On Augmented Reality
some recent work for Industry

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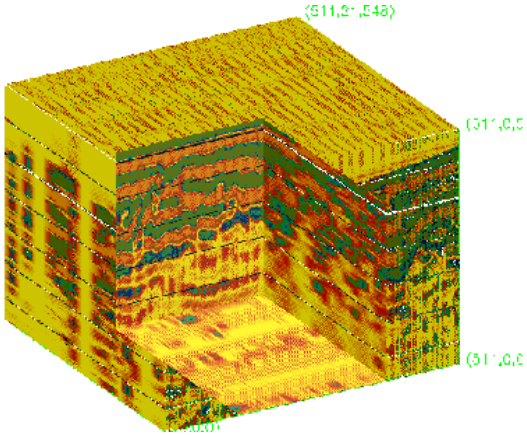
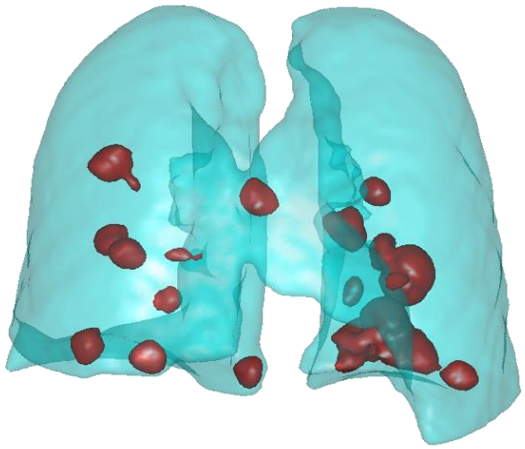
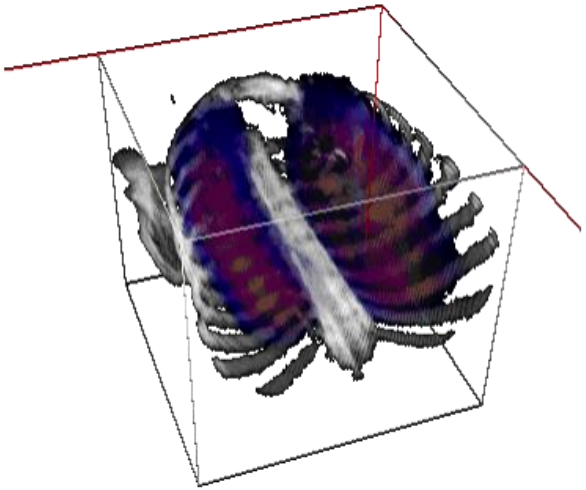
ICGI 2021
NOVEMBER 4th - 5th, 2021
FEUP - PORTO - PORTUGAL

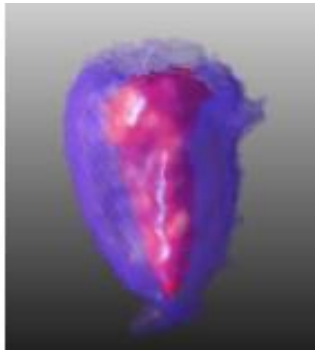
November, 2021

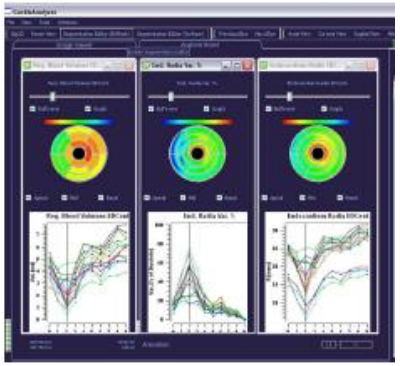
Before I knew about AR …

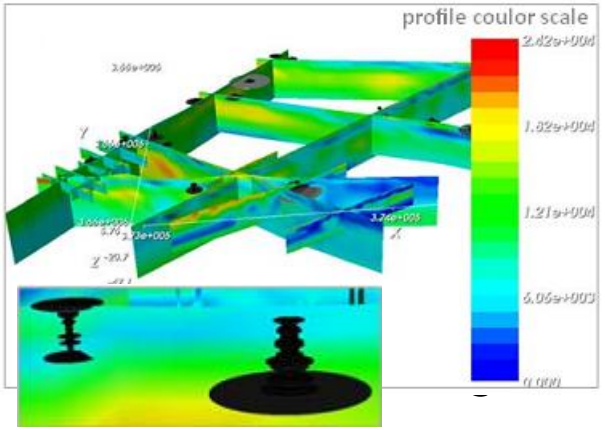












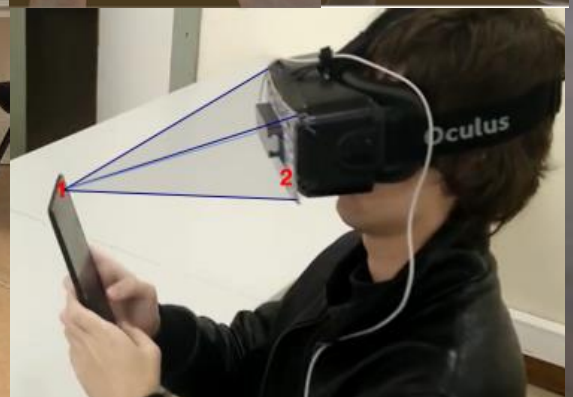
In the 90's **2000's**

t

Usable and affordable VR

Exploring:

- interaction devices and methods
- Setups and systems
- Applications
- …

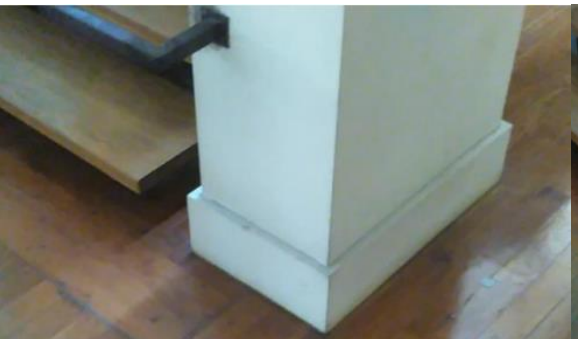


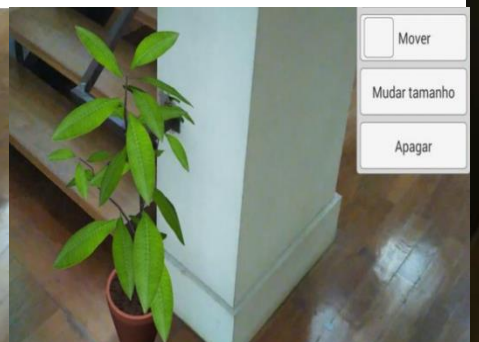
And AR …

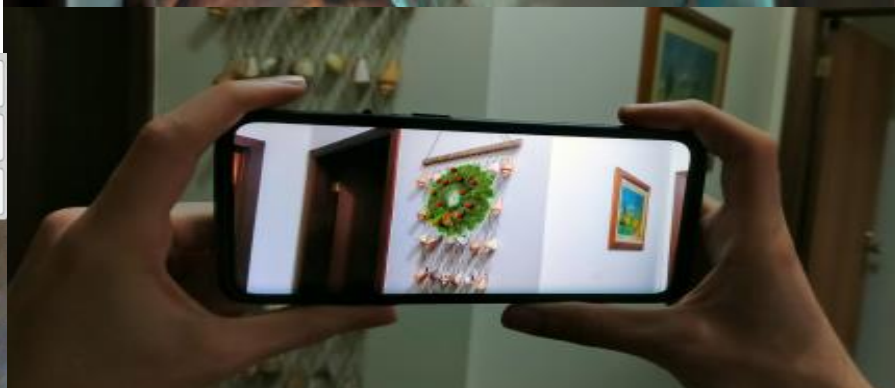
- Exploring AR for:

- Quasi-continuous experiences
- Easily setting augmented environments in AR or VR
- Collaboration (also hybrid AR/VR)

- …







- But after all what defines Augmented Reality

  and how did it evolve?

These ideas are not new …

The ultimate display?

"… a room within which the computer can control the existence of matter…"

(Sutherland, 1965)

The first Augmented Reality (AR) system …. **(Sutherland, 1968)**

50+ years later: still far from Sutherland's ultimate display …

Disseminated by Sci-Fi …

“Help Me, Obi-Wan Kenobi. You're My Only Hope” **(Star Wars, 1977)**

Several realities …

- Virtual Reality (VR)
- **Augmented Reality (AR)**
- Mixed Reality (MR)
- Extended Reality (XR)
- …

AR is part of the Reality Virtuality “Continuum”

“Augmenting natural feedback to the operator with simulated cues”

(Milgram & Kishino, 1994)

Mixed Reality (MR)

Real Environment **Augmented Reality** Augmented Virtuality Virtual Environment

(Steinicke et al., 2009)

Has a plethora of potential compelling AR applications

"make the computer **interface invisible** and make interacting with the computer **as natural as interacting with real world** objects, removing the separation between the digital and physical"

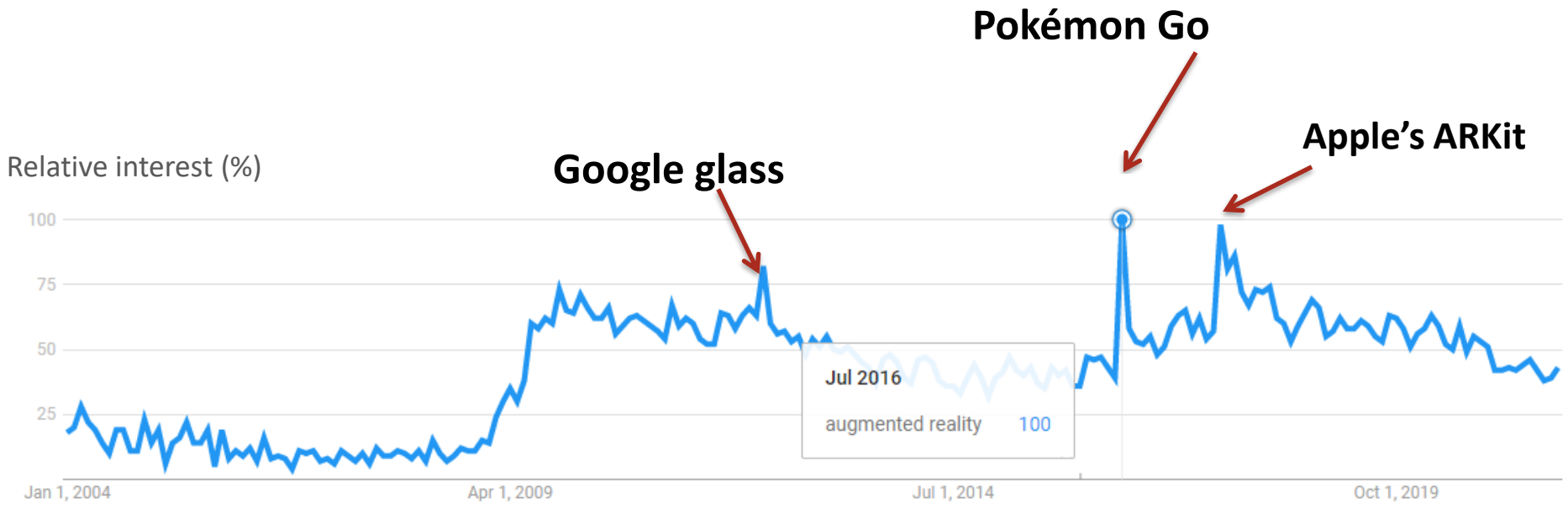
(Billinghurst et al., 2015)

AR interfaces are designed to enhance interactions in the real world

Education/training Medicine Industry Marketing...



Awareness, interest and adoption of AR



(Google trends – Augmented reality, Worldwide)

Pokémon Go demonstrated AR's potential to be adopted by mainstream culture

The global AR services market is expected grow 5x until 2025

Several terms and definitions

M. Speicher, B. D. Hall, and M. Nebeling, “What is Mixed Reality ?,” *CHI ’19 Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, 2019.

(Google trends – Augmented reality)
(Google trends – Mixed reality)

Specific HMDs

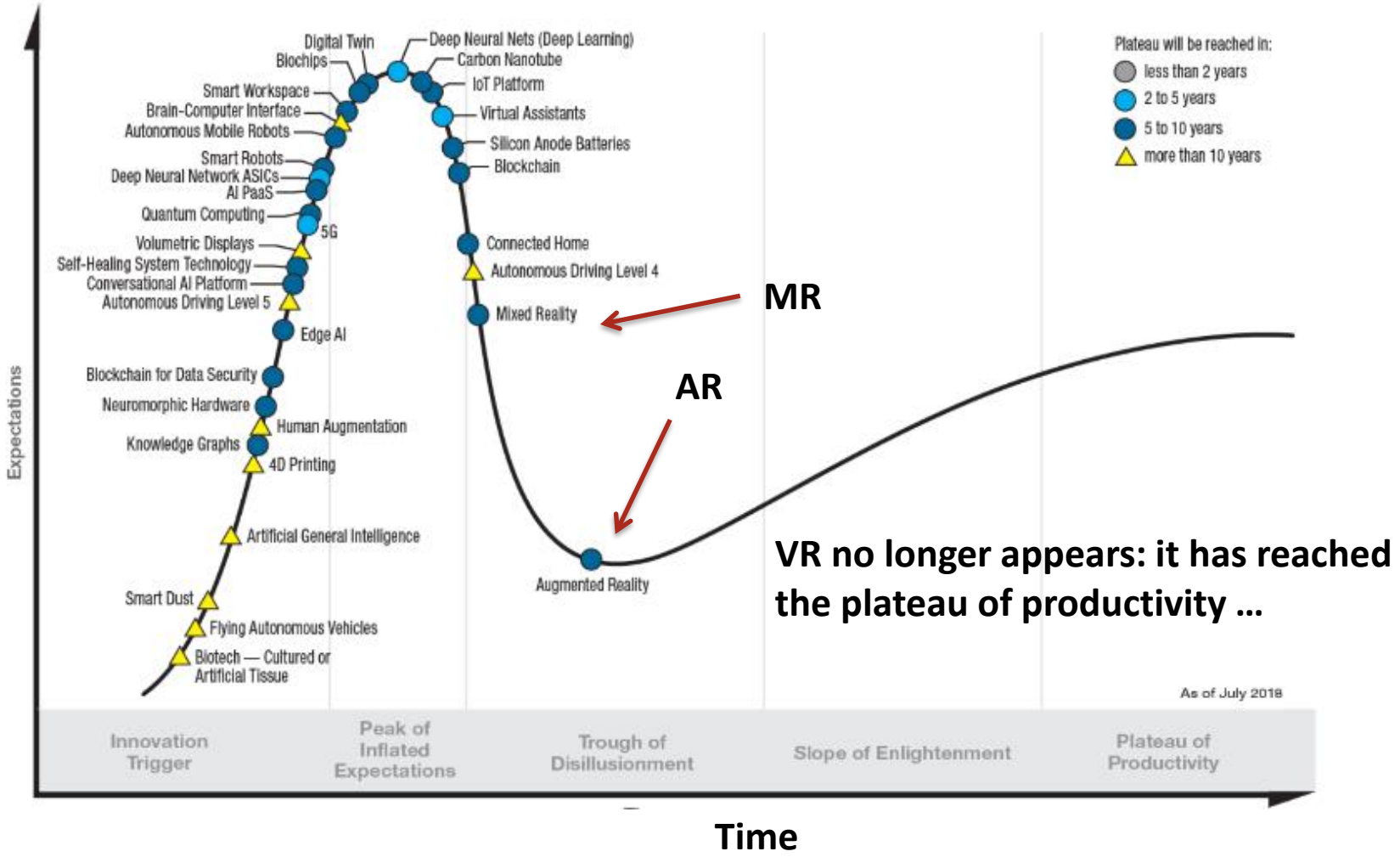
AR *vs* MR: branding strategy, interaction, believability?

Recent umbrella term - Extended Reality (XR)

Gartner's Hype cycle - AR Last appearance

2018

Expectations



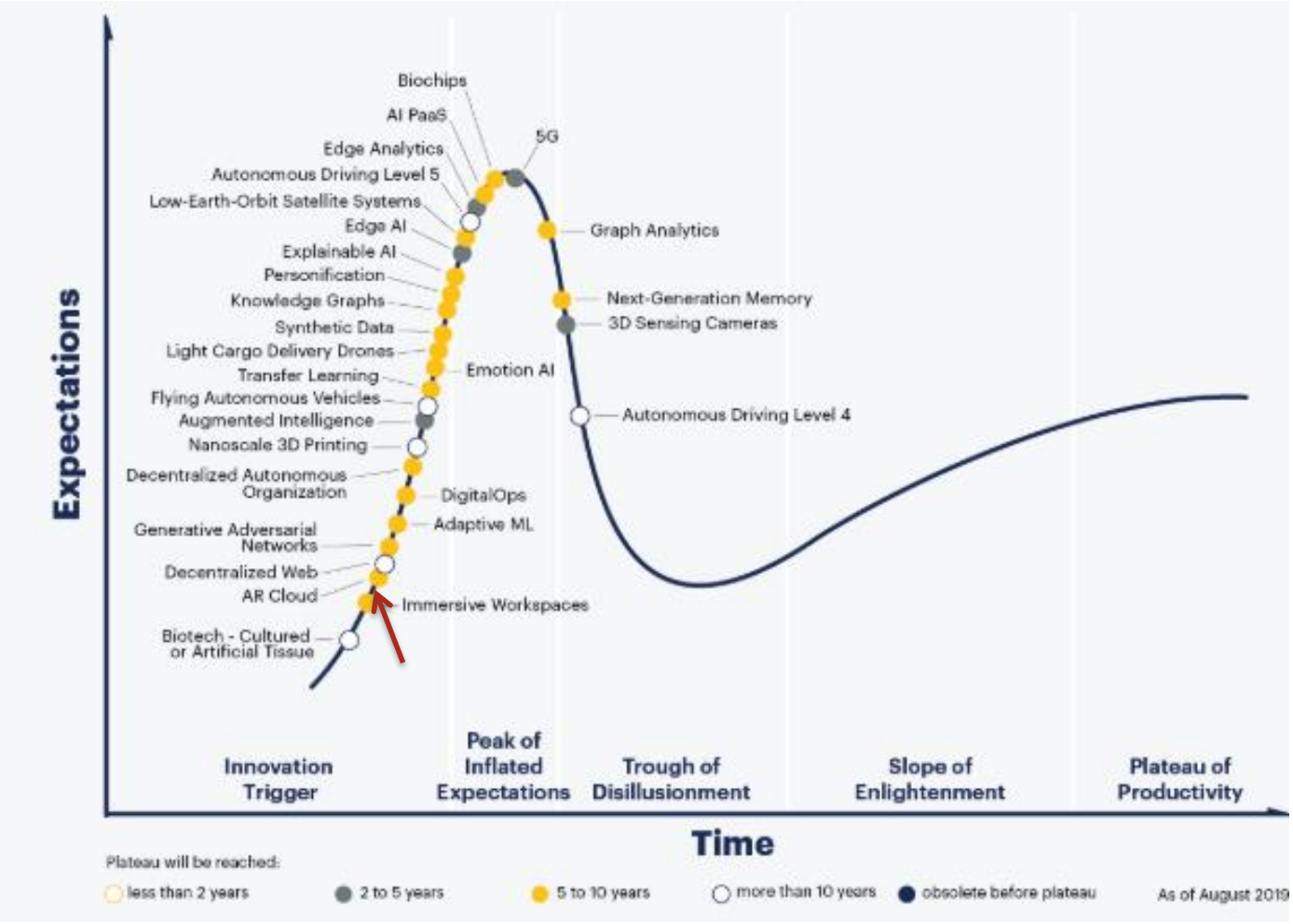
MR

AR

VR no longer appears: it has reached the plateau of productivity …

Gartner's Hype cycle - AR no longer appears

2019



Expanding from a research field into commercially viable technologies …

Augmented Reality …

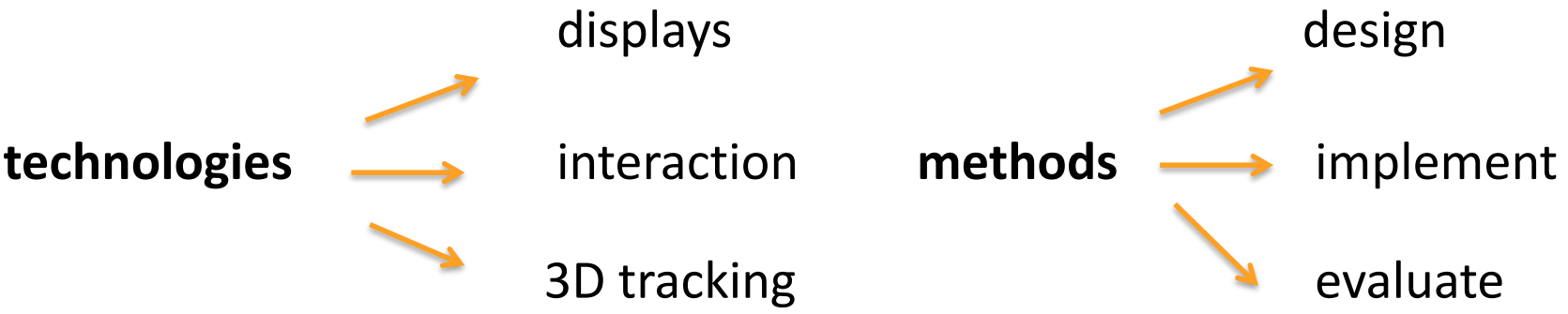
(Azuma, 1997)

1) combines **real and virtual images**,

2) is **interactive** in real time,

3) the virtual imagery is **registered in 3D**

- Requires:



Has evolved and Mobile AR provides an easily accessible entry point

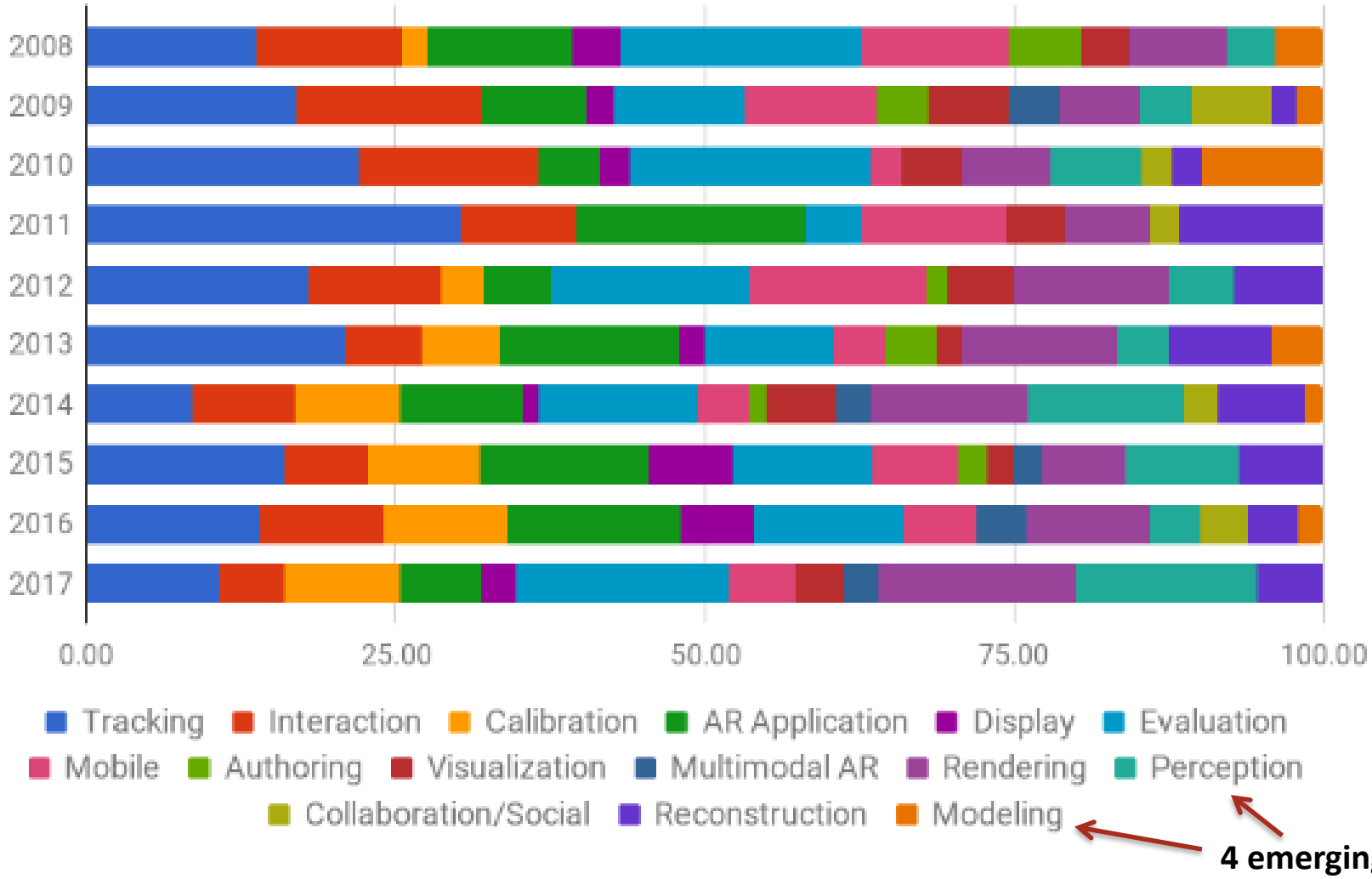
the true potential is achieved through

- HMDs,
- a richer interaction,
- better tracking

In some niche situations, projection AR (SAR) may be Interesting

Research on Augmented Reality (2008-2017)

(Kim et al., 2018)



Trends of ISMAR research topics within ISMAR 2008–2017

Needed Research on Augmented Reality

(Billinghurst, 2021)

1) Displays,

2) Interaction,

3) Tracking,

4) Collaboration,

5) Perception and Neuroscience,

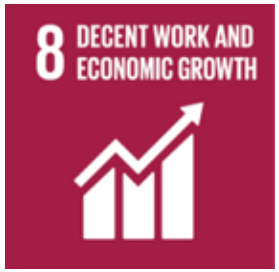
6) Social and Ethical issues + Evaluation

VARLab @ IEETA

- Visual / Interactive systems and methods:
  - Useful
  - Usable
  - Affordable

Human-centered!

- Conceptual, experimental/empirical, and/or applied/real-world



AR research @ IEETA

- Collaboration – Conceptual:
  taxonomy
  roadmap
  evaluation
  Experimental: comparing methods

- Interaction - Experimental:
  comparing methods in assembly
  hybrid systems: AR + VR to configure Augmented spaces
  Applied:
  AR for manufacturing
  Conceptual:
  Situated Visualization

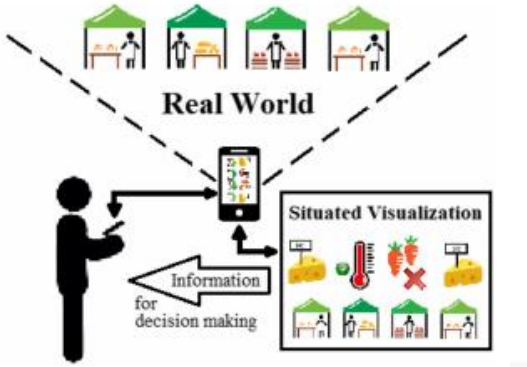
Some recent works:

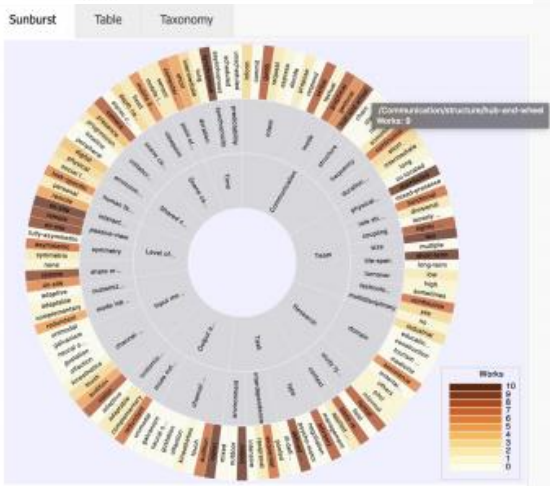
- Conceptual

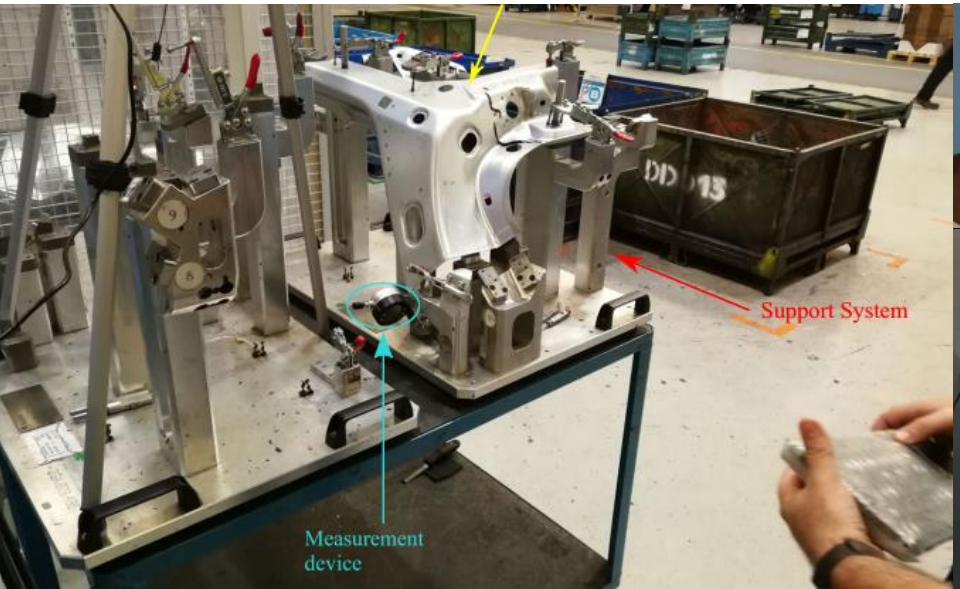
  AR-based Collaboration, Situated Visualization

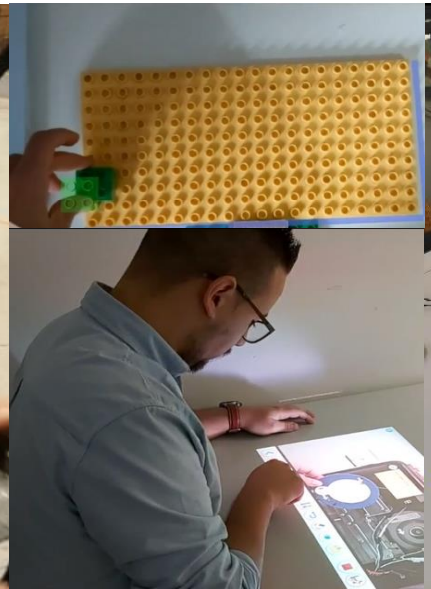
- Experimental – AR for assembly

- Applied - AR for manufacturing









I- A Conceptual Model and Taxonomy for Collaborative AR

- AR has been explored to assist in scenarios of collaboration
- It is vital to understand what is involved in AR-mediated collaboration
- To create a common ground for systematization and discussion
- And inform the creation of new methods and systems

(Marques, Silva et al., 2021)

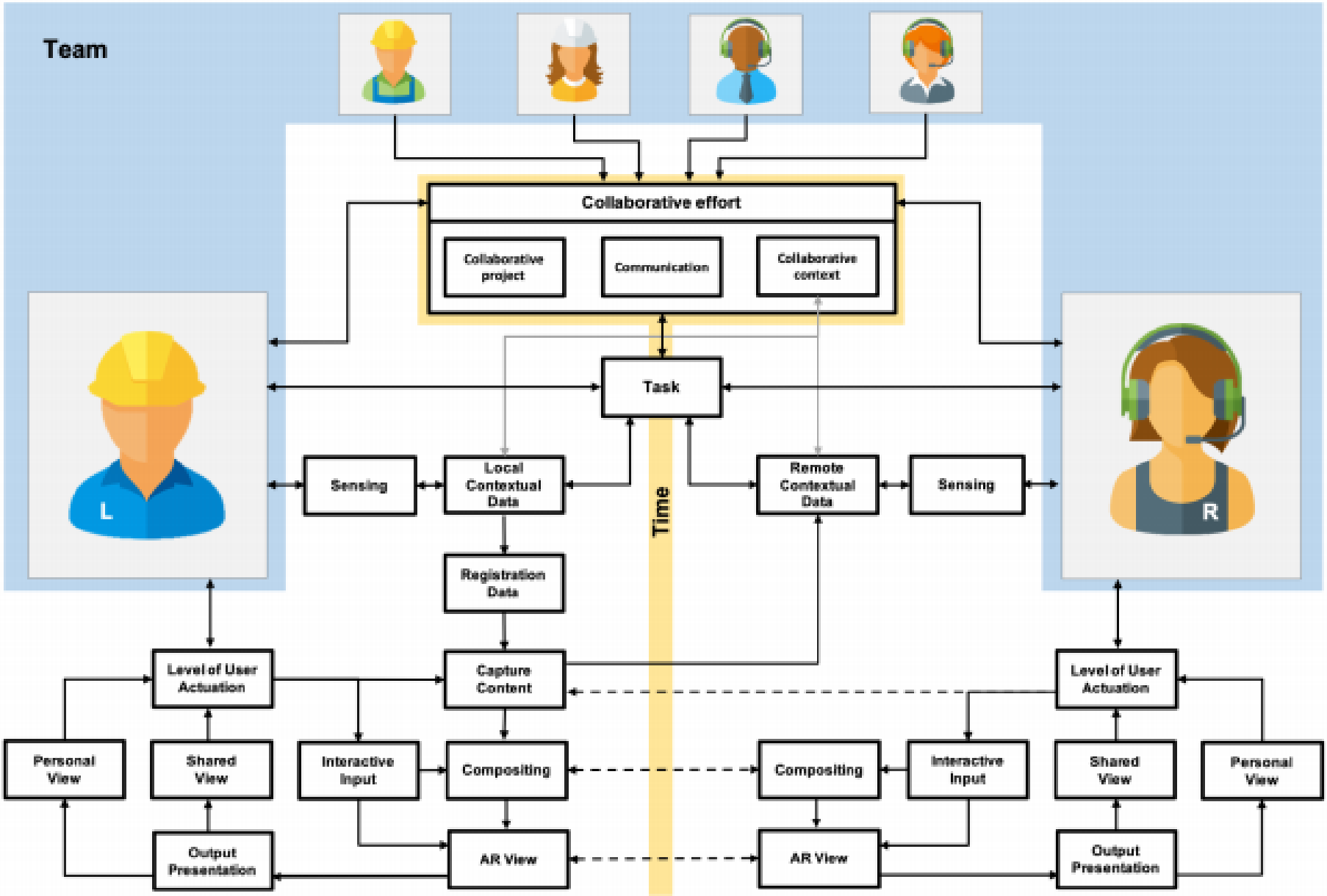
Conceptual Model and Taxonomy for Collaborative AR

- Understanding the problem involved:
- Focus group session at an Industrial partner including:
  - Target users and other stakeholders
  - AR researchers
- Brainstorming sessions …

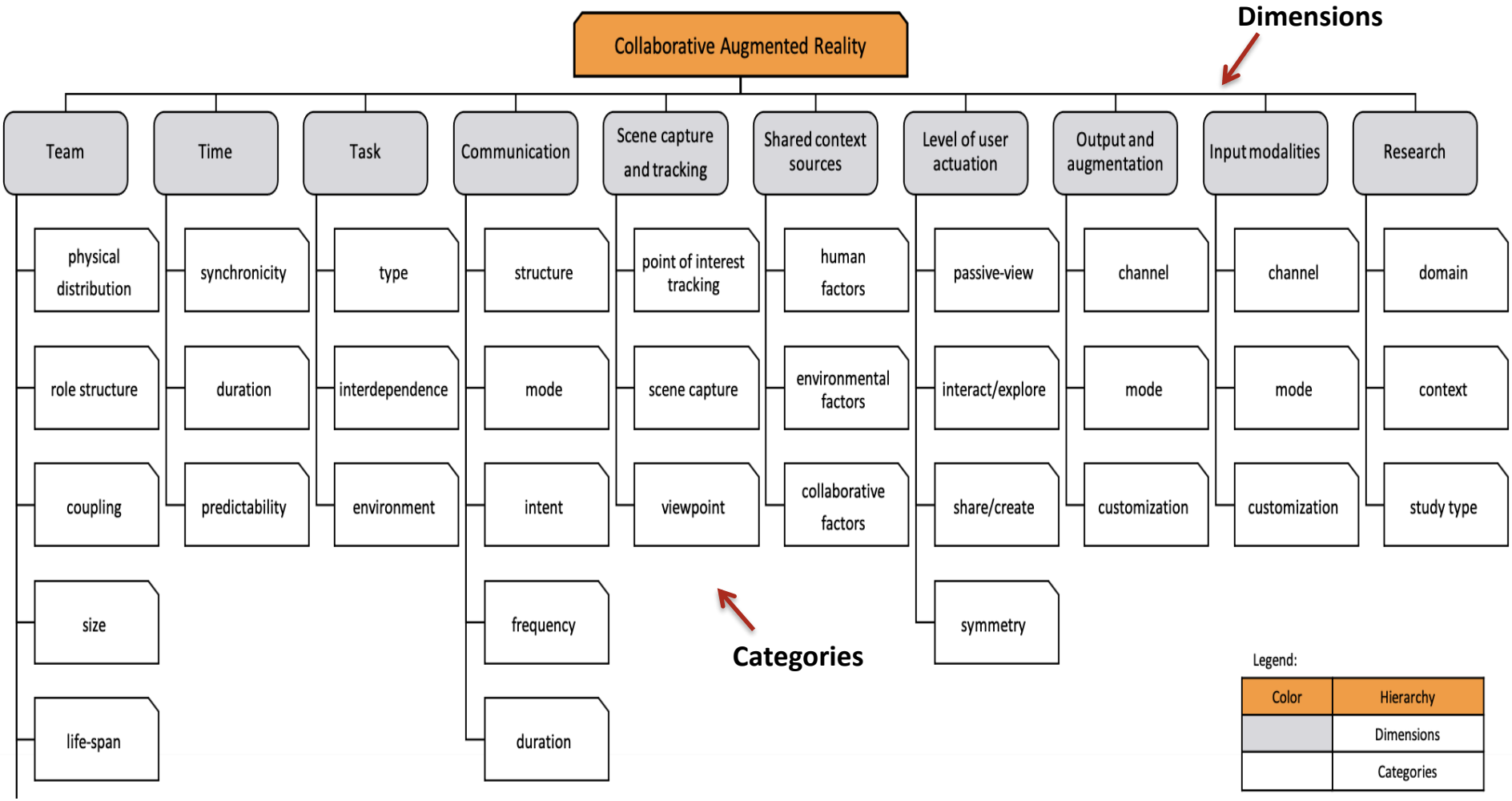
Conceptual Model and Taxonomy for Collaborative AR

- We propose a human-centered taxonomy for the categorization of the main features of Collaborative AR
- To help create a common ground for systematization and discussion
- Present examples of the use of the taxonomy
- Illustrating its potential as the grounds to elicit further studies

A Conceptual Model for Collaborative AR

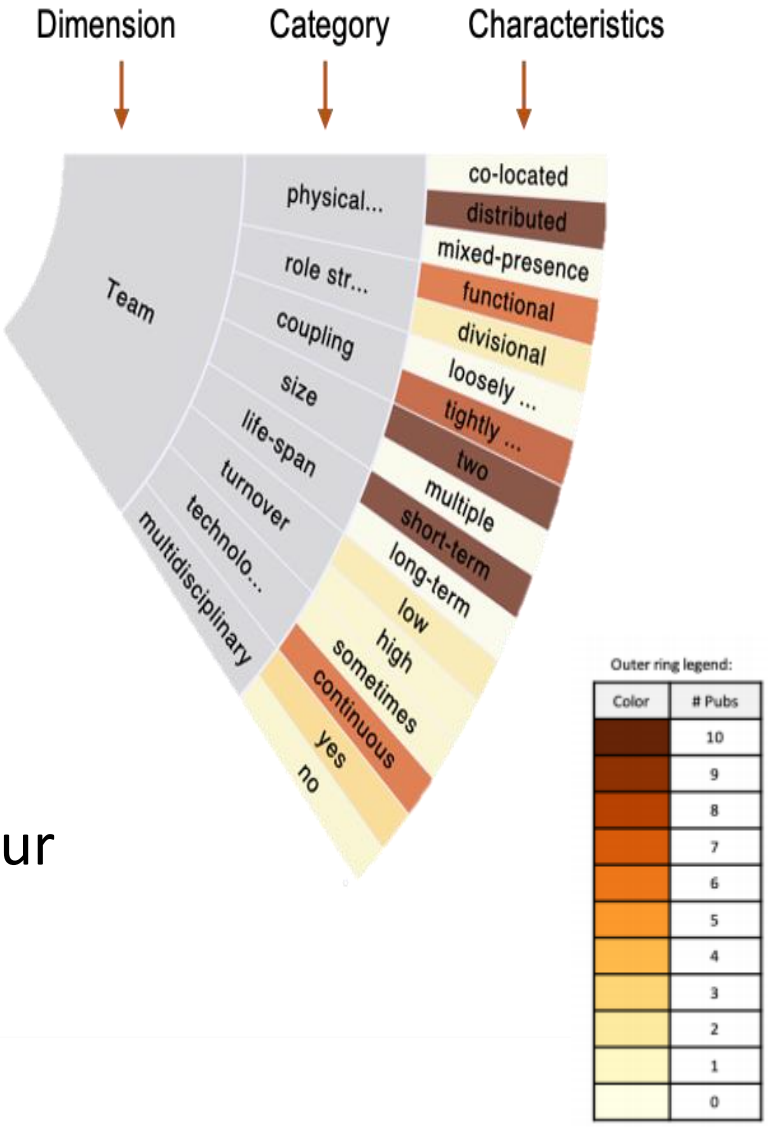


A Human-centered Taxonomy for Collaborative AR



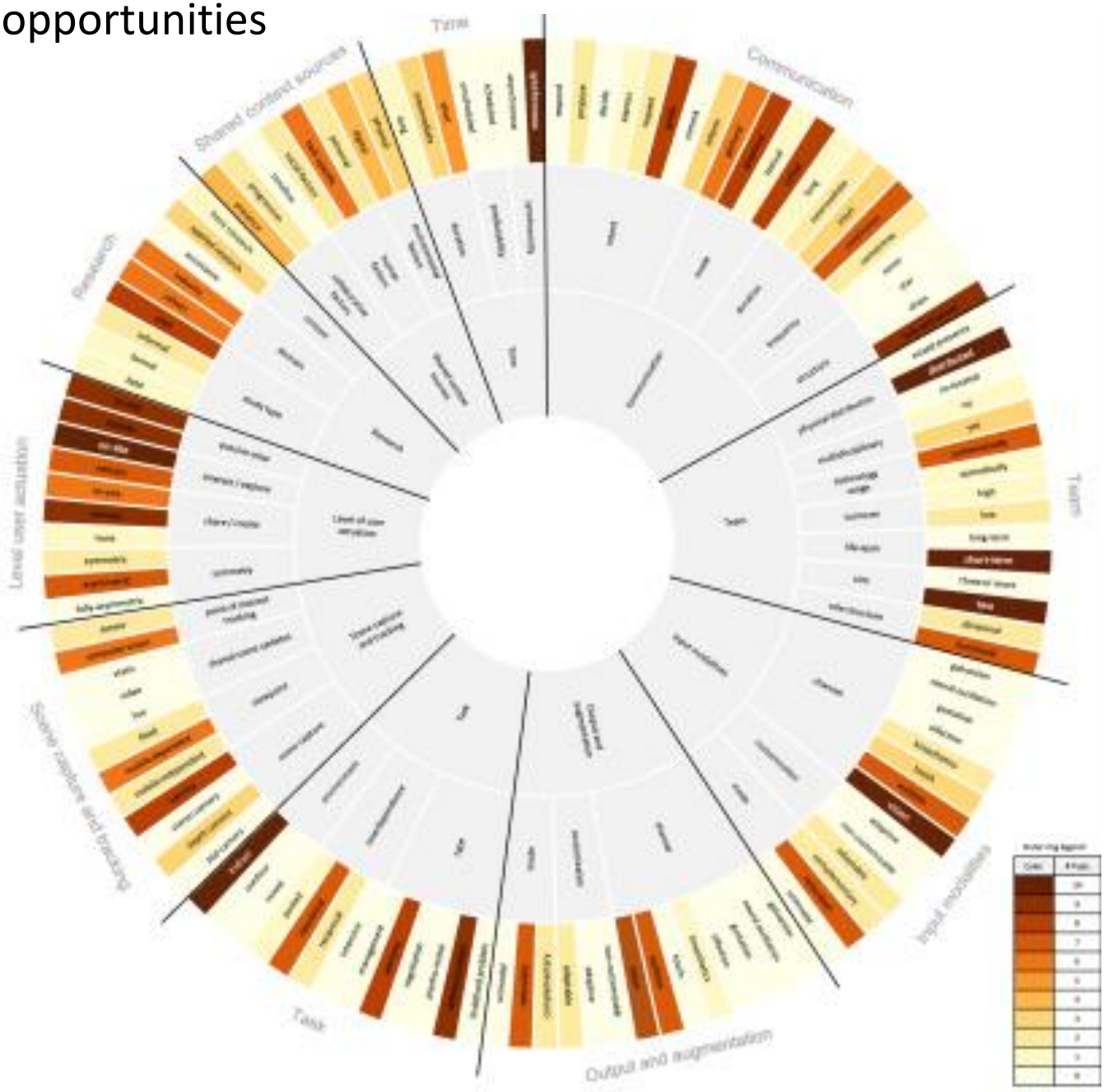
Visually exploring the Taxonomy for Collaborative AR

- Visual exploration of a corpus of papers using the taxonomy
- To identify research trends and opportunities
- Each paper is represented by slicing and dividing rings of a sunburst
- Number of papers is encoded by colour

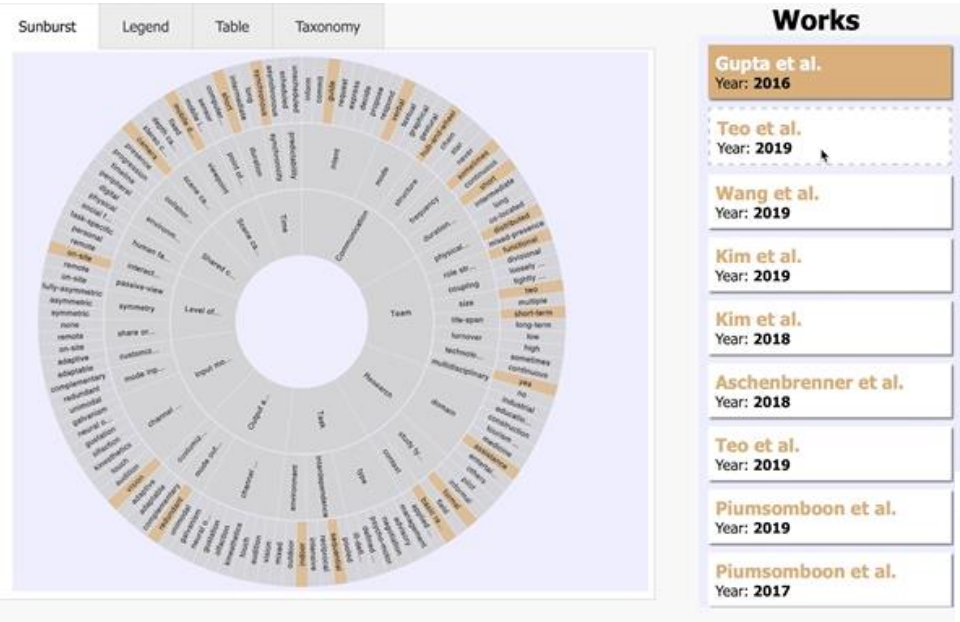


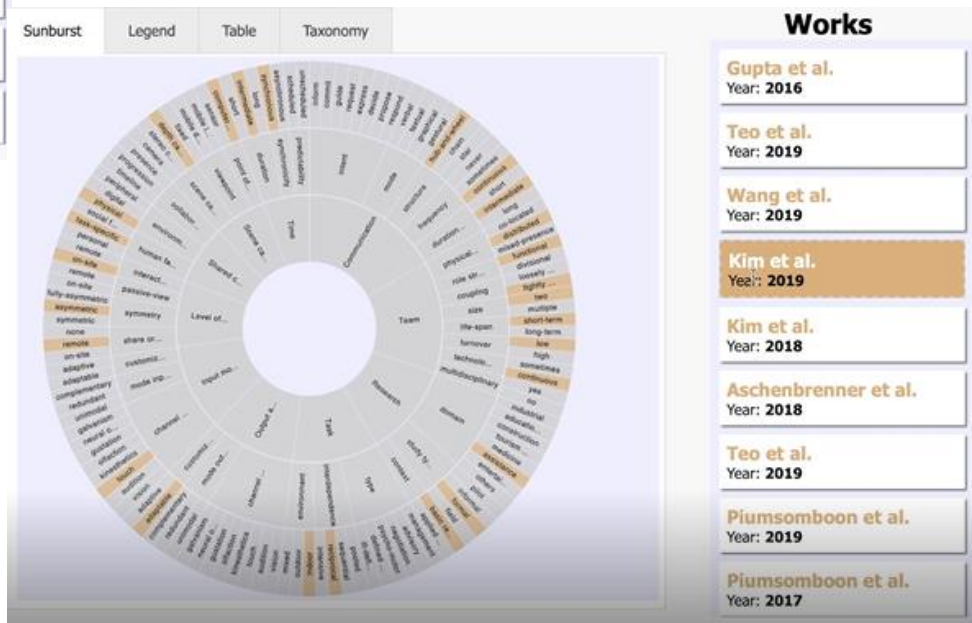
(Marques, Araújo et al., 2021)

Getting an overview of collaborative AR publications: insight on opportunities



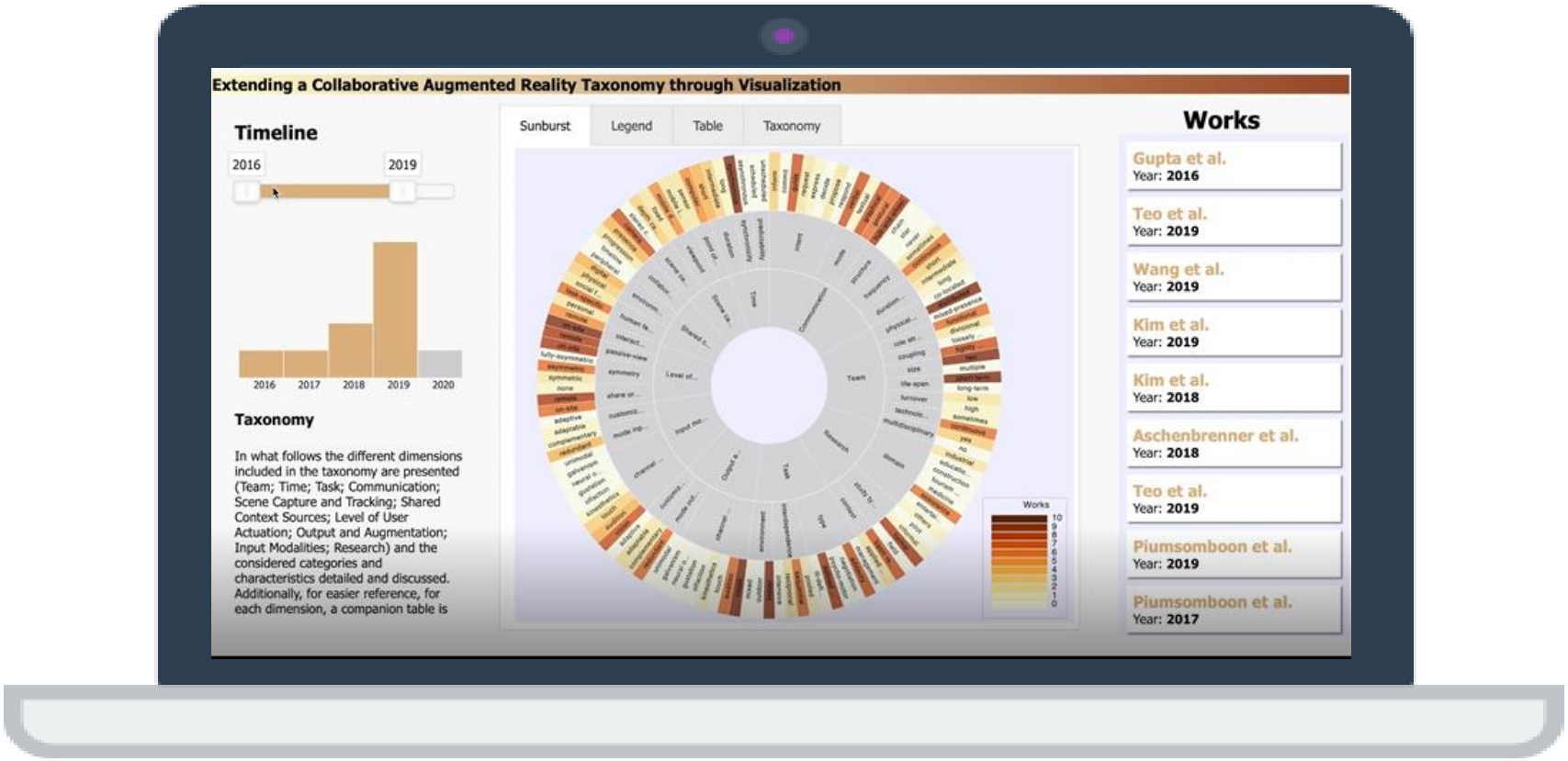
Comparing Collaborative AR publications:
based on the taxonomy

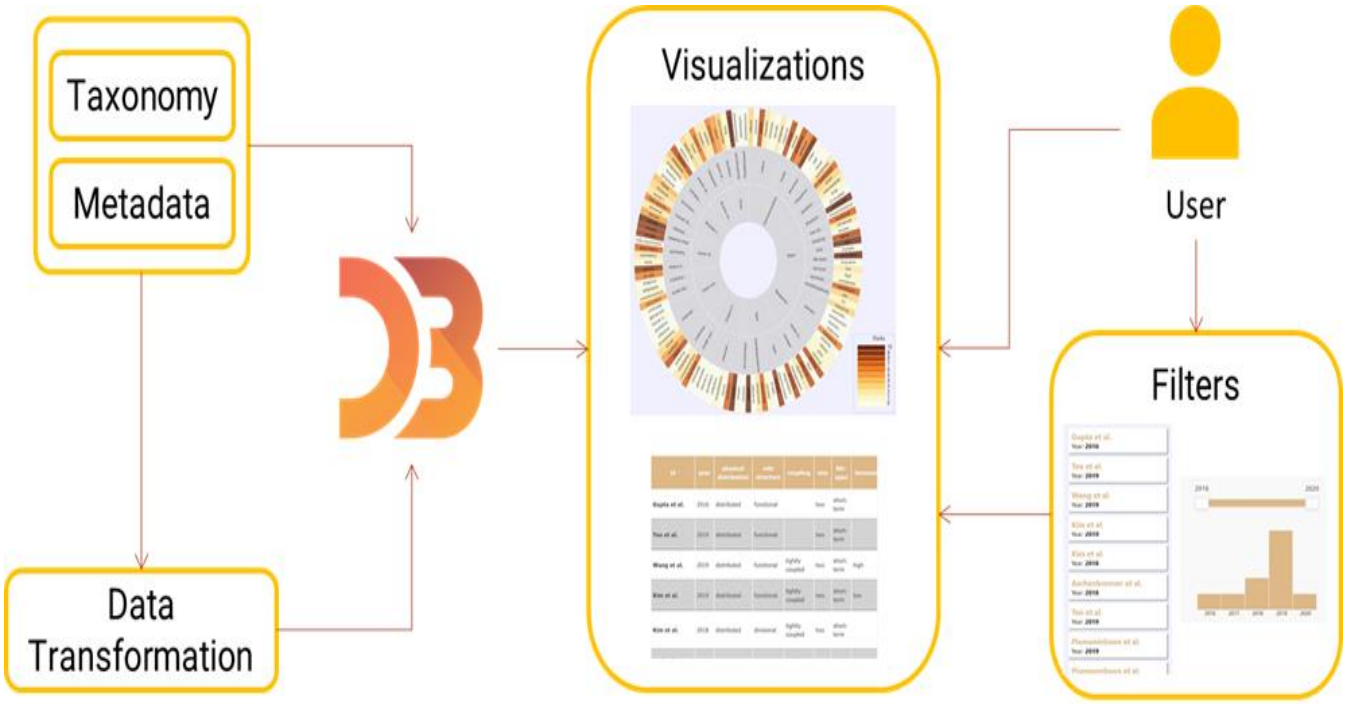




Web-based visualization tool

- Explore the taxonomy to get insights on trends, opportunities, …
- Filter works by year, display a specific work, compare …





User study

- Understand if the tool may be useful/usable to analyse a corpus
- 40 participants (36 experienced in visualization)
- Tasks and survey (SUS + specific questions) -> SUS ~ 72

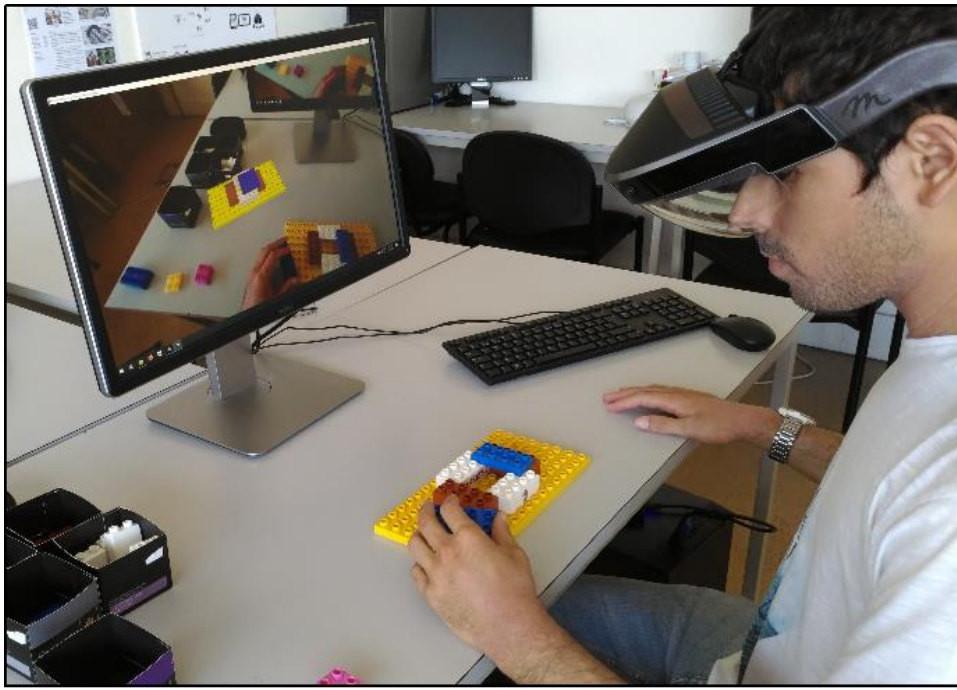
Take-away

- AR has potential to **ease remote collaboration**
- **It is vital to consider aspects beyond technology**
- A **Human-centered approach** is fundamental
- Visual exploration helps **understand the body of knowledge**
- Explore trends and **identify research opportunities**

II -Comparing AR visualization methods for assembly

- Assembly requires more than ever new ways to improve efficiency
- AR has been used to enhance environments and influence UX
- AR-based methods can support users in assembly procedures
- More studies are needed

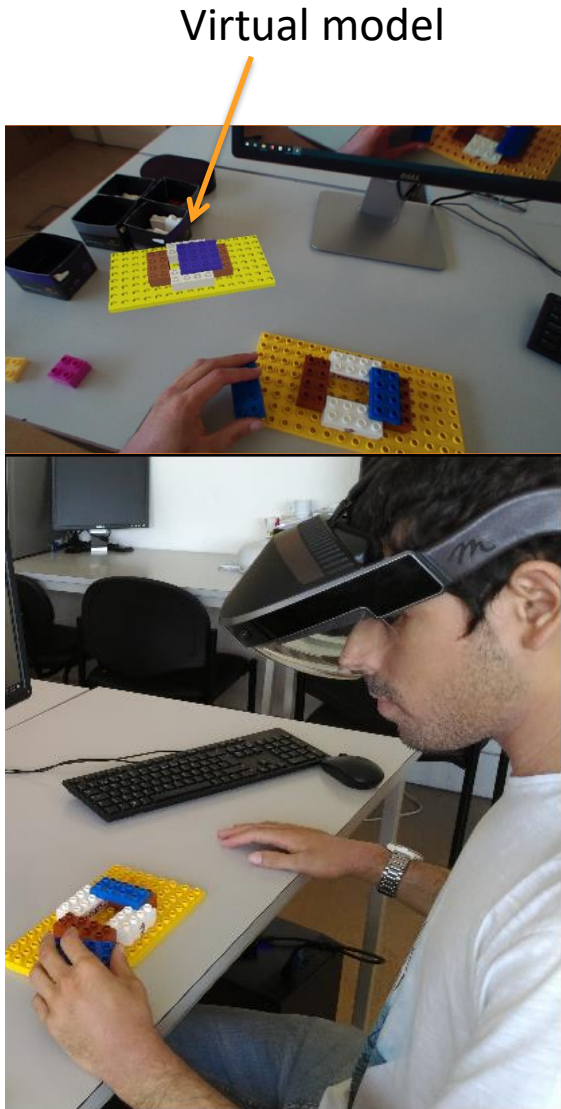
(Alves, Marques et al., 2021)



Comparing AR visualization methods for assembly

- Evaluate three different **AR-based methods**
  - mobile AR,
  - indirect AR,
  - see-through HMD

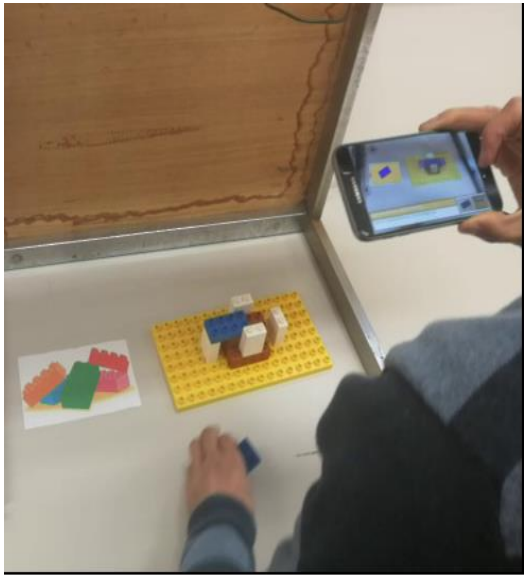
- **User study** to assess
  - performance,
  - mental/physical workload,
  - preferences



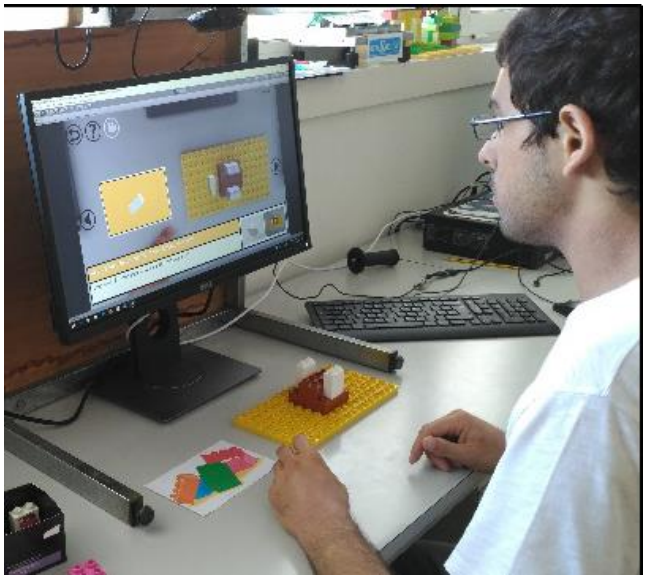
Comparing AR visualization methods for assembly

- **H_0 = all methods lead to similar user performance and acceptance**

Three experimental conditions (independent/input variables):



Mobile AR



Indirect AR

HMD (see-through)

Comparing AR visualization methods for assembly

- Experimental design: Within Groups (condition order randomized)

- Dependent (output variables):
  - Performance (times and types of errors)
  - mental/physical workload,
  - opinion

- Secondary variables:
  - order in using the conditions
  - demographic data
  - previous experience with AR and assembly

Comparing AR visualization methods for assembly

- Tasks:

Assembly of 18 building blocks

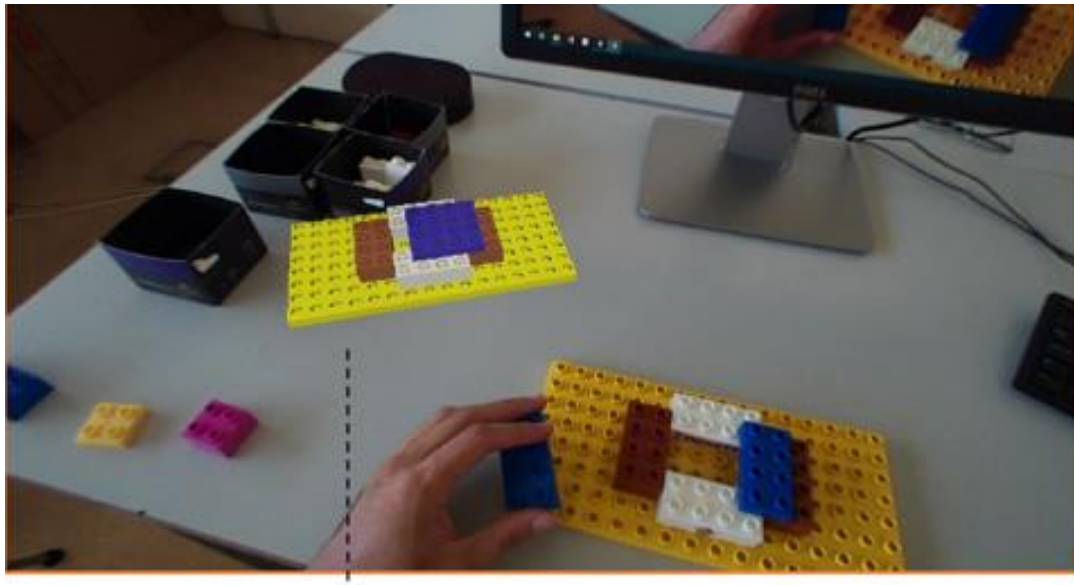
in 18 step-by step 3D instructions

- Analysis:

EDA, non-parametric tests

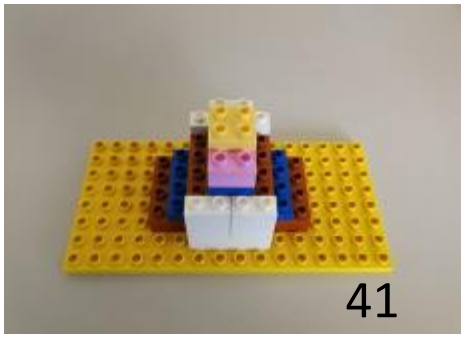
multivariate analysis

- Thirty participants

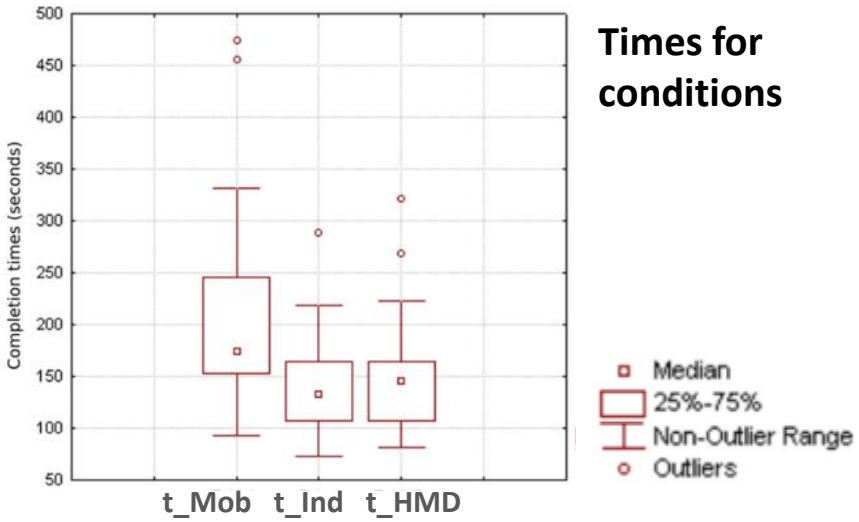


Virtual model

Similar but different goals for different conditions



Comparing AR visualization methods for assembly



Times for conditions

Types of errors for conditions

Condition	Errors		
	E_Color	E_Location	E_shape
Mob	0	9	15
Ind	0	1	7
HMD	3	16	3

- Main results

  - all methods may support users

  - no “best method” concerning performance and preferences

  - insights on the strengths and weaknesses of each method

  - identifying guidelines for specific use cases

Comparing AR visualization methods for assembly

- Future work

  - Improve the methods to overcome technical limitations

  - Further study with more:

    - complex tasks to better differentiate between methods

    - realistic settings (noise, illumination, movement, …)

Take-away

- User studies and controlled experiments are fundamental to obtain insight and improve methods/systems

- In controlled experiments it is essential to:
  - Clearly formulate objectives and hypotheses
  - Carefully select the experimental method
  - Involve an adequate number of participants
  - Register quantitative and qualitative data
  - Use adequate data analysis

- Data analysis expertise is required from the beginning!

III - Using augmented reality for industrial quality assurance: a shop floor user study

- Quality control procedures are essential in industrial production
- Using AR, operators can focus on the task and get visual feedback
- Only early prototypes exist
- More real cases are needed

(Alves, Marques et al., 2021)

Using augmented reality for industrial quality assurance: a shop floor user study

- AR-based **quality control system** to help perform real-time validation

Implying complex steps and movements

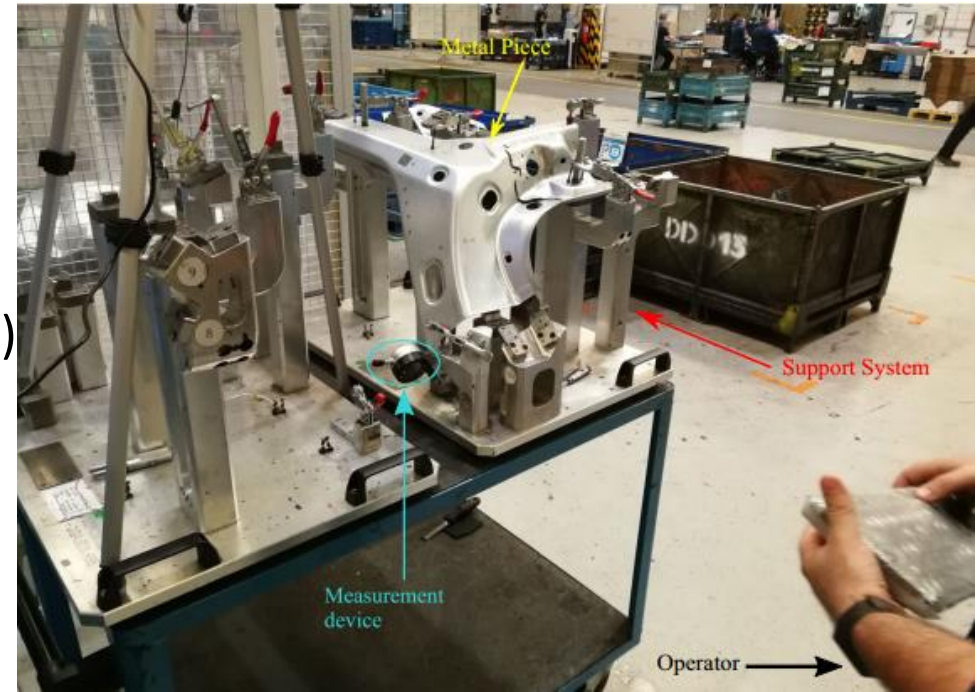
Using augmented reality for industrial quality assurance: a shop floor user study

- AR-based **quality control system** to guide operators, perform real-time validation, and create instructional contents

- Evaluated:
  - in an industrial shop floor
  - 1 week,
  - 7 operators

  (experienced and non-experienced)

- To improve robustness and understand gains



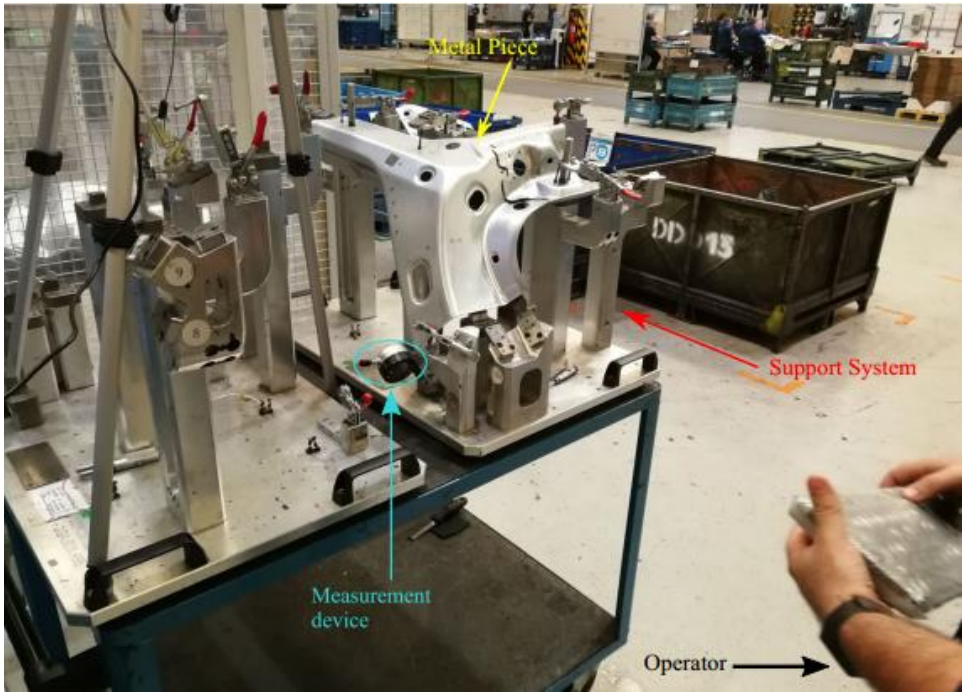
Using augmented reality for industrial quality assurance: a shop floor user study

- Helping on a **complex real task**:

measuring deviation errors of an automotive part at specific positions, an important specification of the clients, resulting in much waste

- Identified by domain experts
- In several visits and meetings

User-centered approach



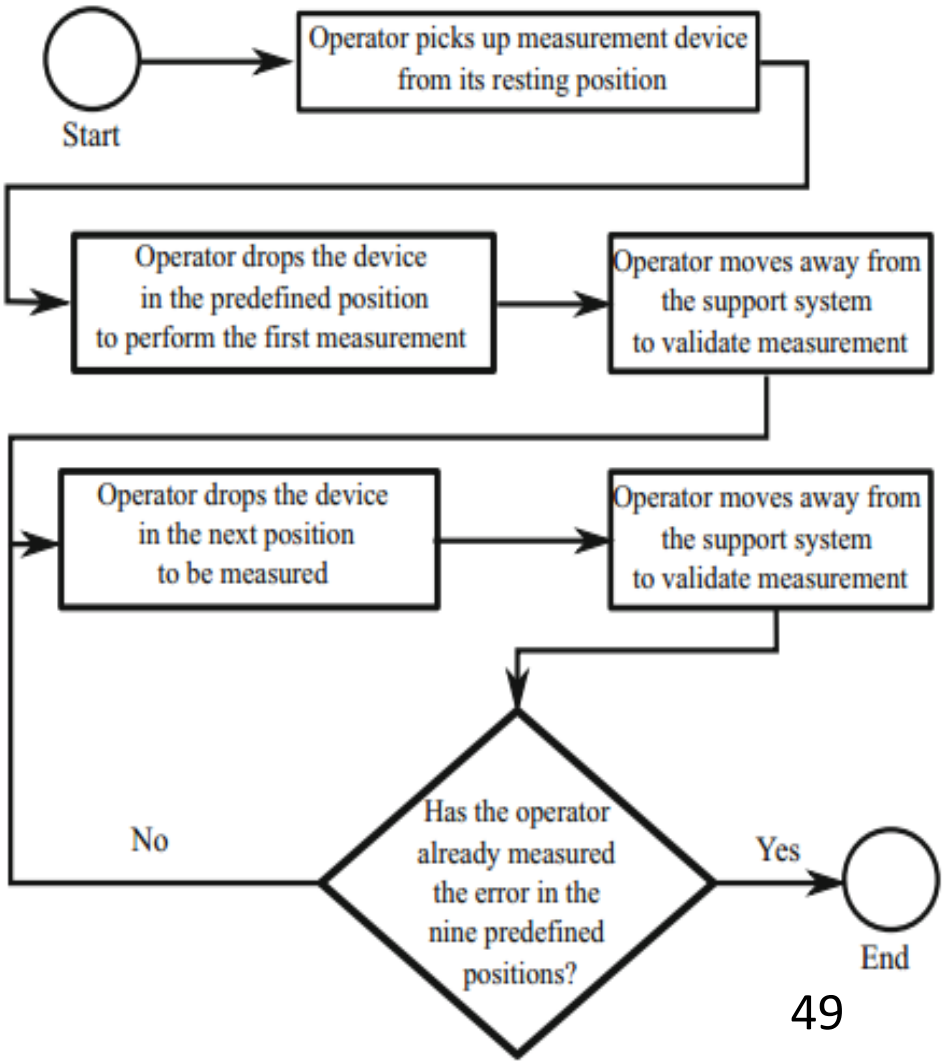
Using augmented reality for industrial quality assurance: a shop floor user study

- **Inefficient workflow**:

- taking several measures in different places

- using a keyboard

- confirming by looking at a display



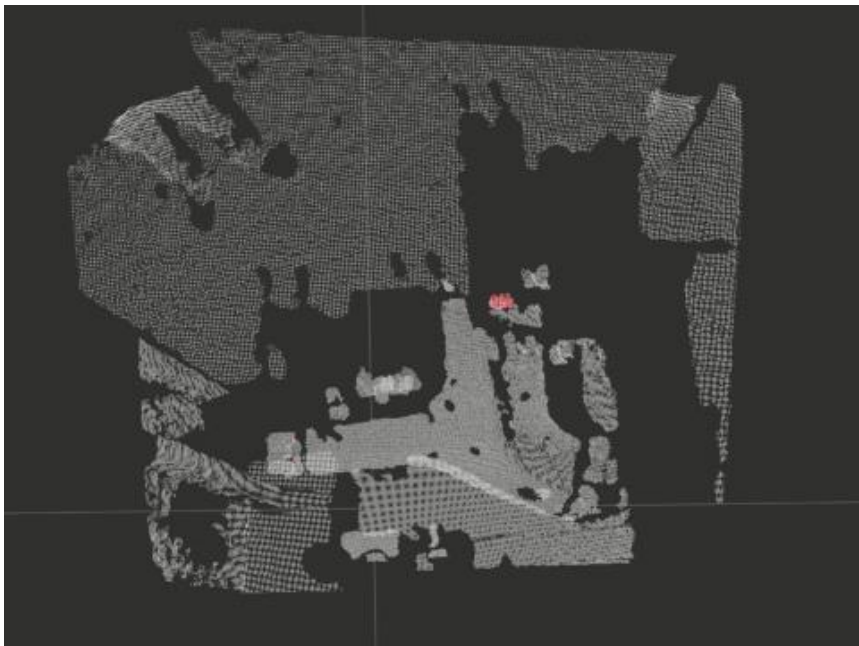
Using augmented reality for industrial quality assurance: a shop floor user study

- A vision-based method:

- triggers the measurement when the device is correctly positioned

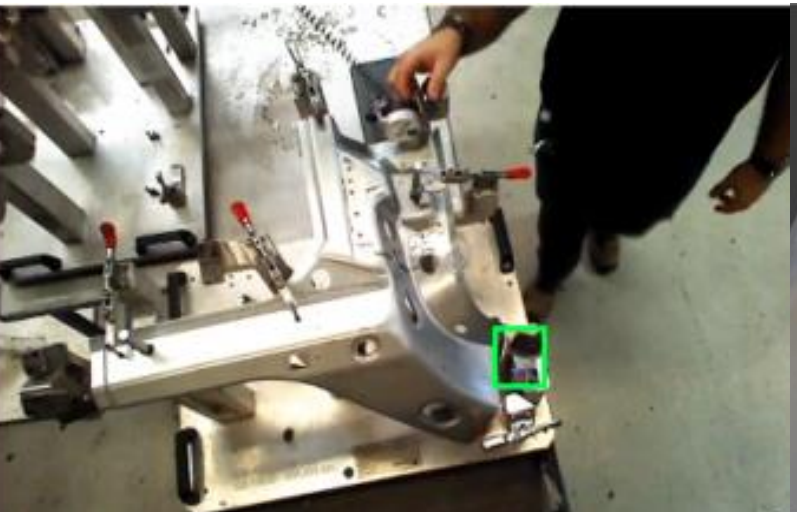
- moves to the next stage showing the next location

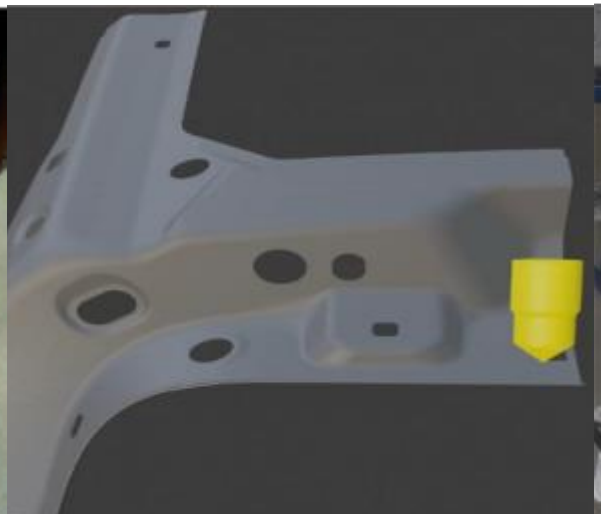
- without any user intervention

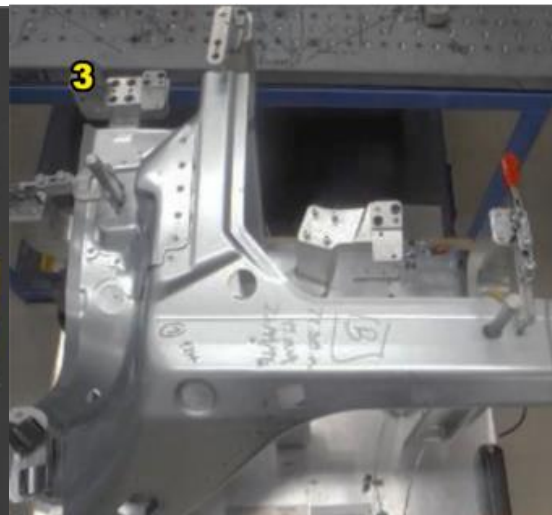


Using augmented reality for industrial quality assurance: a shop floor user study

- the validation process can be used to **create virtual content** based on human demonstration
- a 3D model of the automotive part was augmented with a virtual 3D object indicating the next measurement







Using augmented reality for industrial quality assurance: a shop floor user study

- User study:

Assessing robustness and comparing with the video-based method currently used

- In the shop-floor
- Real quality assurance task
- 7 operators (4 unexperienced)
- 1 week

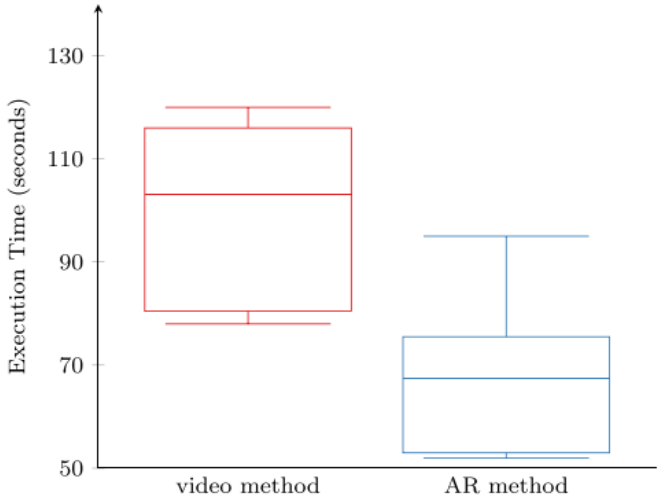
Current instructional video

Augmented 3D model

Using augmented reality for industrial quality assurance: a shop floor user study

- All operators used both methods (randomized)

- Measures:
  - Performance
  - Opinion
  - Experience



- Main results

  - With the proposed method:
    - Operators were faster regardless of experience

    - Difference between unexperienced and experienced operators decreased

Using augmented reality for industrial quality assurance: a shop floor user study

- The AR-based method seems **robust enough**
- provided a ~60% increase in efficiency
  implying a **significant potential financial gain**
- Improved the learning curve
- The industrial partner is **interested in deploying the system** in several other machines

Take-away

- AR has potential to **increase productivity**

  by improving KPIs (e.g. rate, count, rejection rate)

  and **decreasing training costs**

  contributing to a leaner approach in several ways,
  reducing time, waste, motion, and additional work

- A **Human-centered approach** is fundamental

What future?

- There are still **many challenges**
  - technical aspects
  - human and social factors

  to the general use of AR technology as a new form of media
- I believe the interest in AR/MR will continue increasing,

toward the vision of a more **pervasive presence** in our lives

“Each new technology is just a new technology, it will have a lot of enthusiasm about what you could do with it that you couldn’t do before, but it will need a lot of research to understand how it can be used to support us humans in the way we want to be supported”

(Sheelagh Carpendale, 2020)

Acknowledgments

To all colleagues and students that have contributed in any way …

As well as Institutions

References

G. Anthes, “Augmented Reality Gets Real,” *Commun. ACM*, vol. 62, no. 9, pp. 16–18, 2019.

R. T. Azuma, “The road to ubiquitous consumer augmented reality systems,” *Hum. Behav. Emerg. Technol.,* December 2018, pp. 26–32, 2019.

M. Billinghurst, “Grand Challenges for Augmented Reality,” *Front. Virtual Real.*, vol. 2, no. March, pp. 1–4, 2021.

M. Billinghurst, A. Clark, and G. Lee, “A Survey of Augmented Reality,” *Found. Trends Human-Computer Interact.*, vol. 8, no. 2, pp. 73–272, 2015.

J. Grubert, T. Langlotz, S. Zollmann, and H. Regenbrecht, “Towards Pervasive Augmented Reality :,” *IEEE Trans. Vis. Comp. Graph.*, vol. 23, no. 6, pp. 1706–1724, 2017.

K. Kim, M. Billinghurst, G. Bruder, H. Duh, and G. Welch, “Revisiting Trends in Augmented Reality Research: A Review of the 2nd Decade of ISMAR (2008–2017),” *IEEE Trans. Vis. Comp. Graph.*, vol. 24, no. 11, pp. 2947–2962, 2018

M. Speicher, B. D. Hall, and M. Nebeling, “What is Mixed Reality ?,” *CHI ’19 Proc. SIGCHI Conf. Hum. Factors Comput. Syst.*, 2019.

.

Works

J. Alves, B. Marques, P. Dias, B. Sousa Santos, “Using augmented reality for industrial quality assurance: a shop floor user study”, *Int. J. Advanced Manufacturing Tech.* May, 2021

J. Alves, B. Marques, C. Ferreira, P. Dias, B. Sousa Santos, “Comparing Augmented Reality visualization methods for assembly procedures”, *Virtual Reality*, June, 2021

B. Marques, S. Silva, J. Alves, T. Araújo, P. Dias, B. Sousa Santos, “A conceptual model and taxonomy for collaborative Augmented Reality”, *IEEE Trans. Vis. and Comp. Graph*., 2021

B. Marques, T. Araújo, S. Silva, J. Alves, P. Dias, B. Sousa Santos, “Visually exploring a Collaborative Augmented Taxonomy “, *Int. Conf. Information Visualization, IV2021*

N. Martins, B Marques, J. Alves, T. Araújo, P. Dias, B. Sousa Santos, “Augmented Reality situated Visualization in decision-making”, *Multimedia Tools and Applications*, May, 2021