Effectiveness of 2D and 3D Symbols on Virtual Globes

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Outline

- Introduction and Motivation
- Research Objective
- Literature Review
- Design and Implement Prototype
- User study
- Result
- Discussion
- Conclusion

What is a Virtual Globe?

A Virtual Globe is a computer-based representation of the real world (Bailey & Chen, 2011).

It is a three-dimensional spherical or rounded object made by software with a map rendering the earth on the surface in various scales and projections (Harvey, 2009), and allowing users to interactively pan, zoom, and rotate (Chien & Tan, 2011).

Motivation

Represent Earth as globe

145 BC (Elvidge et al., 2008)

First Virtual Globe

1995 (Sreevalsan-Nair, 2022)

The launch of Google Earth

2005

Desktop environment VG has been mentioned by 2115 research within various research fields

In next decade (Liang et al., 2018)

Motivation

However……..

There are only few study explore " how to utilize Virtual Globes in a more effective and efficient way".

Research Objectives

The overarching research objective:

To explore and understand the effectiveness of 2D and 3D symbols on Virtual Globes under various circumstance based on the existing design guidelines.

1> the different scales of Virtual Globes (small scale; medium scale; large scale)

2> the perception by different user groups (cartographer group; non-cartographer group)

Research Objectives

RO 1: To explore the usage of 3D and 2D symbols on the Virtual Globe.

1> What are the existing examples of using symbols to represent geographic data on Virtual Globes?

2> What are the visual variables of symbols on a Virtual Globe?

3> How is the design of symbols changing with the development of Virtual Globes in different environments?

RO 2: To design and implement a Virtual Globe prototype in the desktop virtual environment.

4> What platforms are popular and frequently used for building Web-based Virtual Globe applications?

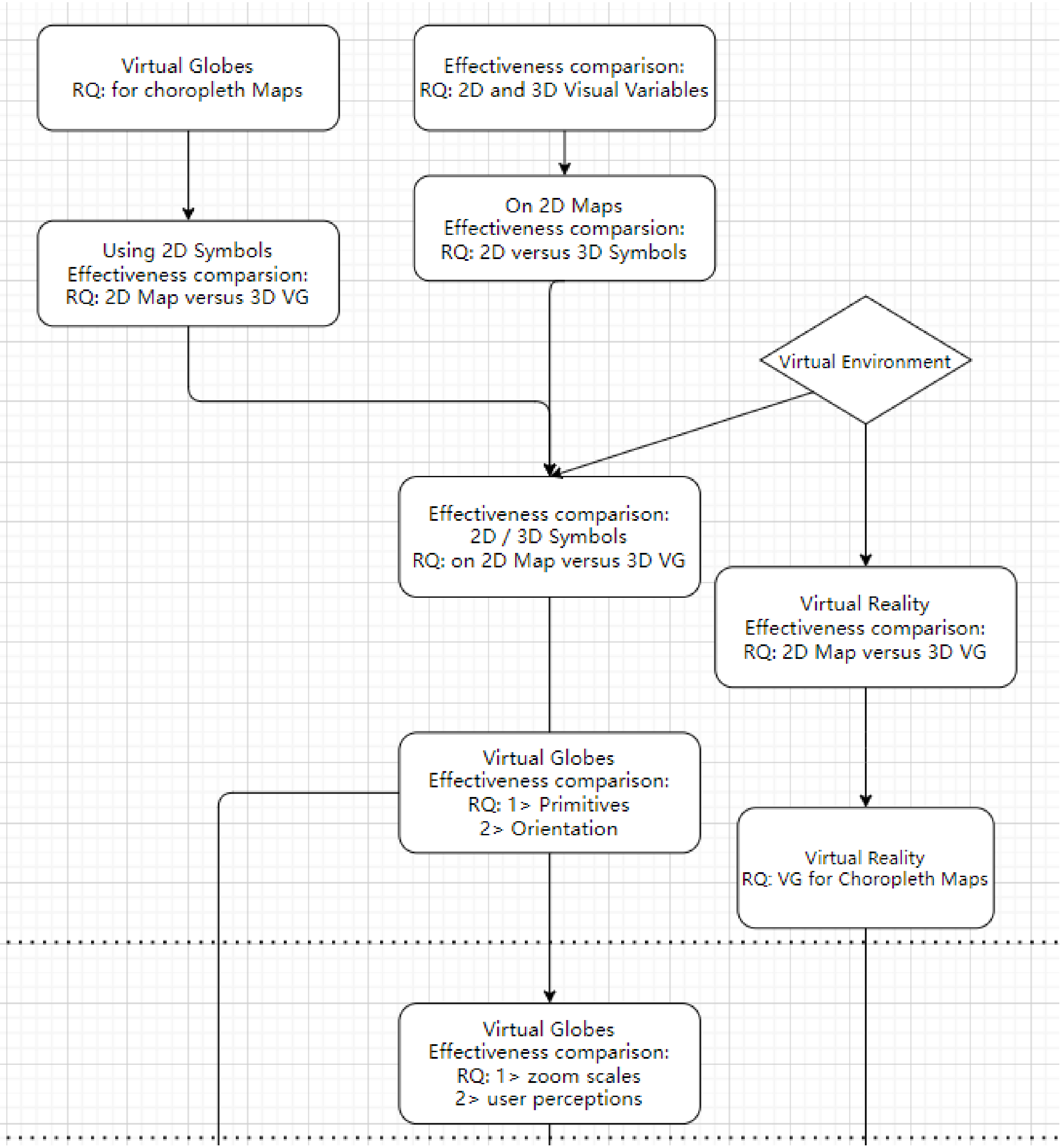
5> How should the 2D and 3D symbols be designed?

6> How to define the concept of "scale" for Virtual Globes?

RO 3: To evaluate the effectiveness of 3D and 2D symbols under different circumstances.

7> How are 2D and 3D symbols performing at different scales?

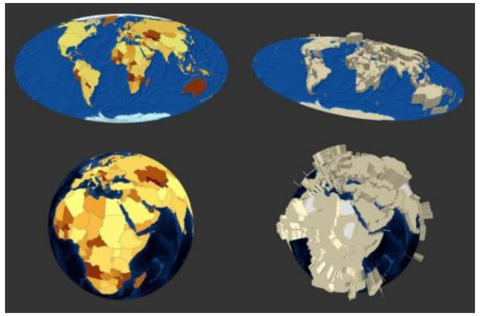
8> How are different user groups perceiving the symbols on Virtual Globes?



Previous Research

This study

Literature Review

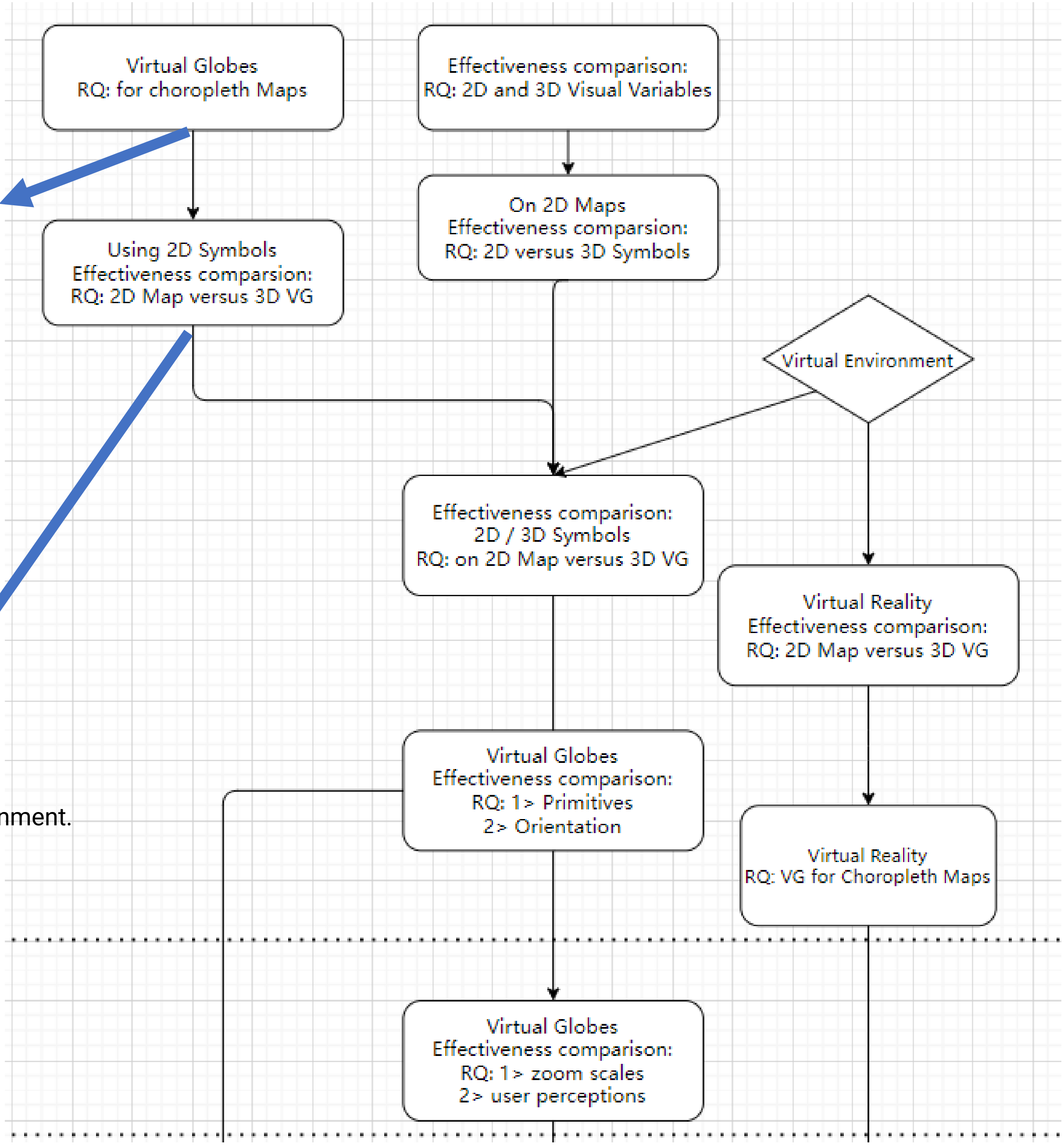


Virtual Globes experiment for Choropleth Visualization (White, 2012)

User Preference on Point Symbols

Comparison between Flat map and VG environment.

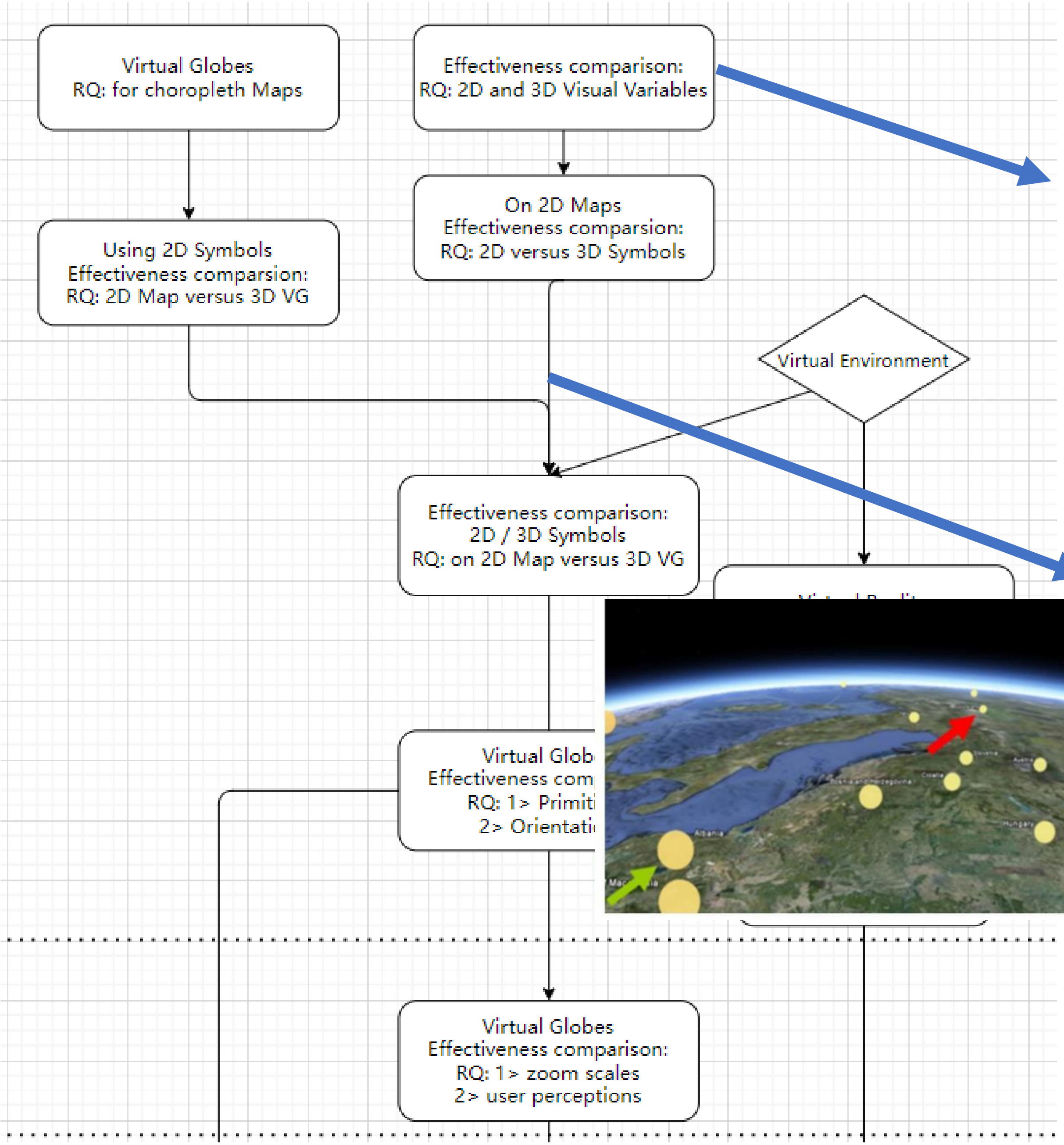
(Popelka & Dolezalova, 2016)

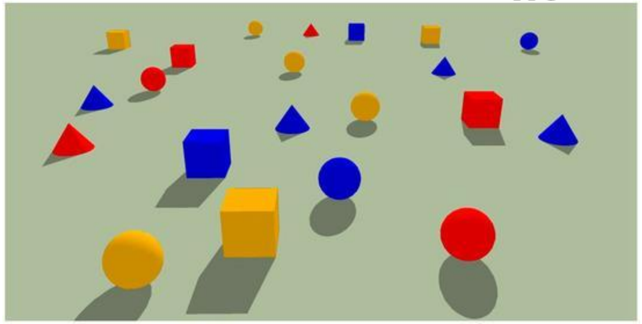


Previous Research

This study

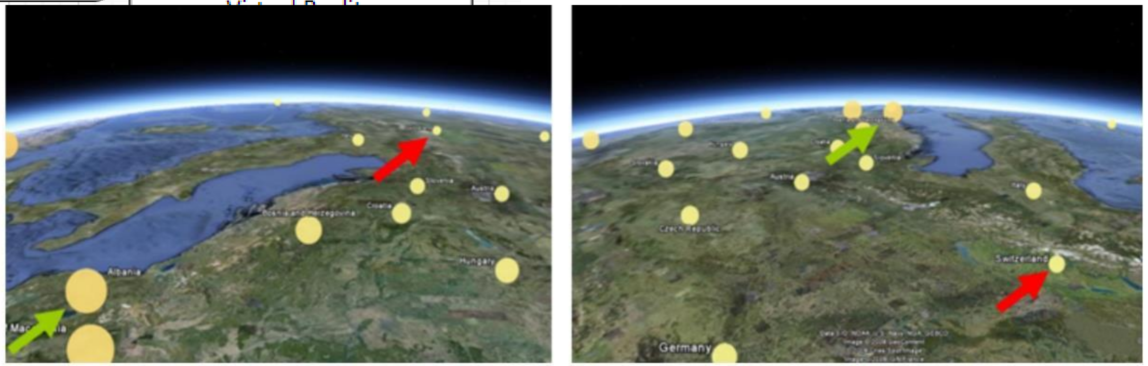
Literature Review





Investigate the 3D Visual Variables

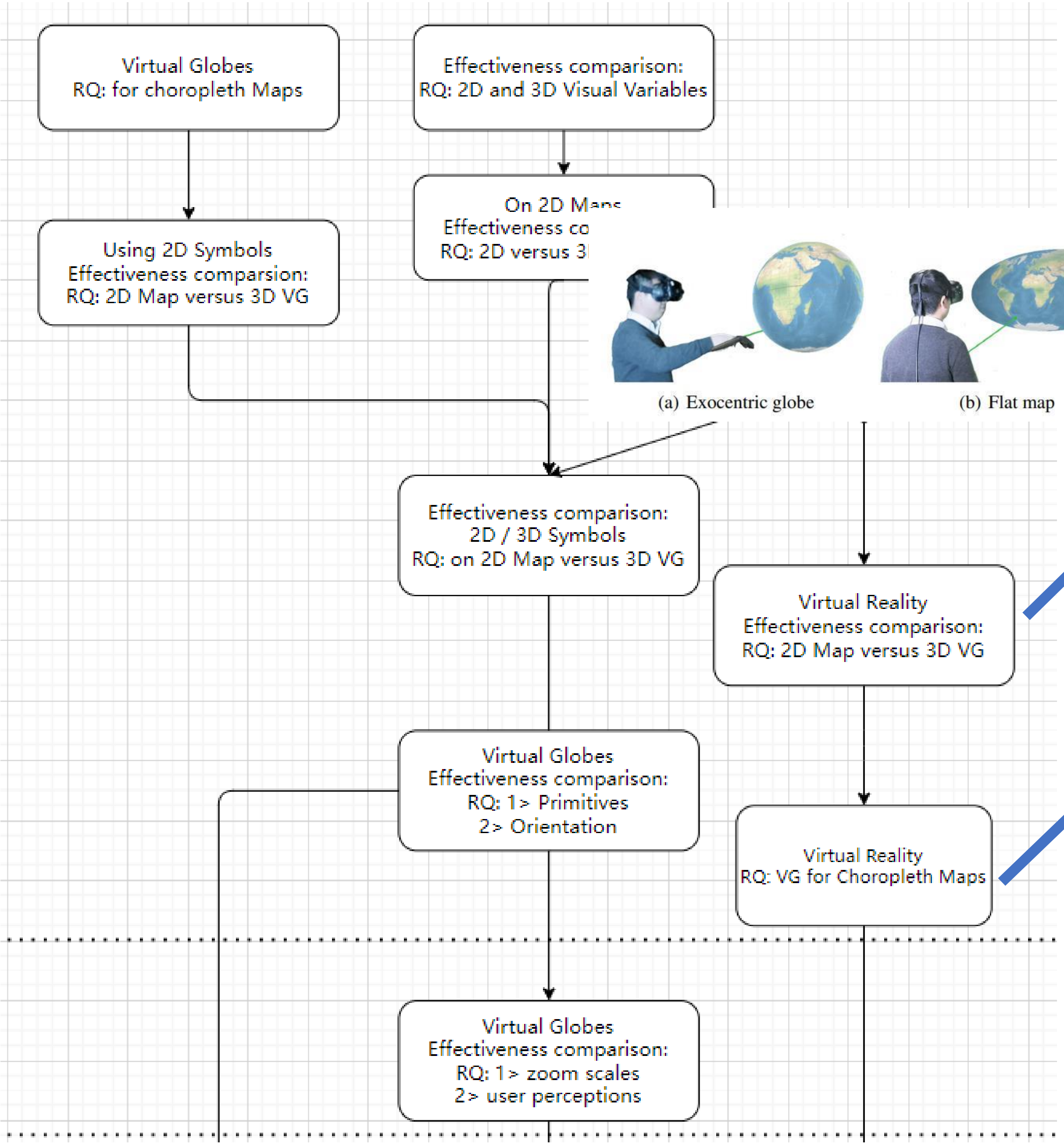
(Liu et al., 2017)

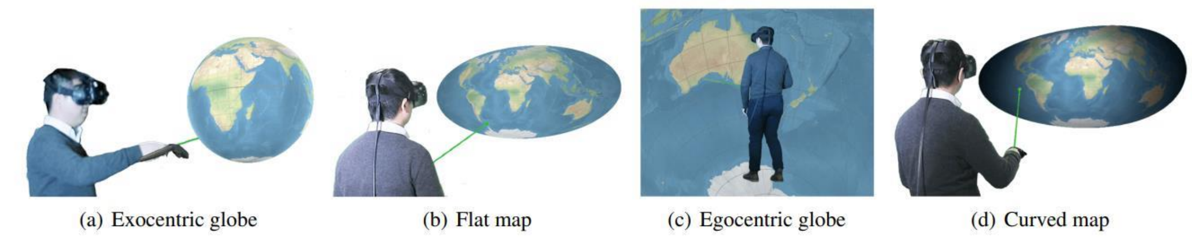


2D symbols on 3D VG

(Bleisch, 2015)

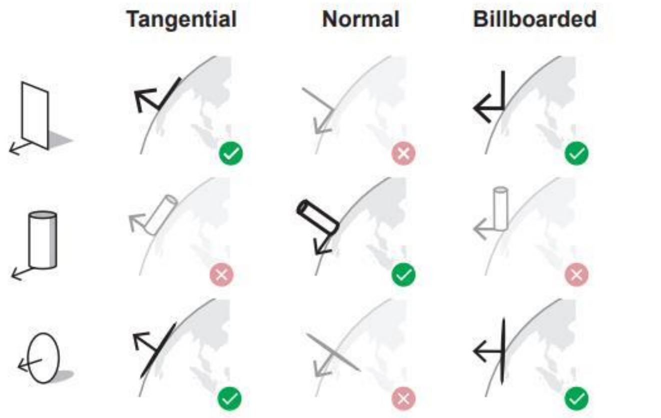
Literature Review





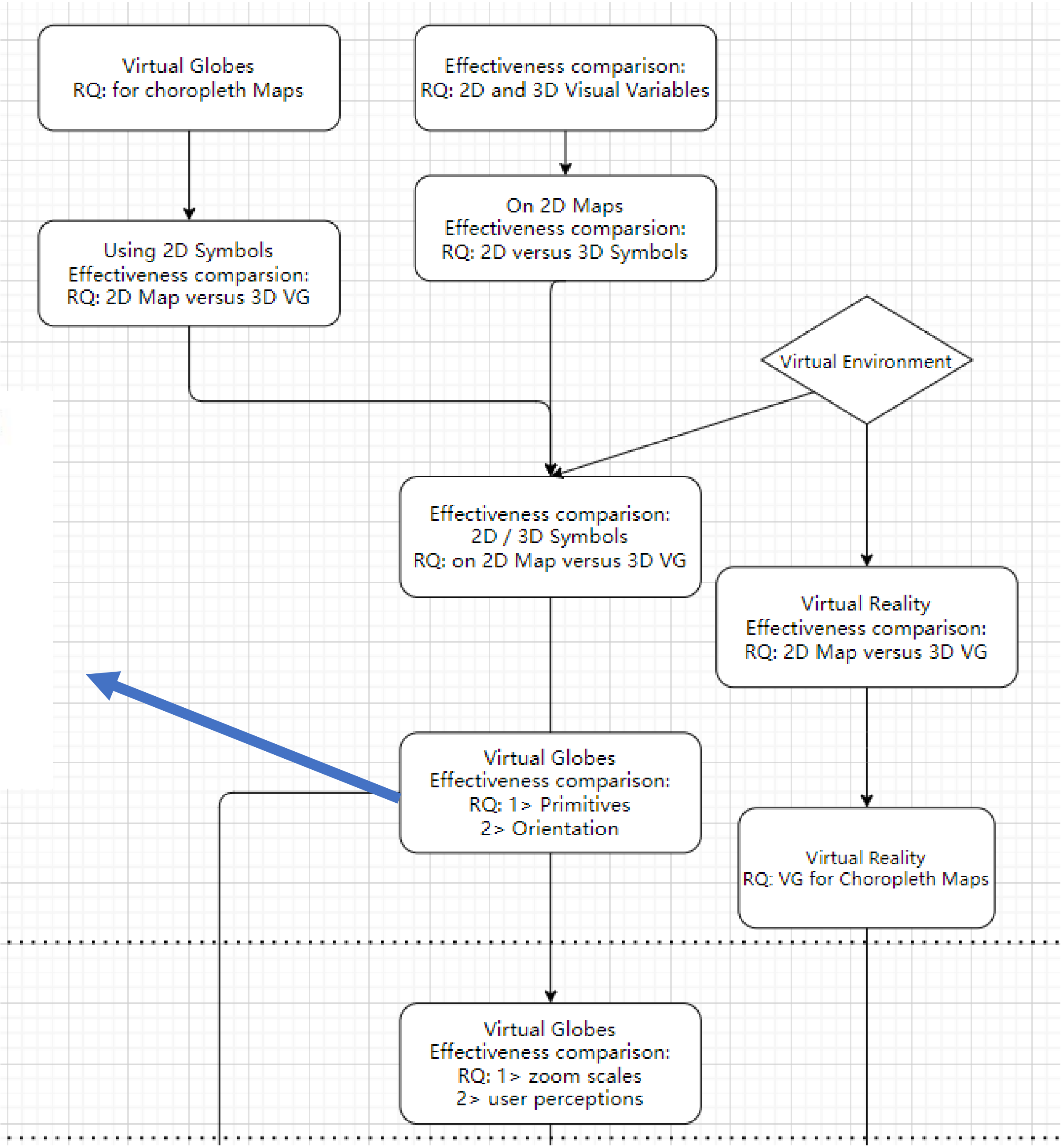
Virtual Globes in VR (Yang et al., 2018)

Virtual Globes for Choropleth Visualization in VR (Kloiber et al., 2022)



Visualization Idioms

(Satriadi, 2021)



This study

Literature Review

Data

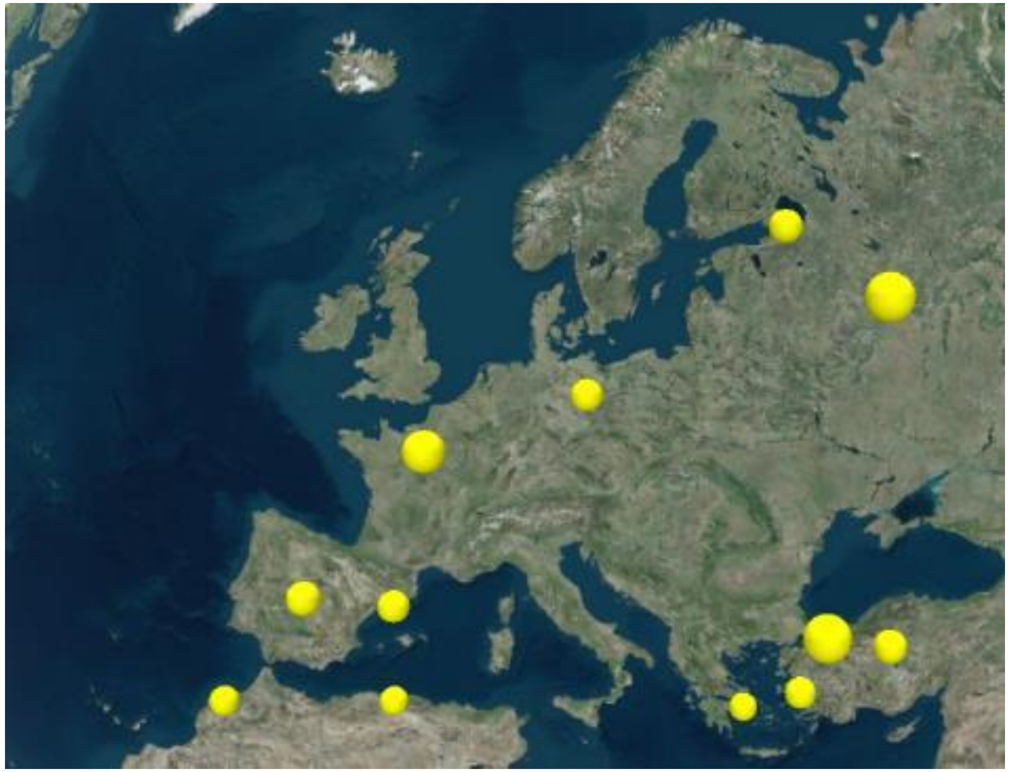
World Cities Database

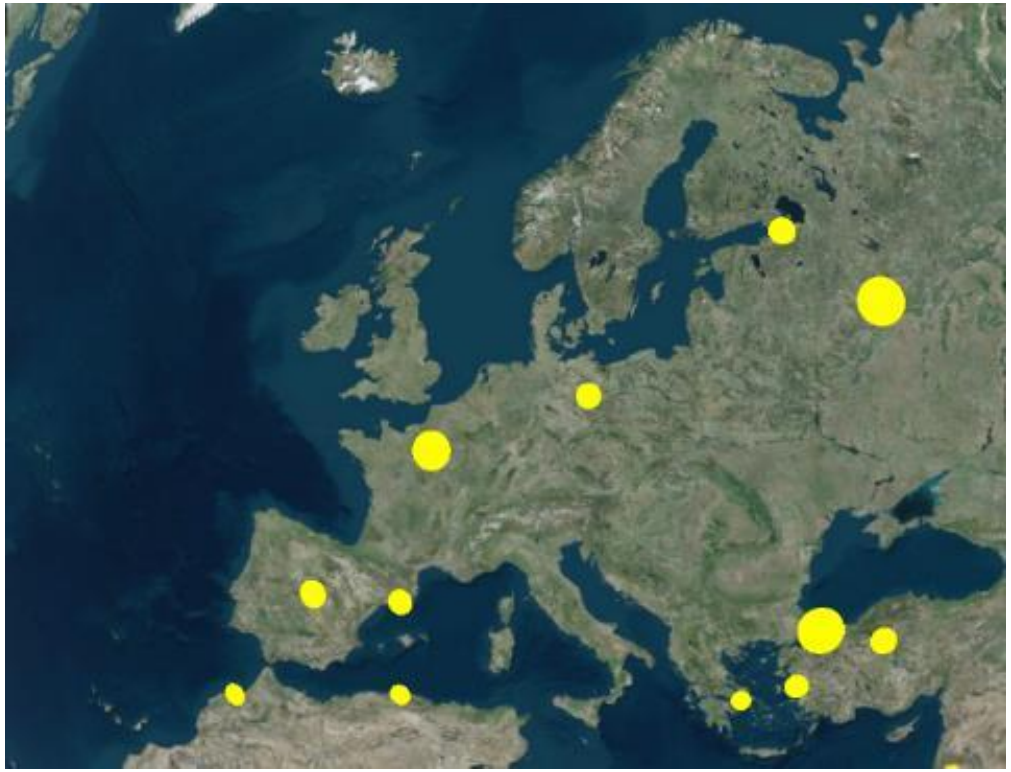
Population > 3 millions

Prototype Platform

Google Earth Plug-in → CesiumJS

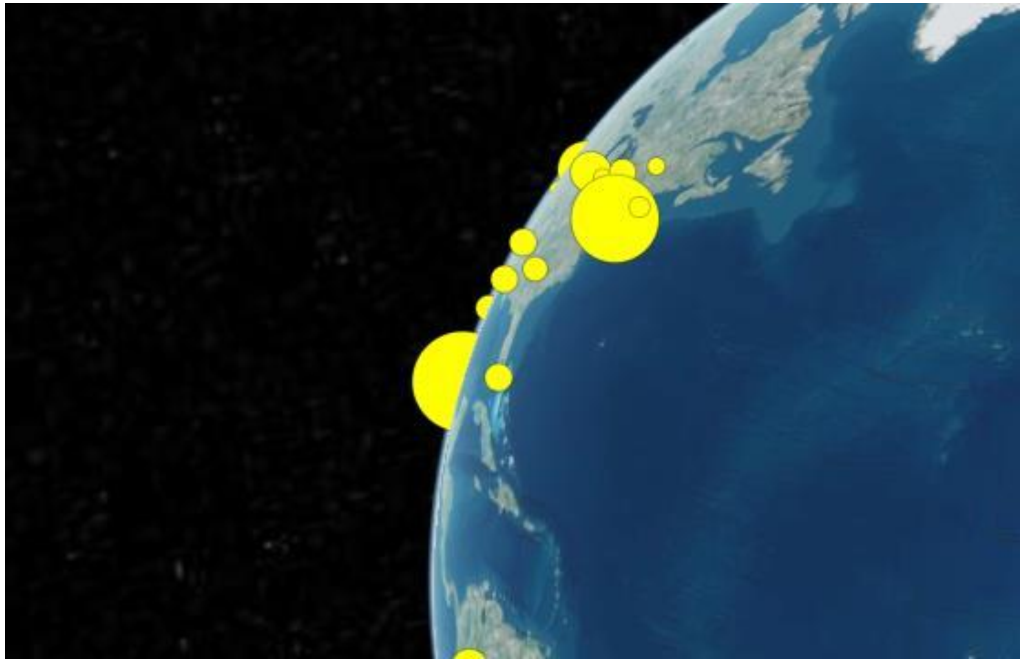
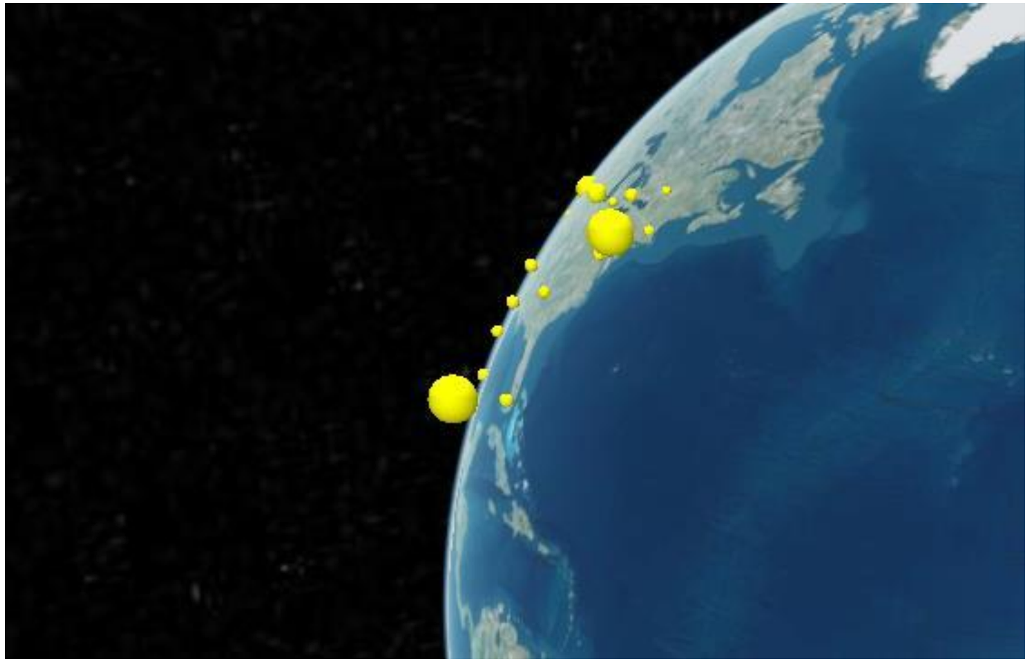
Design Symbols





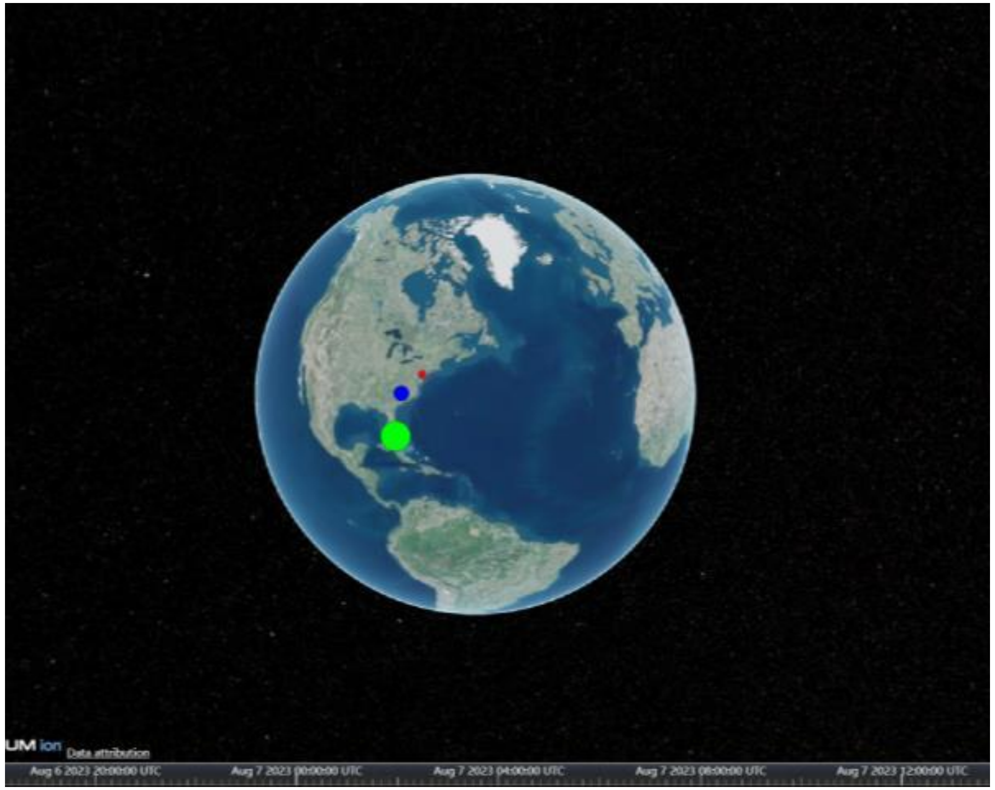
Shape
Similarity

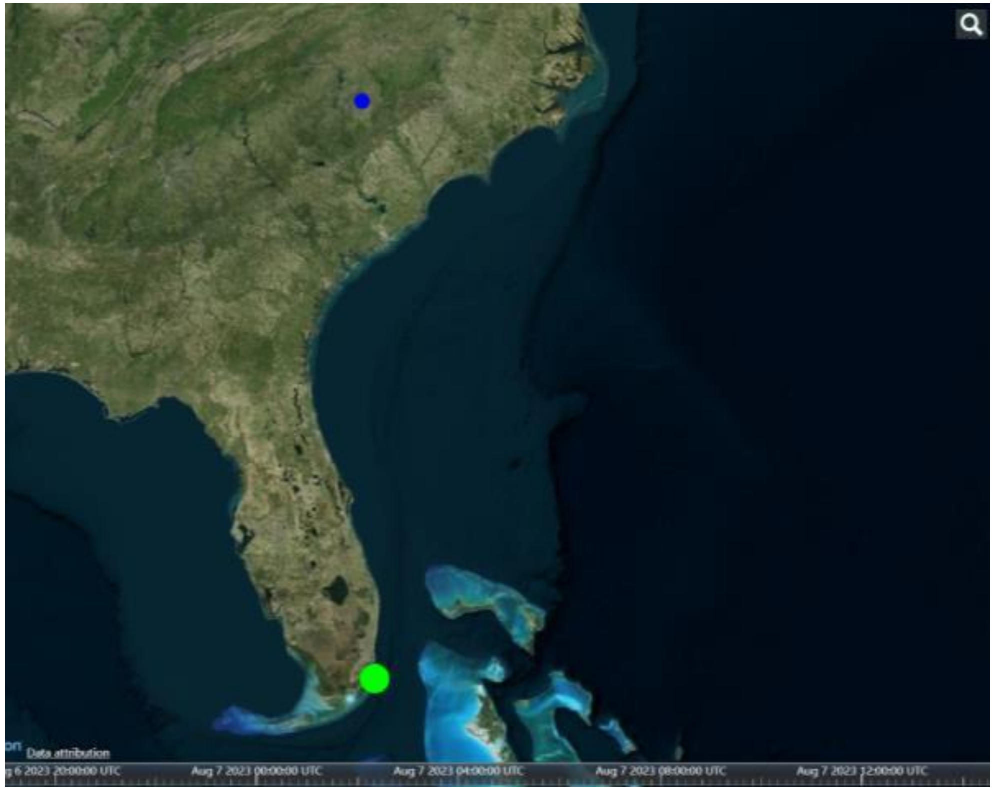
Design Symbols

Orientation
Similarity

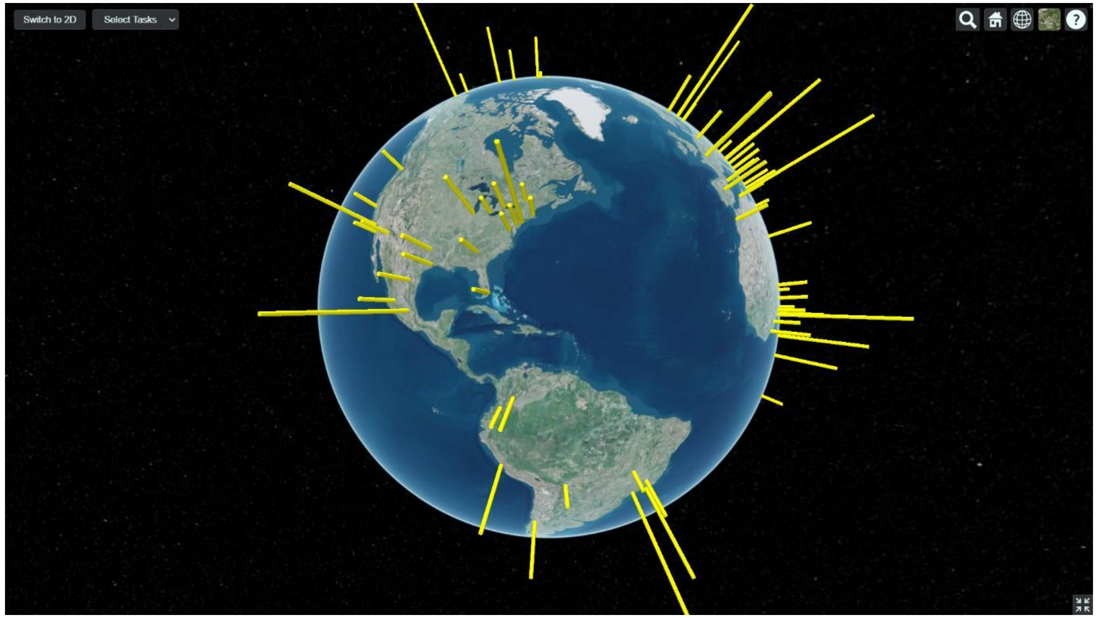
Design Symbols

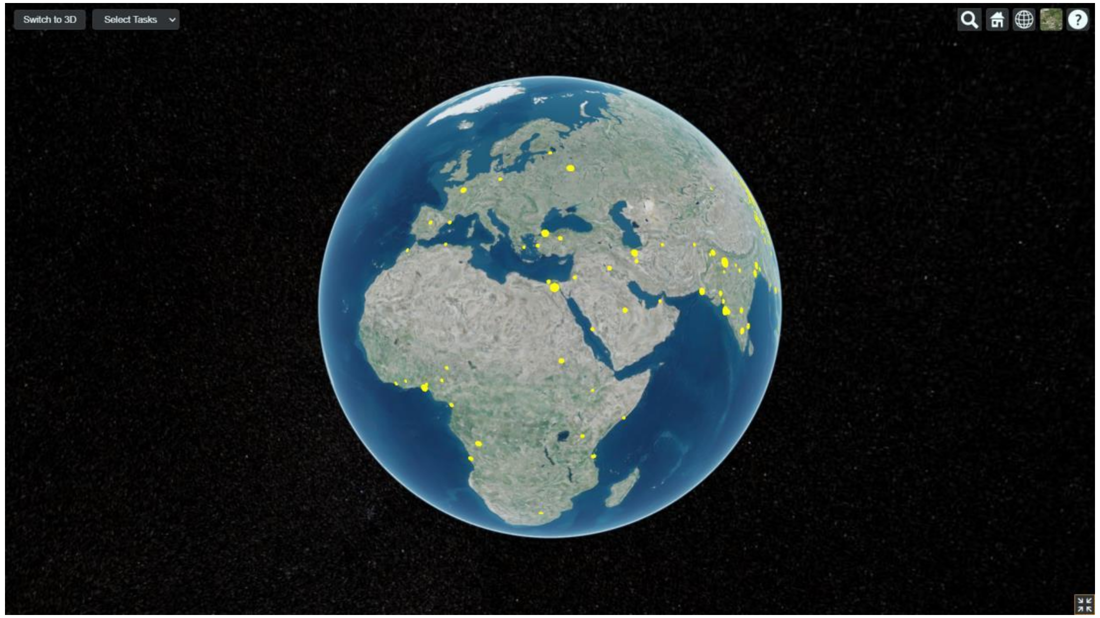




Size difference change between each other

Design Symbols





Final Design

“Scale” for Virtual Globes

There is no definition of scale for Virtual Globes…..

Therefore, the concept “ zoom level” is used to fits the concept of “scale” for Virtual Globes:

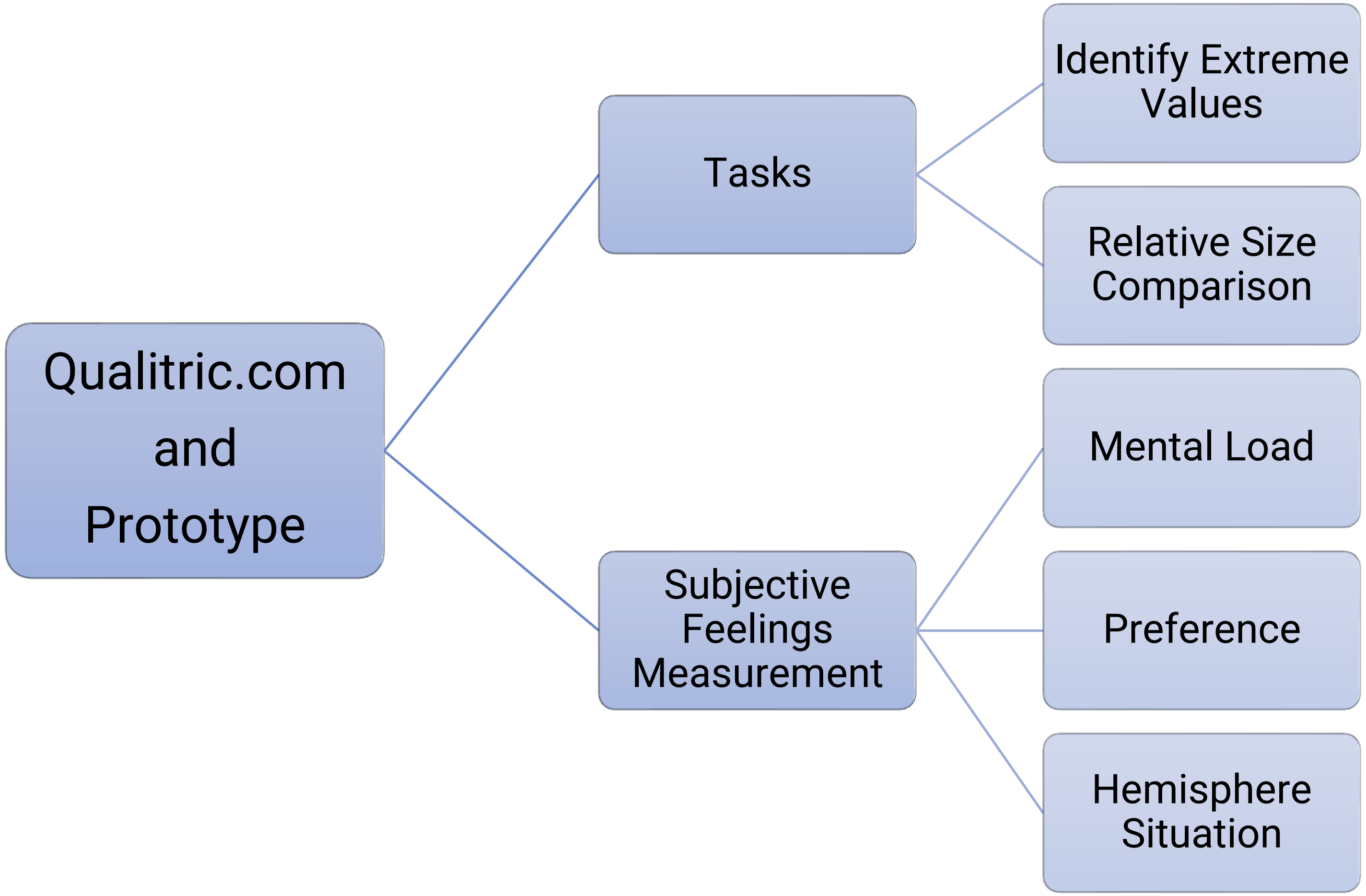
And in Cesium environment, the zoom level is corresponding to the camera height.

1> Small scale VG: Small zoom level - high camera height where the entire globe is visible.

2> Medium scale VG: Medium zoom level - medium camera height where only part of the curvature of the globes is visible.

3> Large scale VG: Large zoom level - Low camera height where the curvature is invisible, and the VG looks like a flat map.

User study



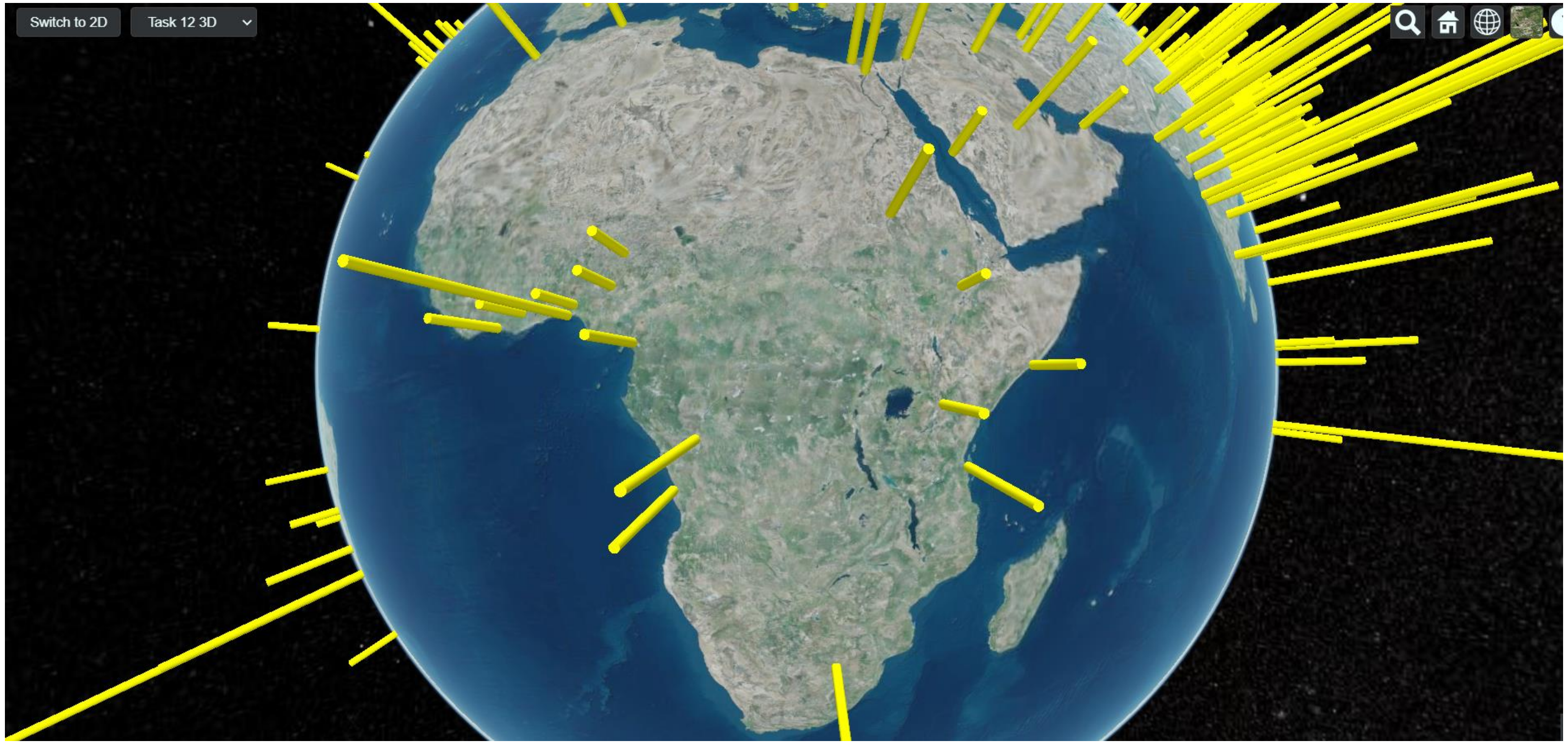
Qualitric.com and Prototype
Tasks
Identify Extreme Values
Relative Size Comparison
Subjective Feelings Measurement
Mental Load
Preference
Hemisphere Situation

User study

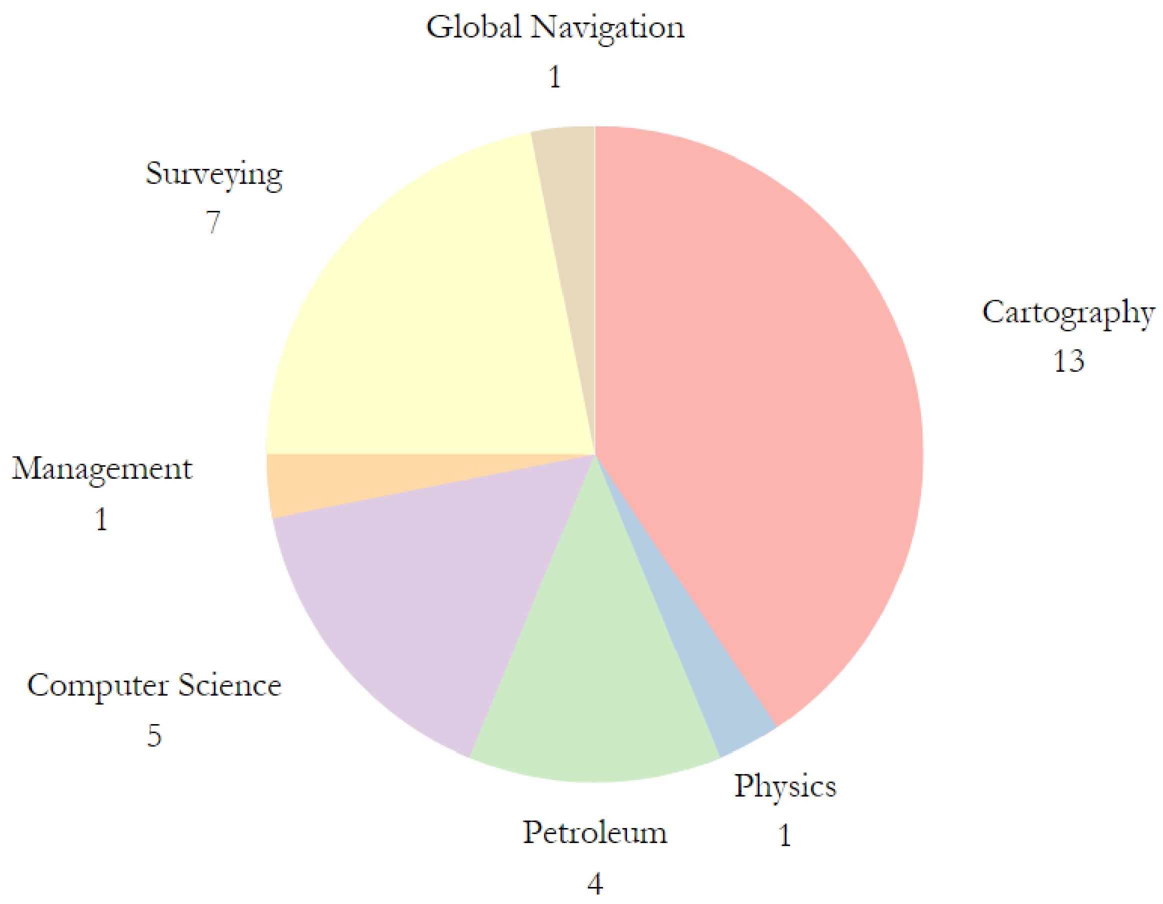
Example:
Task 5: Identify the approximate ratio of population – San Diego : Los Angeles

User study

Example:
Task 12: Identify the city with the largest population in Africa.

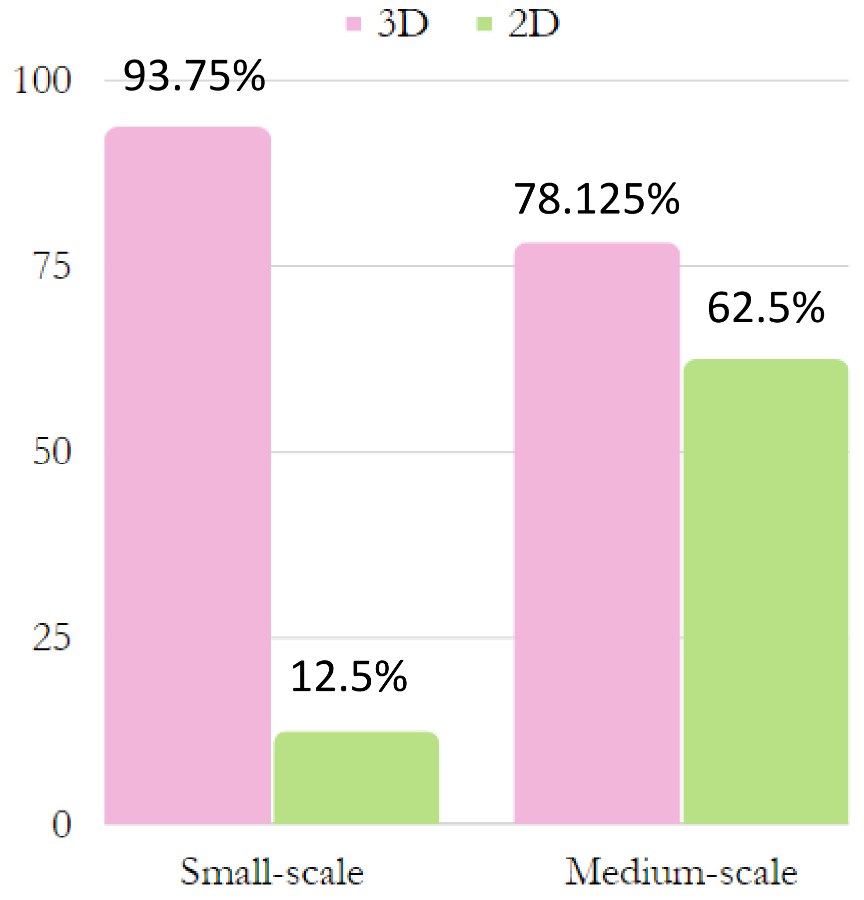


Result - Participants



Result - Effectiveness

Identify extreme value tasks:



Result - Effectiveness

Relative Size Comparison:

Symbols	Scale	Group			
		All			
		Z	p	r	Difference
3D	small scale	0.8	p = .446	0.1	Non-sig small
	medium scale	0.9	p = .386	0.1	Non-sig small
	large scale	-2.8	**p = .006**	-0.3	**Sig. medium**
2D	small scale	2.8	**p = .005**	0.5	**Sig. medium**
	medium scale	-2.6	**p = .010**	-0.3	**Sig. medium**
	large scale	-3.9	**p < .001**	-0.5	**Sig. medium**

Applied statistical methods:

Shapiro-Wilk Test: check the normality of the data distribution.

Wilcoxon Test: compare all response to the correct answer.

Result - Effectiveness

Relative Size Comparison:

Symbols	Scale	Group			
		Cartographer			
		Z	p	r	Difference
3D	small scale	-0.3	p = .736	-0.08	non-significant very small
	medium scale	-0.009	p = .993	-0.002	non-significant very small
	large scale	-1.5	p = .137	-0.3	non-significant small
2D	small scale	2.1	**p = .039**	0.5	**significant large difference**
	medium scale	-2.1	**p = .032**	-0.4	significant medium
	large scale	-2.8	**p = .004**	-0.5	**significant large difference**

Applied statistical methods:

Shapiro-Wilk Test: check the normality of the data distribution.

Wilcoxon Test: compare all response to the correct answer.

Result - Effectiveness

Relative Size Comparison:

Symbols	Scale	Group			
		Non-Cartographer			
		Z	p	r	Difference
3D	small scale	1.5	p = .123	0.4	non-significant medium
	medium scale	1.4	p = .152	0.3	non-significant small
	large scale	-2.5	**p = .010**	-0.5	**significant medium**
2D	small scale	1.9	p = .058	0.5	non-significant medium
	medium scale	-1.5	p = .136	-0.3	non-significant small
	large scale	-2.5	**p = .013**	-0.4	**significant medium**

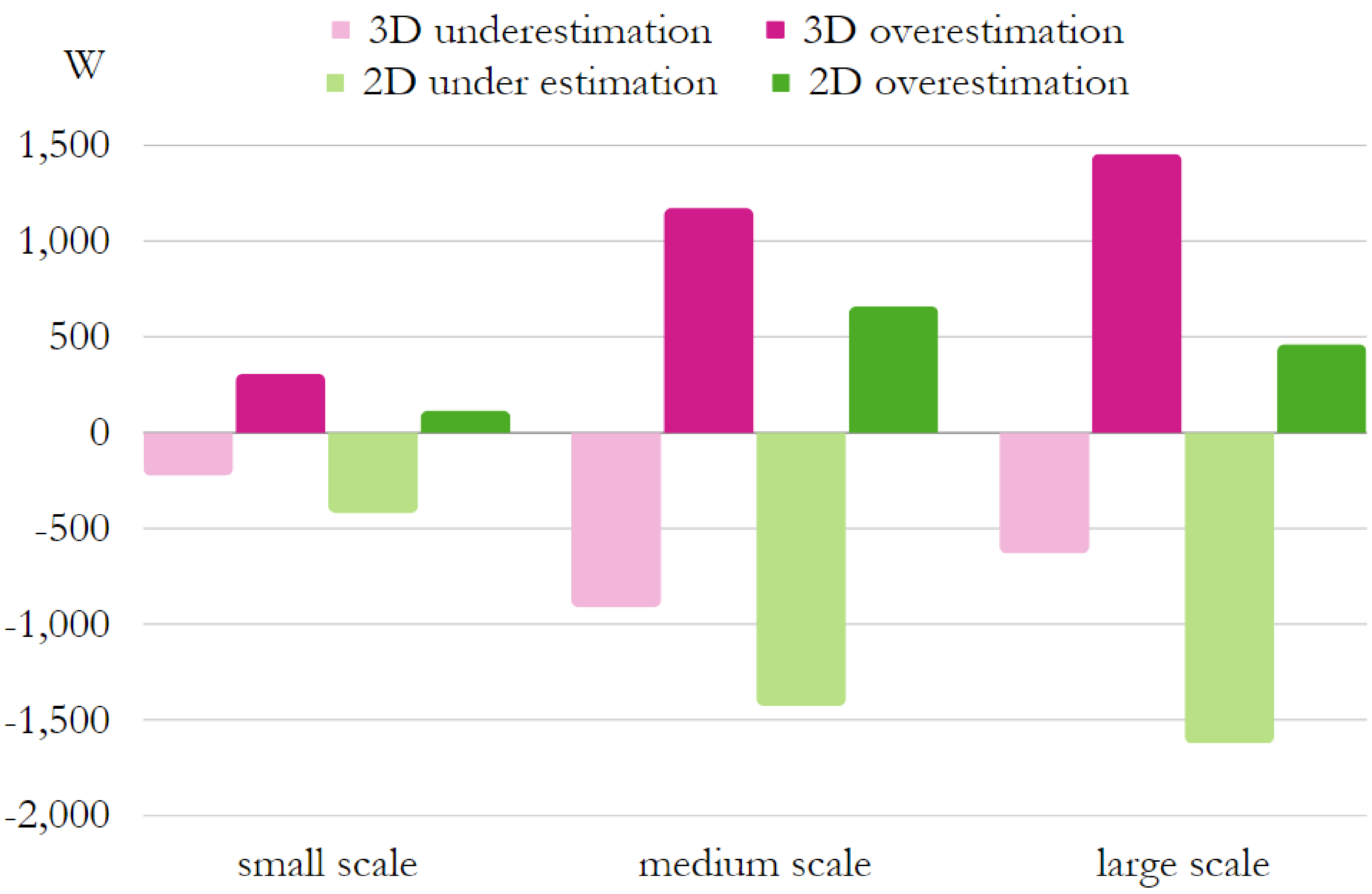
Applied statistical methods:

Shapiro-Wilk Test: check the normality of the data distribution.

Wilcoxon Test: compare all response to the correct answer.

Result - Bias

Over- and under estimation of all Users response



Result – Mental Load

Groups	Kruskal-Wallis Test	Difference appears between
All	($\chi^2(2) = 33.06, p < .001$)	Small – Medium - Large
Cartographer	(χ^2 (2) = 13.67, p = .001)	Small – Large; Medium - Large
Non-cartographer	($\chi^2(2) = 18.9, p < .001$)	Small – Large; Medium - Large

No significant difference is detected across groups.

Applied statistical methods:

Shapiro-Wilk Test: check the normality of the data distribution.
Kruskal-Wallis H Test: compare responses between scales and groups.
Post-hoc Dunn‘s test: test where the difference appears.

Result – Preference

Groups	Kruskal-Wallis Test	Difference appears between
All	($\chi^2(2) = 34.45$, $p < .001$)	Small – Large; Medium - Large
Cartographer	($\chi^2(2) = 9.71$, $p = .008$)	Small – Large; Medium - Large
Non-cartographer	($\chi^2(2) = 24.12$, $p < .001$)	Small – Large; Medium - Large

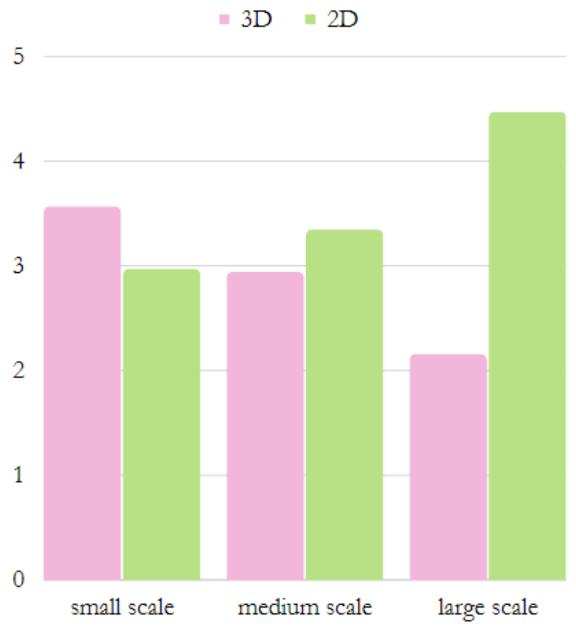
No significant difference is detected across groups.

Applied statistical methods:

Shapiro-Wilk Test: check the normality of the data distribution.
Kruskal-Wallis H Test: compare responses between scales.
Post-hoc Dunn‘s test: test where the difference appears.

Result – Objects on same sides of the Globe

Rating of all users



No significant difference is found when objects are on the different sides of the globe.

Applied statistical methods:

Shapiro-Wilk Test: check the normality of the data distribution.
ANOVA: compare responses between groups.

Discussion – Effectiveness:

1> **Statistically, the effectiveness of 3D cylinders performs well at small and medium scale. It becomes worse as zoom in.**
Users need to rotate the globe to specific angles to see the contrast between two one-dimensional objects.

2> **The effectiveness of 2D circles does not perform well at all scales of zoom level, especially at small scale and large scale.**
Distortion and professional knowledge.

3> **Users are more likely to overestimate the 3D cylinders, underestimate the 2D circles. The likelihood of overestimation and underestimation becomes larger as the zoom level becomes larger.**
Adaptation level (Cox, 1976)

4> **When objects are not on the same side of the globe, users have no preference in 3D and 2D symbols, but 3D cylinders statistically perform better.**
Impact of visibility take higher percentage.

5> **3D cylinders are more effective in representing similar values than 2D circles at small scale and medium scale.**
Difference in dimension.

Discussion - Across users:

Cartographer users are more likely to be influenced by the symbols, while non-cartographers are more likely to be influenced by the scale, especially large scale.

Discussion - User perspectives:

3D cylinders create less mental load and are preferred at small scale.

2D circles create less mental load and are preferred at large scale.

Discussion - Medium scale

Where more likely to be the changing point:

Statistically, 3D cylinders perform better; Subjectively, 2D circles are preferred.

Conclusion

Rather than indicate a specific scale point as design guideline, this study uses the result of the user study to **propose the idea that dynamic symbols, changing from 3D symbols to 2D symbols as zooming in, could be a better design for Web-based VG applications**.

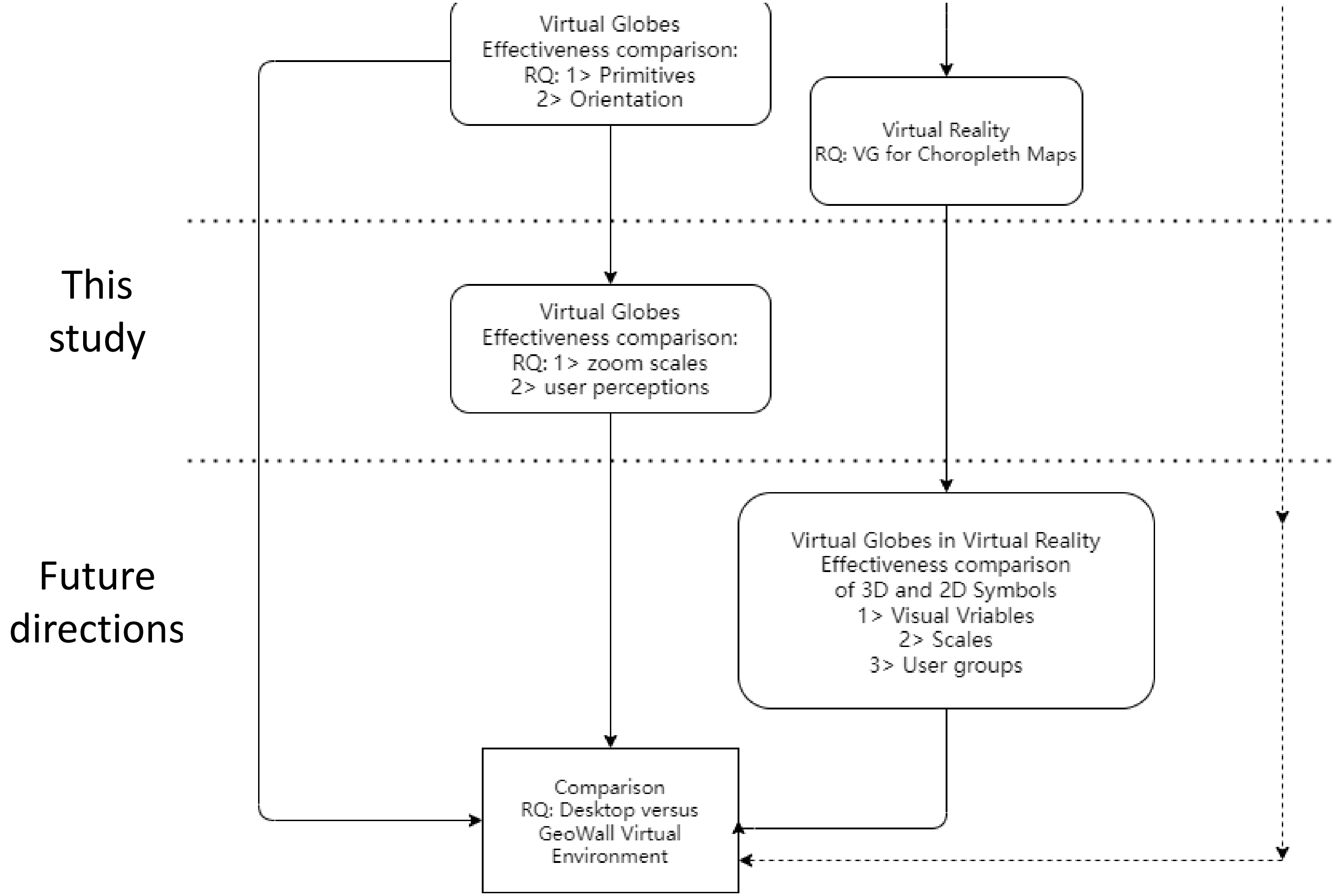
However, the specific changing point **should always** consider the purpose of visualization, the targeting users, the density of the objects, and other influencing factors.

Future Direction

- **Other Visual Variables**

  (Desktop environment)
- **More Complex tasks**
- **Visual Variables & Circumstance**

  (Virtual Reality & Augmented Reality)
- **Compare Virtual Environment**
- **Efficiency**



Thank you!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Link to the prototype: http://map.sonnenberg.app