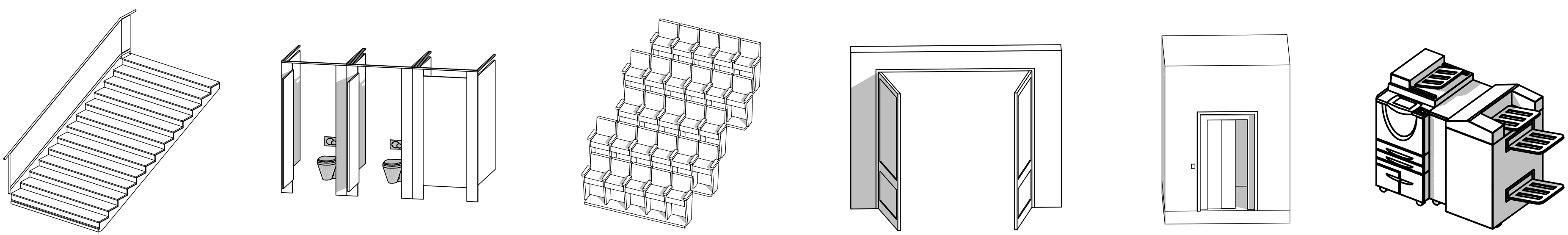
Landmark design

Pictogram approach



stairs toilet auditorium door elevator printer

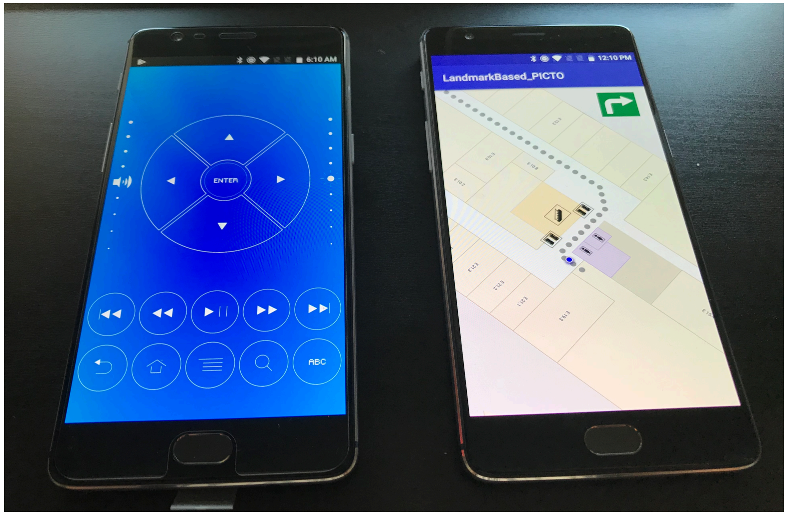
Axonometric approach



stairs toilet auditorium door elevator printer

Wizard of Oz methodology

- Technique used to avoid technical weaknesses (lack of accurate GPS signal)
- Participant's impression that interacts with the system
- Experimenter acts as 'Wizard' to control user - system interaction



Two android devices connected via Tablet Remote APK

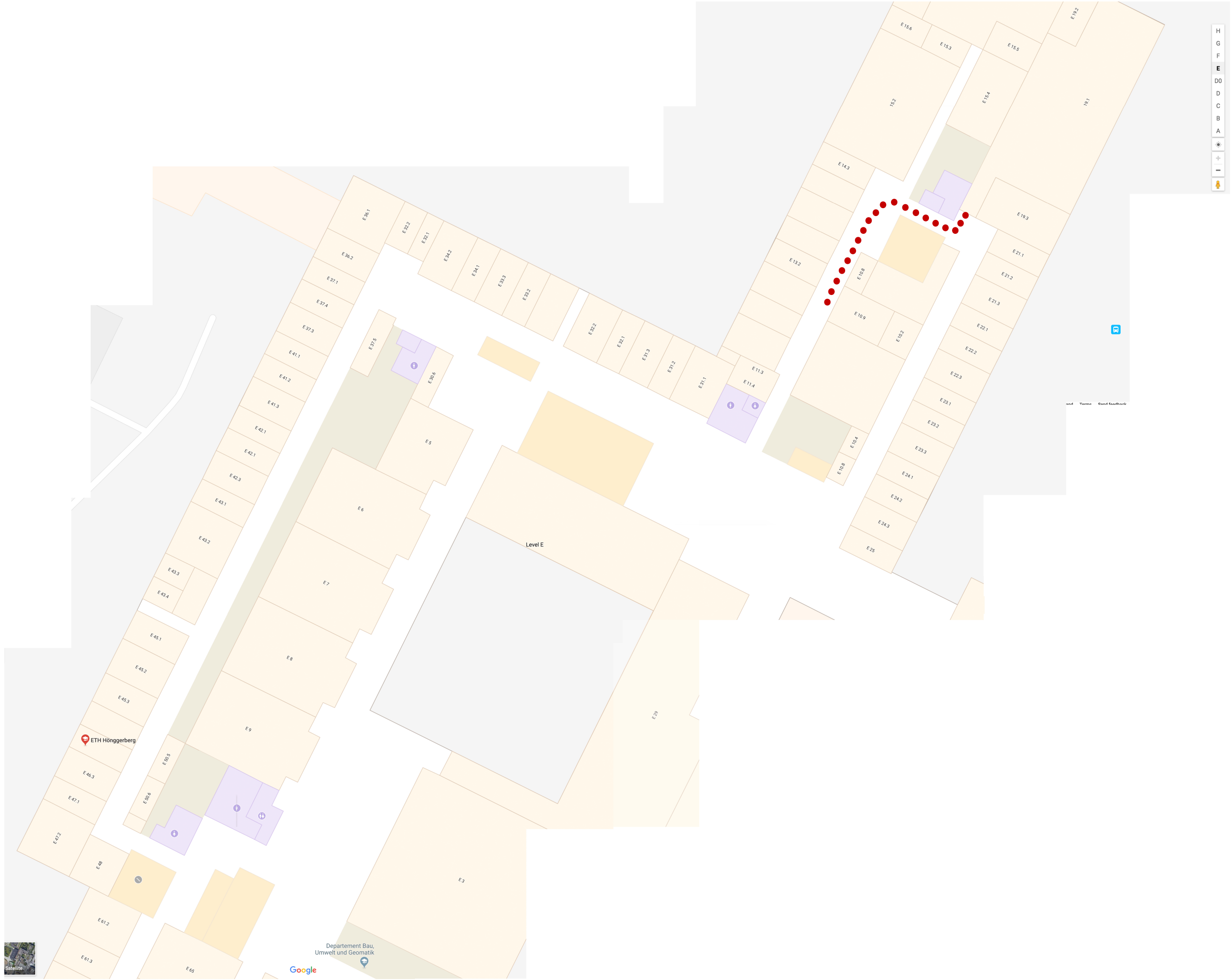
Android route application

- Background map designed within Adobe Photoshop
- 85-87 high resolution static images were created
- Application written in Java (Android software studio)
    - Image switcher
    - 2 invisible buttons
    - “saveText” method

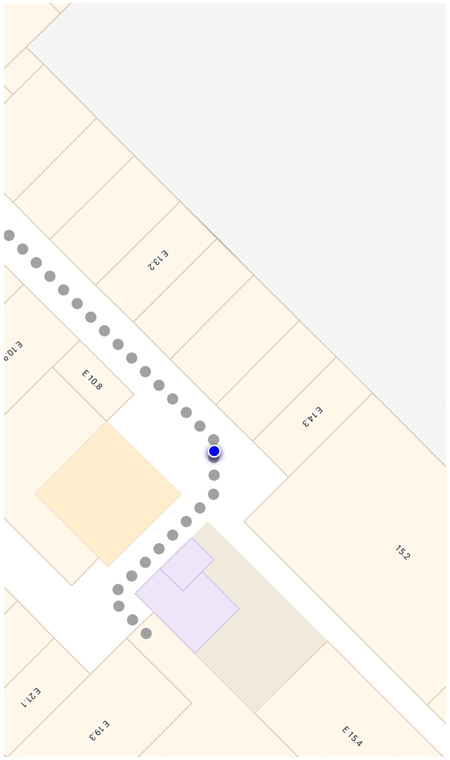
```java
@Override
protected void onCreate(Bundle savedInstanceState) {...}

// create function for saving info to external storage

private void saveText(String content) {


    //create file
    File file = new File(Environment.getExternalStorageDirectory().getAbsoluteFile(),
            FILENAME);

    //Write to file

    try {
        FileOutputStream fos = new FileOutputStream(file);
        fos.write(content.getBytes());
        fos.close();
    } catch (FileNotFoundException e) {
        e.printStackTrace();
    } catch (IOException e) {
        e.printStackTrace();
    }

}
```

Method for saving to a txt file, within device’s internal storage, the number of times “Back” button was clicked

Android route application



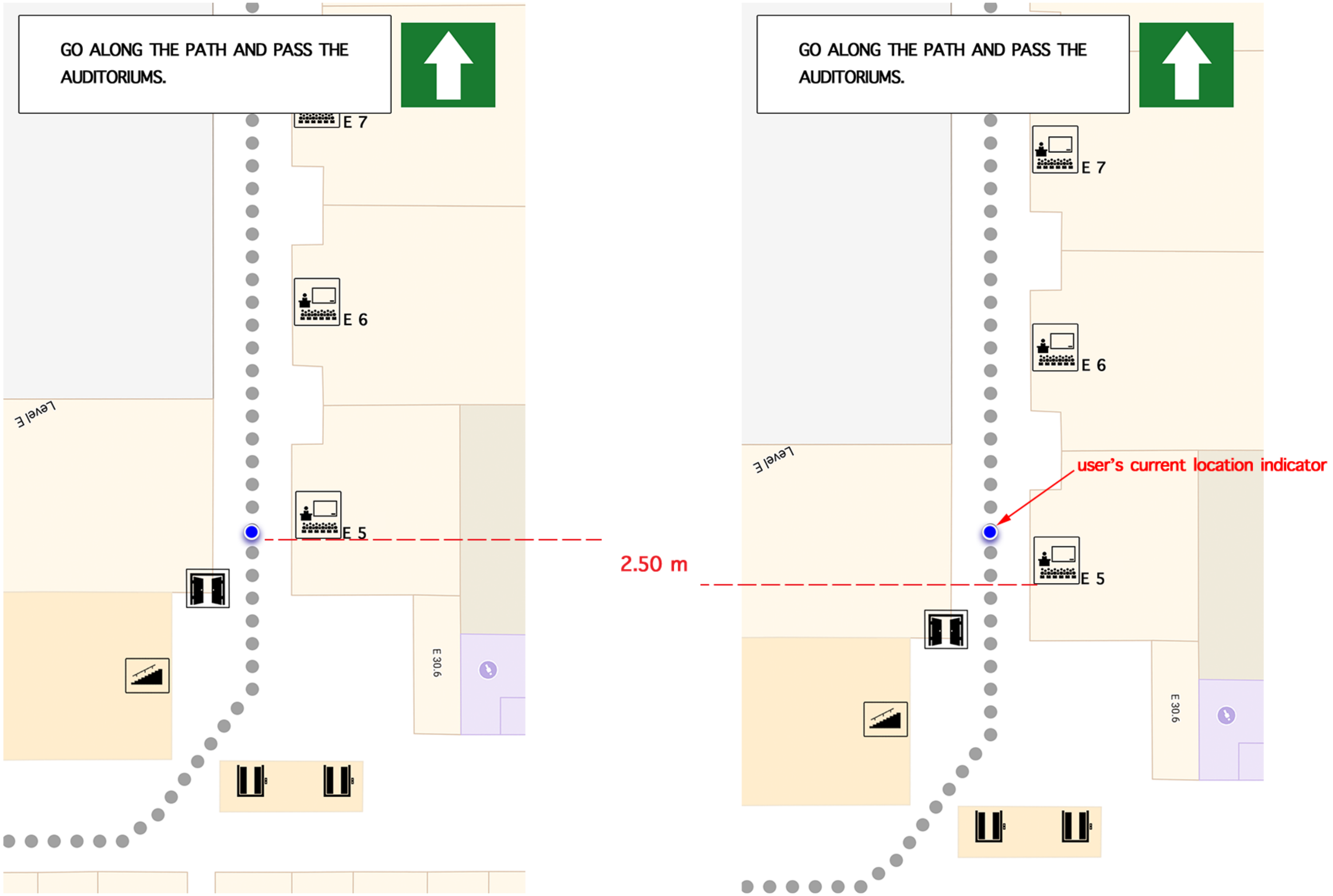
(base map)



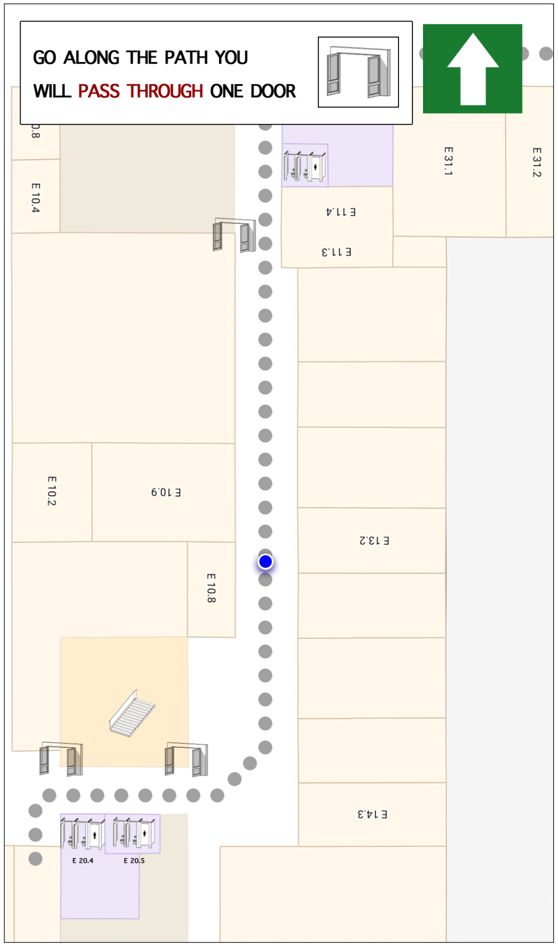
(generated image)

Android route application

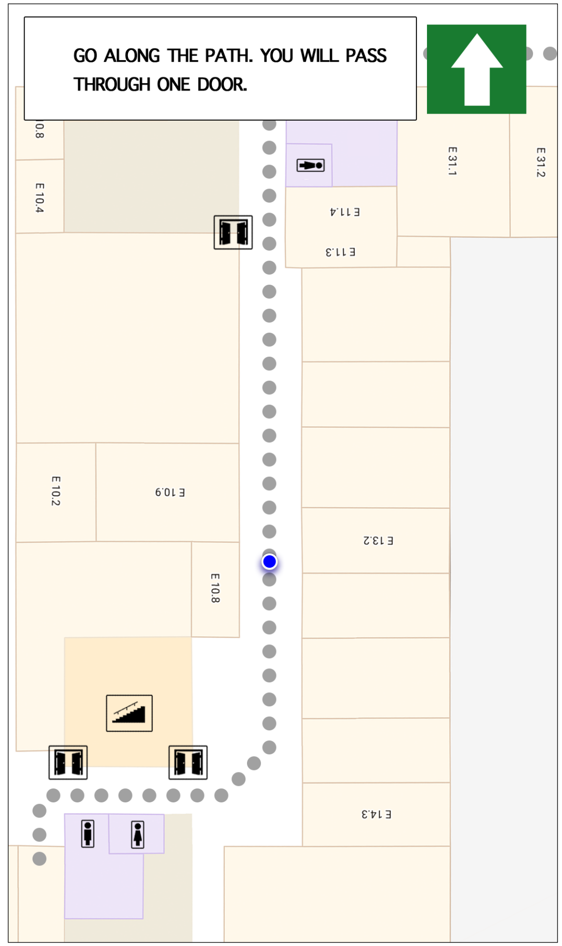
Successive images along the routing path (from left to right)



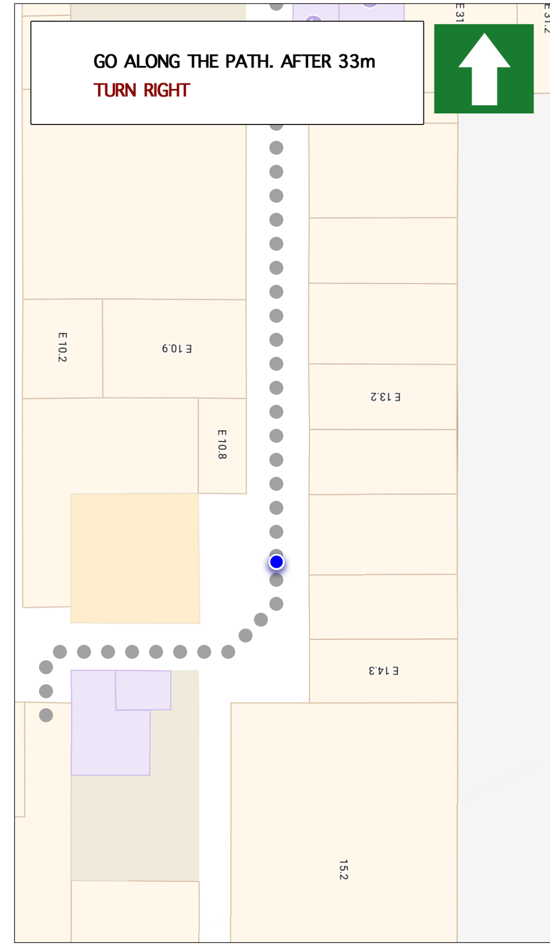
Android route application



Axonometric-based

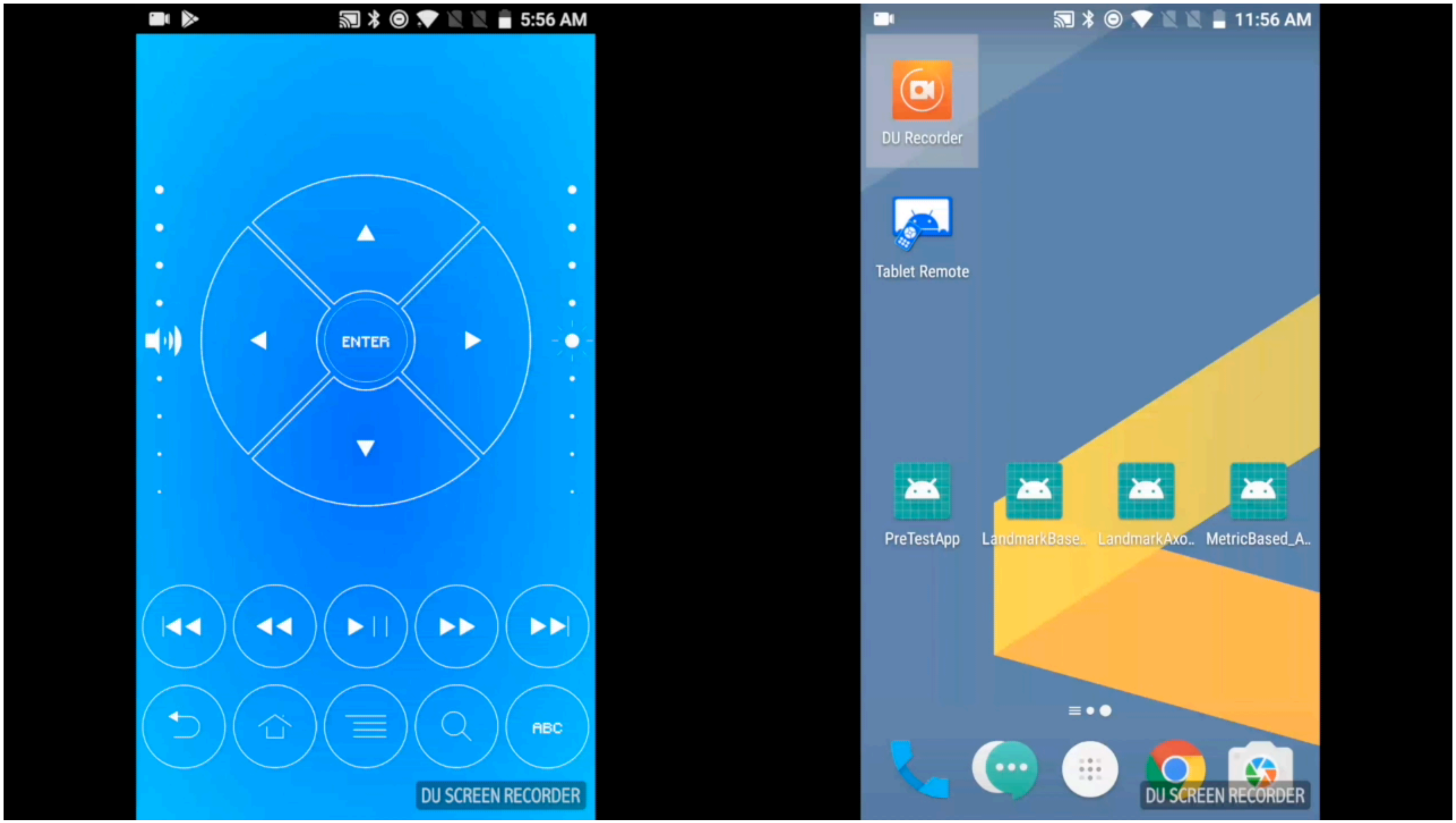


Pictogram-based



Metric-based

Wizard of Oz methodology

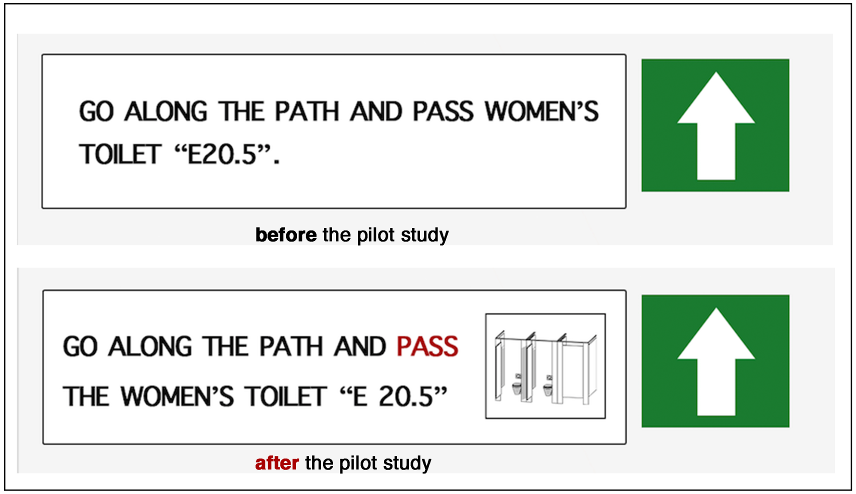


Experimenter’s phone **Participant’s phone**

Wayfinding experiment

- Pilot study (feedback)
  - Development of a pre-test application (~40m path, G Floor)
  - Clearer UI design for the axonometric-based application

Pre-test app



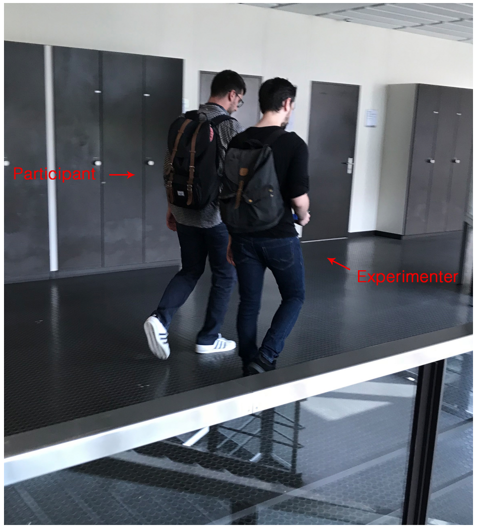
Design changes after the Pilot study

Wayfinding experiment

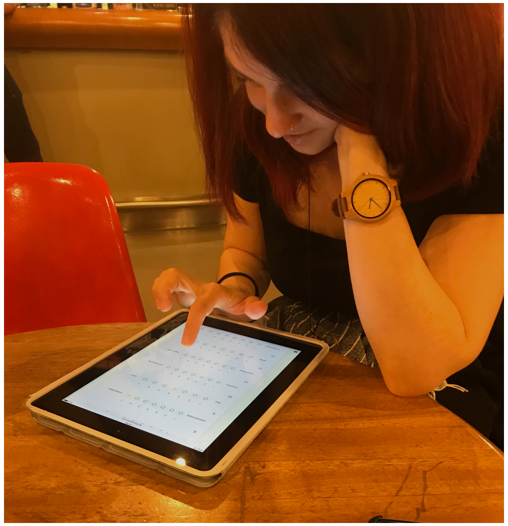
- Actual experiment / Procedure
  - Two pre study questionnaires
    - regarding participants' profile (e.g. demographic data)
    - regarding participants' spatial abilities (SBSODS)
  - Participation in a small pre-test experiment
  - Participation in the actual experiment

Wayfinding experiment

- Three questionnaires (after finishing the wayfinding task)
  - User experience (UEQ, Laugwitz *et al*., (2008))
  - Cognitive workload (NASA TLX, Hart and Staveland, 1988))
  - Landmarks visualization evaluation



Participant during the experiment



Participant fills in the after-study questionnaires

Wayfinding experiment

- Participants' profile
  - 30 participants (10 for every scenario)

PICTOGRAM SCENARIO	
	N (number)
Male	8
Female	2
Experienced in HIL	7
Non-Experienced in HIL	3
Age	Mean (yrs) = 28.9
	SD = 4.43

AXONOMETRIC SCENARIO	
	N (number)
Male	9
Female	1
Experienced in HIL	7
Non-Experienced in HIL	3
Age	Mean (yrs) = 30.1
	SD = 9.66

METRIC SCENARIO	
	N (number)
Male	6
Female	4
Experienced in HIL	6
Non-Experienced in HIL	4
Age	Mean (yrs) = 28.4
	SD = 5.36

Data analysis & Results

Data analysis

- Statistical analysis of participants' responses, concerning their:
  - demographic data
  - level of experience with navigation systems
  - level of experience with digital maps
  - spatial abilities

	Age	Experience with digital maps	Experience with navigation systems	How many hours did you sleep last night?	How do you feel	Santa Barbara Sense of Direction Scale
Kruskal-Wallis H	0.334	0.460	0.745	0.853	4.896	2.313
df	2	2	2	2	2	2
Asymp. Sig	0.846	0.794	0.689	0.653	0.086	0.315

Kruskal-Wallis H Test results regarding pre study participants' answers

Data analysis

- Statistical analysis, concerning participants':
  - Navigation performance
  - User experience
  - Cognitive workload
  - Landmarks visualization preferences

- Use of **non-parametric tests**
  - Kruskal-Wallis H test (**comparison among the three different conditions**)
  - Mann-Whitney U test (**for pairwise comparisons**)

Navigation performance

- **Participants' navigation performance**
  - Number of errors during the wayfinding task
  - Total time needed for completing the task

	Number of Errors _ Mean	Completion Time (min) _ Mean
Pictogram	0.40	2.94
Axonometric	0.40	2.85
Metric	2.30	2.80
	Number of Errors _ SD	Completion Time (min) _ SD
Pictogram	0.69	0.29
Axonometric	0.84	0.48
Metric	1.34	0.41

Descriptive statistics for number of errors and completion time

Navigation performance

	Completion Time	Number of Errors
Kruskal-Wallis H	0.873	5.102
df	2	2
Asymp.Sig	0.646	0.78

Kruskal-Wallis H Test results among three scenarios (1:Pictogram, 2:Axonometric, 3:Metric)

- **No statistically significant differences**, in terms of:
  - number of errors; $\chi^2(2) = 5.102$, $p = 0.78$
  - total completion time; $\chi^2(2) = 0.873$, $p = 0.646$

Navigation performance

	Completion Time	Number of Errors
Mann-Whitney U **(Pictogram vs Axonometric)**	41.50	47.00
Asymp. Sig. (2-tailed)	0.520	0.765
Mann-Whitney U **(Axonometric vs Metric)**	47.00	27.00
Asymp. Sig. (2-tailed)	0.820	0.055
Mann-Whitney U **(Metric vs Pictogram)**	34.00	20.50
Asymp. Sig. (2-tailed)	0.369	**0.028**

Mann-Whitney U Test results between all pairs of conditions

- **Statistically significant difference**, in terms of:
  - number of errors; $U = 20.50$, $p = 0.028$

Navigation performance

- **Navigation performance between two groups:**
  - Participants **experienced** in navigating within HIL building
  - Participants **non - experienced** in navigating within HIL building

- Use of non-parametric **Mann-Whitney U test**
  - Dependent continuous variables (1.number of errors; 2.total completion time)
  - One independent variable consists of two independent groups (1.Experienced in HIL; 2. Non-experienced in HIL)

Navigation performance

	Pictogram		Axonometric		Metric	
	Time of Completion	Number or errors	Time of Completion	Number or errors	Time of Completion	Number or errors
Mann-Whitney U	8.50	9.00	5.00	8.50	0.000	4.000
Z	-0.457	-0.423	-1.257	-0.655	-2.558	-1.783
Asymp. Sig. (2-tailed)	0.648	0.673	0.209	0.513	**0.011**	0.075

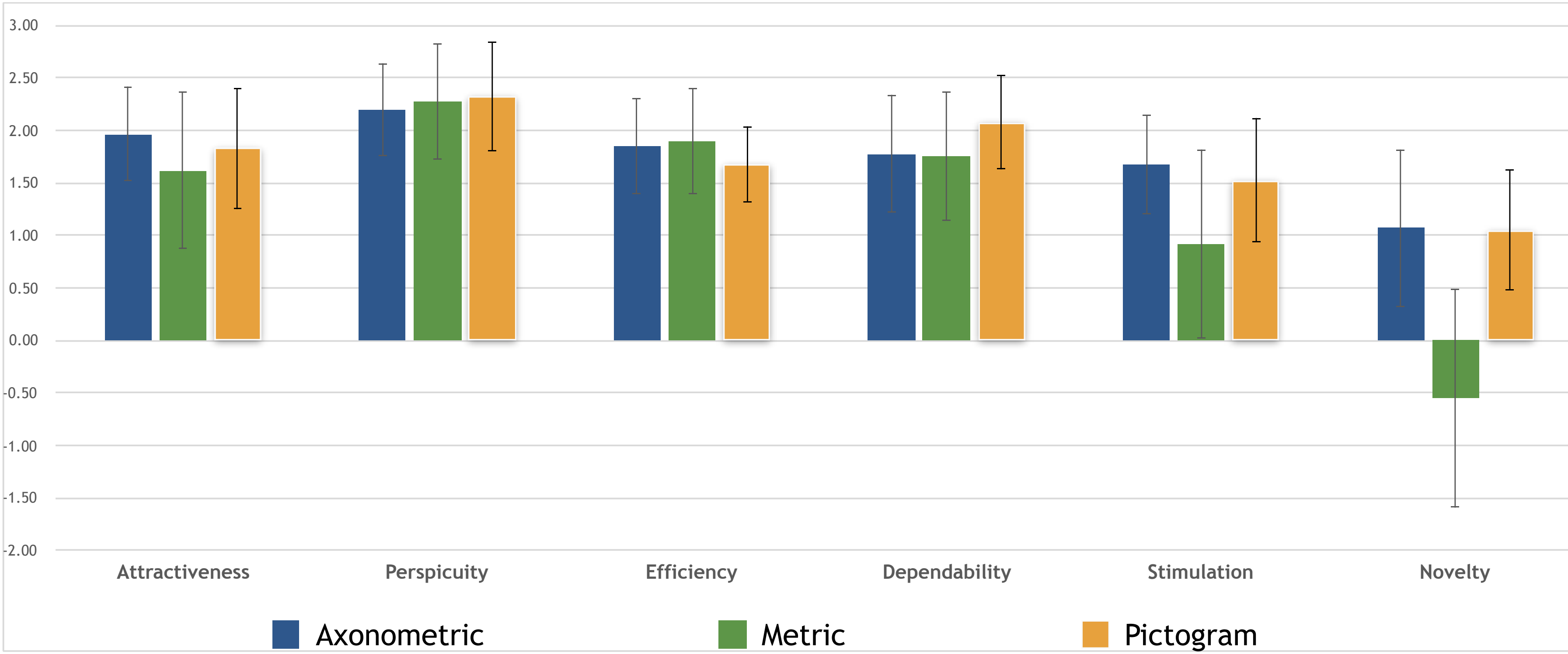
Mann-Whitney U Test results between experienced and non-experienced in navigating within HIL Building, participants.

- **Statistically significant difference**, in terms of:
  - time of completion; $U = 0.000$, $Z = -2.558$, $p = 0.011$

User experience

- UEQ is used to assign a score to each of the approaches for the following **six user experience categories:**
  - *Attractiveness*
  - *Perspicuity*
  - *Efficiency*
  - *Dependability*
  - *Stimulation*
  - *Novelty*

User experience



User Experience results for each UX category and condition. The black error bars indicate the confidence level

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User experience

- Use of non-parametric **Mann-Whitney U test** **(for pairwise comparisons)**

	Attractiveness	Perspicuity	Efficiency	Dependability	Stimulation	Novelty
Mann-Whitney U **(Pictogram vs Axonometric)**	46.00	41.50	43.00	41.00	46.50	44.50
Asymp. Sig. (2-tailed)	0.762	0.510	0.591	0.493	0.789	0.684
Mann-Whitney U **(Pictogram vs Metric)**	48.00	47.00	40.50	42.50	38.00	19.50
Asymp. Sig. (2-tailed)	0.879	0.814	0.470	0.567	0.362	**0.021**
Mann-Whitney U **(Axonometric vs Metric)**	42.00	45.50	48.5	47.00	34.00	21.50
Asymp. Sig. (2-tailed)	0.544	0.729	0.909	0.820	0.224	**0.029**

Mann-Whitney U Test results, between all pairs of conditions (Pictogram vs Axonometric, Pictogram vs Metric, Axonometric vs Metric)

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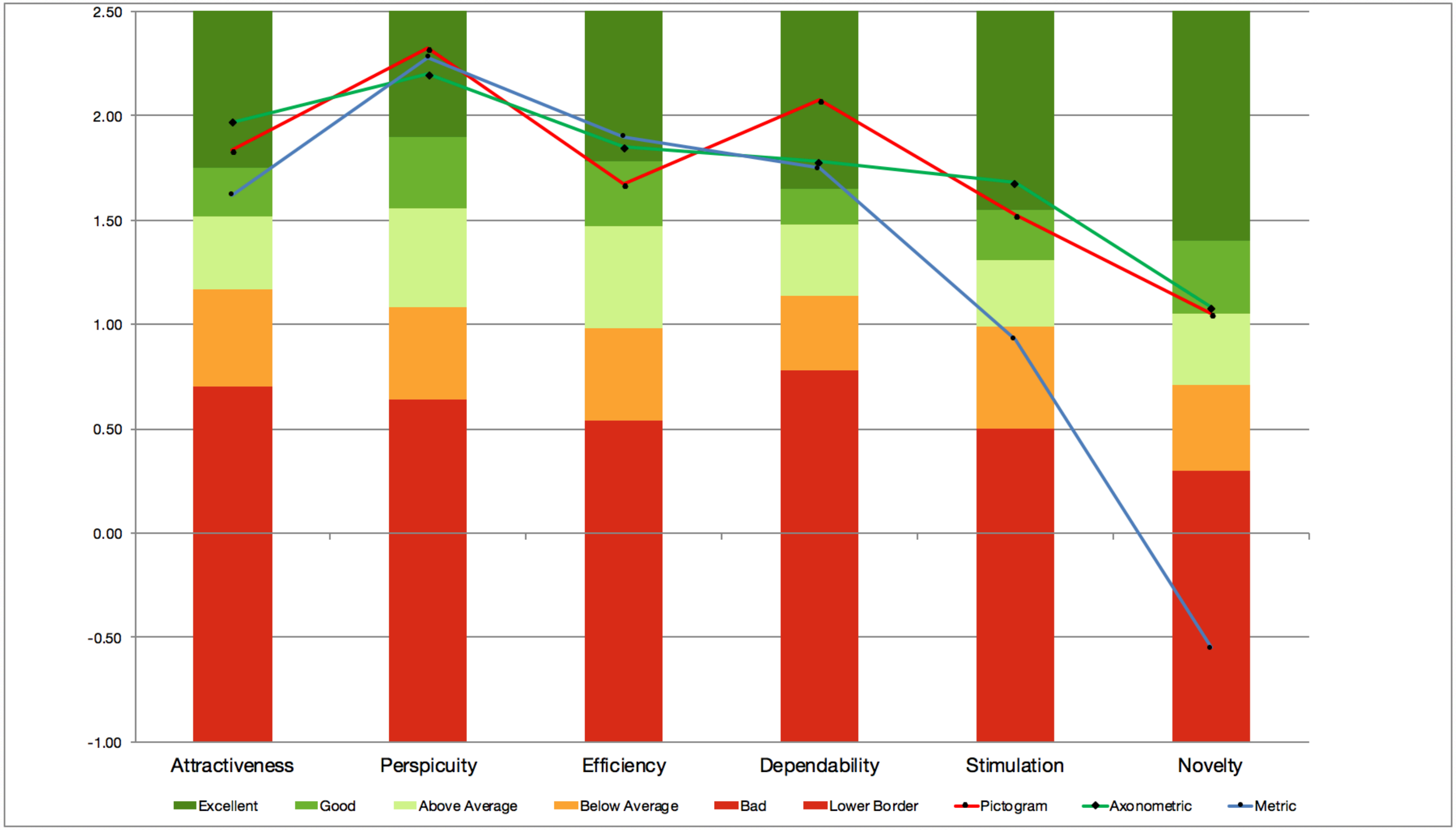
User experience

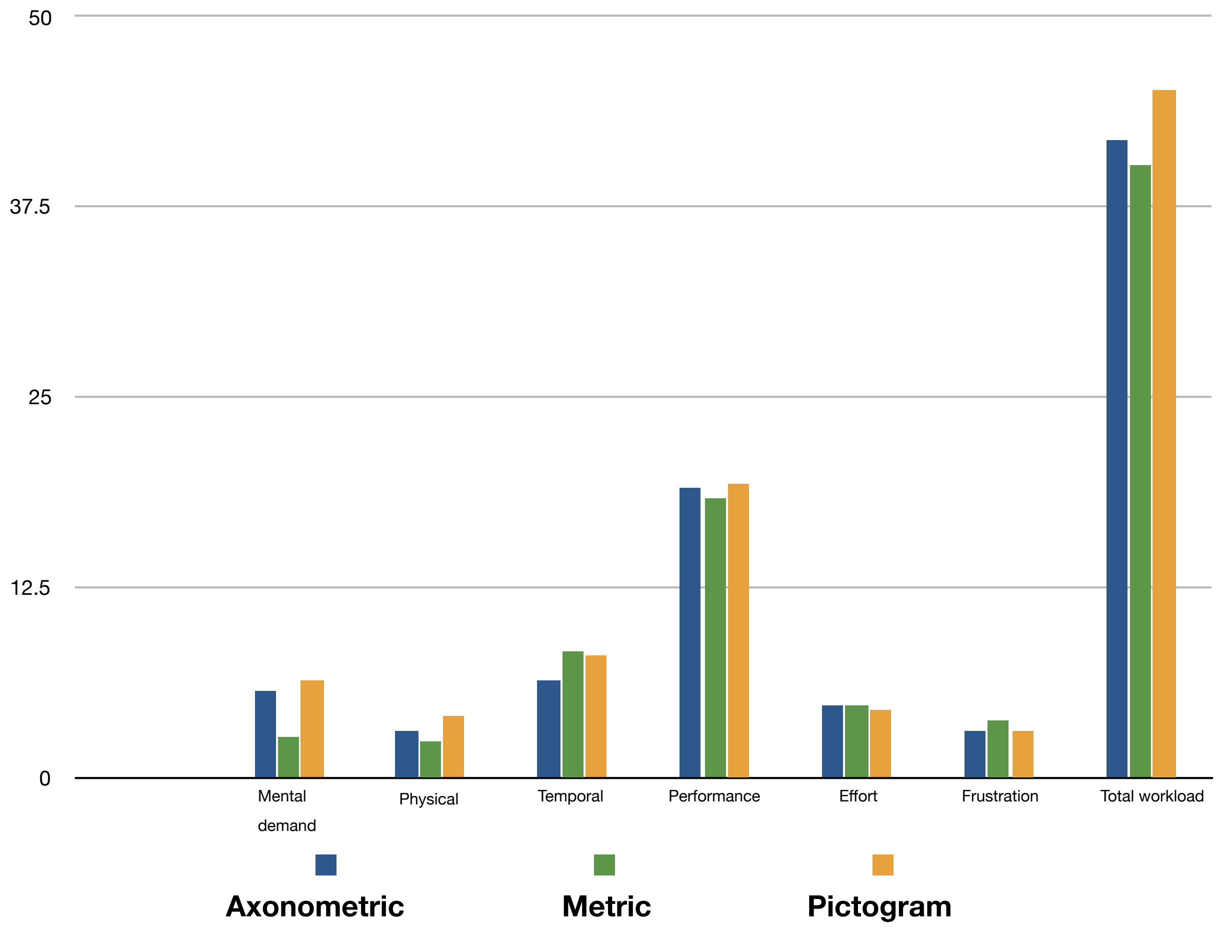


User Experience results per category and per condition, in comparison with a benchmark dataset.

Cognitive workload

- NASA TLX is used to assign cognitive workload estimates for the following **six categories:**
  - *Mental demand*
  - *Physical demand*
  - *Temporal demand*
  - *Performance*
  - *Effort*
  - *Frustration*

Cognitive workload



Cognitive workload estimates for six categories, for all the three conditions (1.Axonometric; 2.Metric; 3.Pictogram

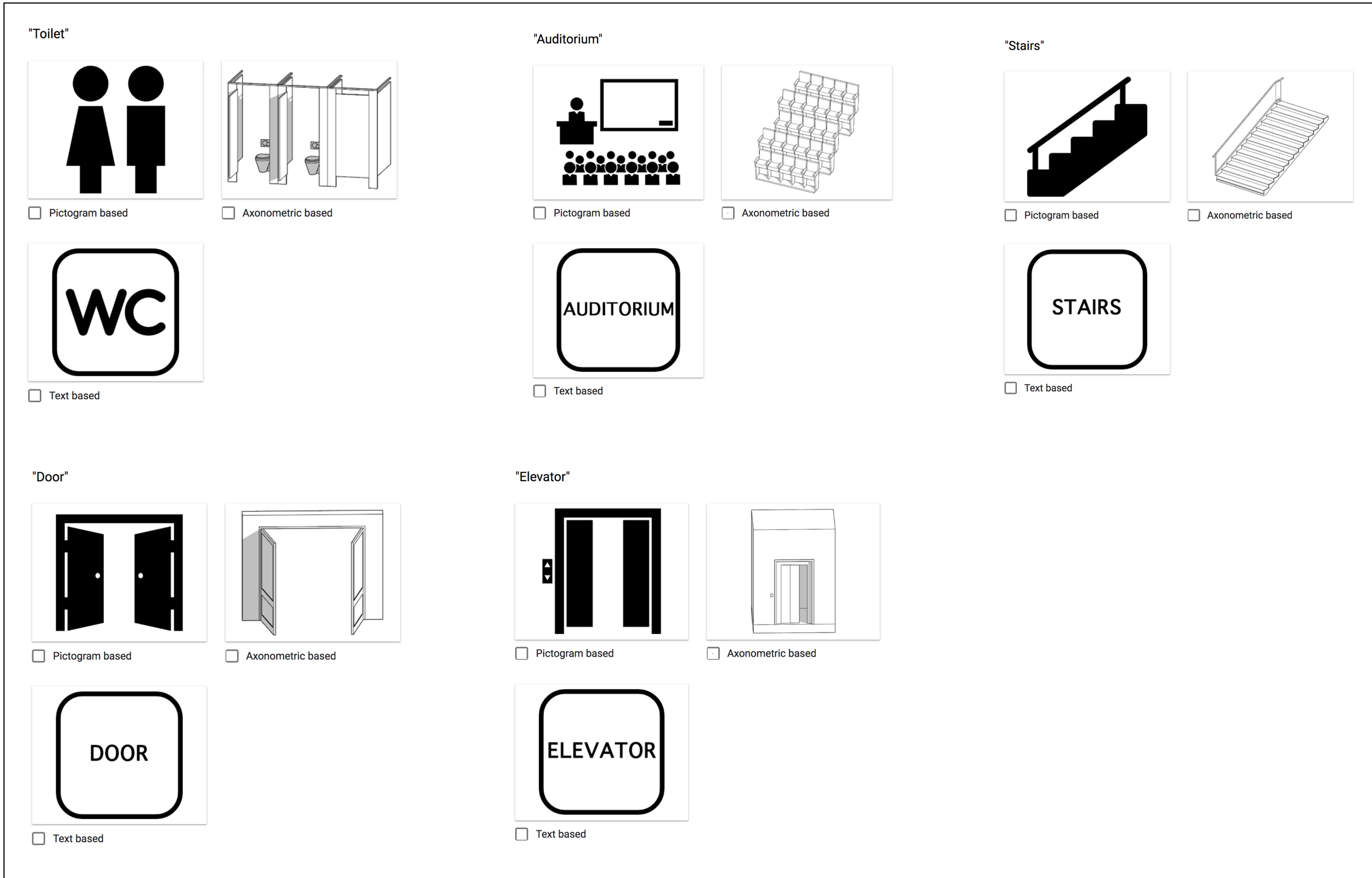
Cognitive workload

- Use of non-parametric **Mann-Whitney U test (for pairwise comparisons)**

	Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration	Total Workload
Mann-Whitney U **(Pictogram vs Axonometric)**	48.00	38.5	36.00	49.50	46.00	41.5	43.50
Asymp. Sig. (2-tailed)	0.875	0.344	0.269	0.965	0.753	0.461	0.621
Mann-Whitney U **(Pictogram vs Metric)**	28.50	31.00	46.00	41.50	47.50	40.50	41.00
Asymp. Sig. (2-tailed)	0.083	0.112	0.749	0.476	0.844	0.413	0.490
Mann-Whitney U **(Axonometric vs Metric)**	25.00	43.00	39.50	43.00	49.50	47.00	47.00
Asymp. Sig. (2-tailed)	0.045	0.547	0.401	0.558	0.967	0.804	0.815

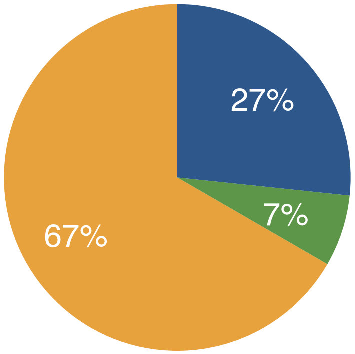
Mann-Whitney U Test results, between all pairs of conditions (Pictogram vs Axonometric, Pictogram vs Metric, Axonometric vs Metric)

Landmarks visualization

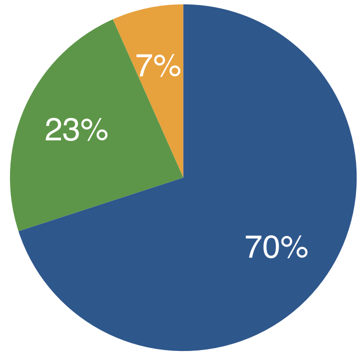


Landmarks visualization

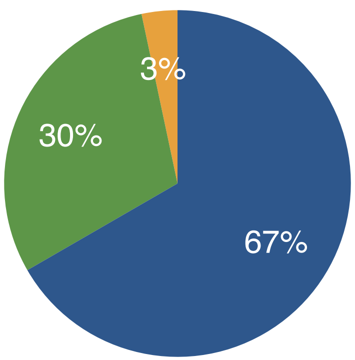
“Toilet”



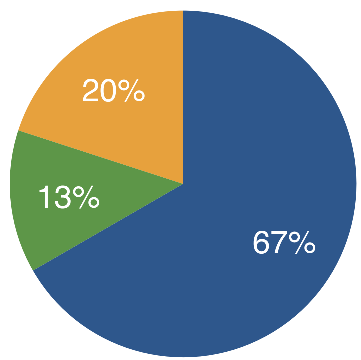
“Door”



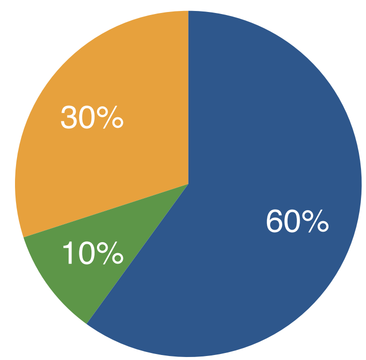
“Stairs”



“Elevator”



“Auditorium”



Pictogram-based Axonometric-based Text-based

Conclusions and future work

Conclusions

- **Navigation performance**
  - ILNM beneficial effect on participants' navigation performance
  - Significant lower number or errors during Pictogram & Axonometric approach
  - Overall better performance in Pictogram approach
    - Statically sign. difference in Pictogram vs Metric comparison (U = 20.50, z = —2.203, $\boldsymbol{p} = \mathbf{0.028}$)

Conclusions

- **Navigation performance** (experienced vs non-experienced in HIL effect)
  - Statically sign. differences observed in **metric approach**
  - In terms of completion time:
    - U=0.000, z = -2.558, **p = 0.011**
  - No statically sign. differences in the two landmark-based approaches

Conclusions

- **User experience**
  - Metric-based approach quite conservative
  - Statically significant differences observed only in the **‘Novelty’** category
    - $\chi^2(2) = 6.846$, $\boldsymbol{p = 0.033}$
  - Pictogram & Axonometric approaches scored higher in terms of:
    - ‘Attractiveness’
    - ‘Hedonic’ quality aspects

Conclusions

- **Cognitive workload**
  - No statistically significant difference in most of the workload categories, among the three approaches
  - Statically significant differences observed only in the **'Mental effort'** category (Axonometric vs Metric)
    - U=25.00, z = -2.002, **p = 0.045**

Conclusions

- **Landmark visualization**
  - **Pictogram** approach the most popular choice
    - Clear and unambiguous landmarks representations
    - No ‘room’ for misinterpretations
    - Quite familiar form of representation
  - **Axonometric** approach the least popular choice
    - High level of detail leads to confusions
    - No standardised design (no ‘design objectivity’)
    - 3d ‘element’ leads to confusions

Future work

- Wayfinding experiment on a larger scale (in terms of route length and in number of participants)
  - Examine navigation experience effect (within the test area) using a larger sample

- Research on formulating general guidelines for describing landmarks, based on the type of the building

- Examine other possible ways for landmark visualization (e.g. text-based, include color, sketch representation)

Future work

- Evaluation of cartographic visualization approaches in different mobile screen sizes

- Development of indoor navigation assistance application for the ETH Campus
  - Combination of ILNM with an Indoor Positioning System

THANK YOU FOR YOUR ATTENTION !