A Tangible Concept for Layered Map Visualizations*

Supporting on-site Civil Engineering Construction Consultations using Elastic Displays

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ABSTRACT

Tangible Interaction in collaborative scenarios represents a natural und intuitive way to explore and discuss complex issues in a playful way, supporting communication, negotiation and teamwork. We present a concept for Elastic Displays to support decision-making processes in the context of civil engineering construction planning, related to the research context of Building Information modelling techniques. This involves the exploration of spatial issues, as well as identifying changes to the project schedule and cost plan. We use the power of Elastic Displays to quickly explore semantic and time layers in complex maps and uses them in conjunction with an integrated overview of the project timeline and cost overview. Furthermore, we discuss some gestures used for interacting with the Zoomable User Interface and navigate Layered Visualizations with magic lenses. Finally, we discuss our findings from the implemented prototype and share some thoughts on future work for Zoomable UIs on Elastic Displays.

CCS CONCEPTS

• Human-centered computing → Human computer interaction (HCI); • Human-centered computing → Interaction design; • Human-centered computing → Visualization

KEYWORDS

Shape-Changing Interfaces, Elastic Displays, Building Information Management, Tangible Interaction, Interface Design, Information Visualization

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Figure 1: Prototypical implementation. Magic lens showing a specific project phase on the construction map.

1 Introduction

Civil Engineering processes are complex, costly, contain many dependencies, involve a large number of stakeholders and are subject to constant changes due to unforeseen circumstances or planning issues. Digital technologies can support to store and connect the vast amount of data. However, there is a lack of easy to use interfaces for retrieve, interpret, visualize and interact with the available documents. Elastic Displays as a specific tangible interface type offers novel ways to interact with complex maps and layered visualizations. The simple and intuitive touch interaction with gradual haptic feedback facilitates the playful and effortless exploration of different semantic aspects of map visualizations and explore more detailed information using Zoomable User Interface visualization techniques. Interaction can be designed to provide natural access by using physical metaphors for manipulating content.

In the following, we present user interface concept and interaction metaphors for supporting decision-making process in construction consultation - to identify issues, discuss possible solutions and their consequences (Figure 1).

2 Related Work

2.1 Elastic Displays

Shape-Changing Interfaces represent a specific type of *Organic User Interfaces* [28] that allow input our output information by changing their physical shape [23]. They can be divided into three

different categories: *Actuated*, *Elastic* and *permanent deformed Displays* [15]. Elastic Displays feature a passive, temporary deformation, typically realized using an elastic fabric suitable for back-projection. In contrast to actuated displays like *Relief* [17] or *TableHop* [24], which can actively deform without user input, they are less mechanically complex and therefore easier to build and less prone to (mechanical) errors. On the other hand, Elastic Displays are more flexible and dynamic than displays that feature a permanent deformation by using modelling materials such as sand clay or gels (e.g. *PhotoelasticTouch* [25], *Softness Control* [26]). Elastic Displays present a novel approach to touch-interaction, providing a more complex haptic sensation and extending the interaction space into the third dimension. There is a large number of research prototypes, that demonstrate the power of deformation for interacting with data (e.g. the *Khronos projector* [8] as one of the first works in this field, *Impress* [12], the *Deformable Workspace* [29] or the *ElaScreen* [30]).

In previous research, we described a *Task Taxonomy* to provide categorization of the different approaches and use cases related to Elastic Displays [15] (Figure 2). We developed some hardware prototypes to demonstrate several approaches, especially for layer-based [21] visualizations und Zoomable UI [14]. The work presented here builds upon the findings from these concepts, the hardware and the software framework developed over the last years and is currently part of the interdisciplinary research project *ZELASTO – Interaction on Complex Data Through Zoomable User Interfaces on Elastic Displays*.

We used our Elastic Display-Wall, the *FlexiWall* [10]. It consists of a large fabric wall, which is back-projected by a short-throw projector. Next to the projector is a depth camera that tracks the surface deformation. By analyzing the depth image, we extract local extrema, that are used for interaction (Figure 3).

2.2 Building Information Modelling

The context for the current work takes place in the field of civil engineering, addressing research fields of process visualization and, in general, the area of *Building Information Modeling* (BIM). BIM describes an approach to extend traditional *Computer-Aided Design* (CAD) techniques with geometric and functional relationships and organizational data, to facilitate the communication, organization, visualization, and change-management in multi-disciplinary teams. [4], [11] It is used throughout the whole project cycle from early ideation and design [31] over planning up to construction phase, project operations, post-calculation and controlling [20].

There has been significant amount of work in this area, mostly focusing on software-technological issues, such as data models, software/framework design, automation, performance and interoperability, as well as Visualization and Simulation. Typically focused on traditional desktop systems, the integration of Augmented and Virtual Reality as novel visualization and interaction technologies have grasped attention in this field in the last years. [19]

Standard BIM techniques have been adopted to a certain degree with several available commercial software solutions (e.g. *Autodesk BIM 360* [3]), from which especially *BIMx* [7] and *Edeficius* [9] provided a baseline for the overall concept and deriving visualizations, e.g. the integrated view of project schedule and the construction map.

Key aspects for collaboration in construction are communication, conflict management, negotiation, and teamwork, which are not well supported by the current software tools [22]. As negotiation and conflict management often involves examining and adjusting inter-dependent processes and process-steps, interactive process-visualization is a central aspect of the work presented here. *Gantt-Charts* with special extensions represent a common and versatile visualization technique [13], [18]. In the desktop-environment, there have been substantial concepts for visualizing hierarchical processes, dependencies, uncertainty, tolerances and delays or shortenings of process steps [1], [16]. Due to its simple design and high flexibility, our implementation is based on the *PlanningLineGlyph* [2] visualization technique (Figure 9).

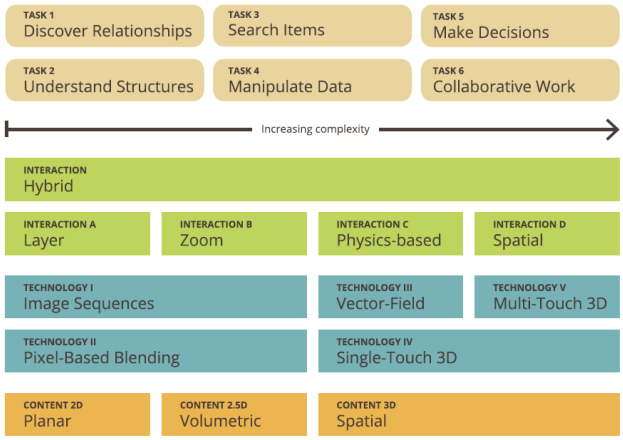

Figure 2: Task-Taxonomy for Elastic Displays [15]

3 Scenario Analysis

The project lifecycle for construction spans a variety of different phases [5] including planning and design, contractor-selection, execution, and or close-out. Our use case focuses on the project operations phase, especially on the monitoring tasks regarding schedule update and cost-control [5]. For analysis of the scenario, requirement analysis and to gain insights into construction processes in detail, we collaborated with a large local construction company, specialized in civil engineering.

Civil engineering tasks have a complex collaborative structure due to many involved disciplines, are very dynamic due to rapidly changing conditions and constantly changing requirements. This involves many internal and external processes with a multitude of different formats for discussing issues. In our use case, we investigate concepts for using Elastic Displays in on-site construction consultation, which is an essential tool to monitor project status. It takes place on a regular basis to identify resource bottlenecks, schedule delays or early completed (sub)processes,

discuss unforeseen circumstances and solve conflicts. The key aspects of this scenario are time-planning, resource management and cost control among the different stakeholders, which include customers, project supervisor, architects, (sub)contractors, administrative departments, and local residents. In an extended format, informing the general public in large public construction projects represents a derived usage scenario.
Our focus on collaboration for identifying issues and finding possible solutions refers to the *Discover Relationships* and *Understand Structures* tasks in the Task-Taxonomy for Elastic Displays, and also contains some aspects of *Collaborative Work* and *Make Decisions* [15] (Figure 2).

4 Interface Concept and Design

The interface concept employs the construction map as its pivotal tool, which is reflected by the interaction and visualization strategy. Therefore, interaction metaphors for accessing context-sensitive data, for zooming and panning, mode switching, have to be specified as well as semantic zoom visualization techniques and the use of magic lenses [6]. The main layout (Figure 3) of the application reflects the map-based approach by putting the *construction map* prominently in the center of the application screen and uses semantic layers for the distinction of the construction processes. This center-based layout is accompanied by small upper and left-side margins containing a brief overview over schedule (*timeline*) and *cost overview*. These margins can be expanded to provide a detailed, full-screen access to planning data – full *project schedule* or *cost plan*. Details regarding these views are provided in section 4.2).

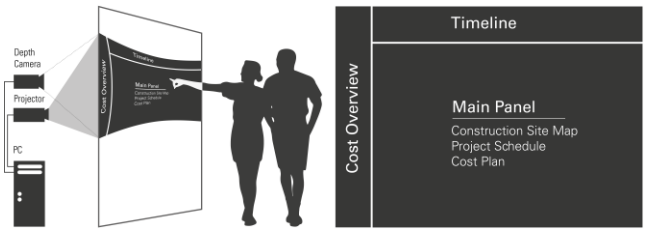

Figure 3: Left: system setup - large fabric wall, short-throw projector and depth camera sensing the surface. Right: application layout centered around the construction map.

The presented concepts therefore relate to the *Volumetric* content dimension in our Task-Taxonomy, employing *Image Sequences* and *Pixel-Based Blending* in combination with *Multi-Touch 3D* gestures. Regarding interaction, we focus on a hybrid approach between *Layer* and *Zoom* interaction techniques (Figure 2).
Finally, we developed concepts for manipulating the time schedule on the Elastic Display, supporting decision making and conflict solving tasks in the given scenario, and extending the concept beyond plain exploration tasks.

4.1 Map Layers

In general, the map view is used to visualize the construction process. We identified two major tasks that are essential for map exploration. The first one is (semantically) zooming and panning the map. As a construction site can become rather large and loaded with information, the application of Shneidermans *Visual Information Seeking Mantra* of „*Overview first, zoom and filter, then details-on-demand*" [27] provides a viable approach to support the tasks regarding the construction map. First, we chose to apply semantic zooming to support the overview in the initial map view, and gradually adding detail as the user zooms into the map view (*Zoom* interaction, Figure 2). Filtering is the second aspect: we divided the map into layers containing the several construction sub-processes in order of their execution time. So the user can explore the different processes by moving through the different time/process layers (*Layer* interaction, Figure 2). One other dimension is the spatial depth of the terrain. A possible approach is be to map the terrain layers to the depth interaction (*Spatial* interaction, Figure 2). However, in civil engineering, there is a correlation between order of process steps and spatial layout, meaning, that the processes in the deeper terrain layers are executed before processes in layers above. After the process has been finished, the layer is sealed, and is usually not touched after layers above have started working. We therefore did not integrate this concept.

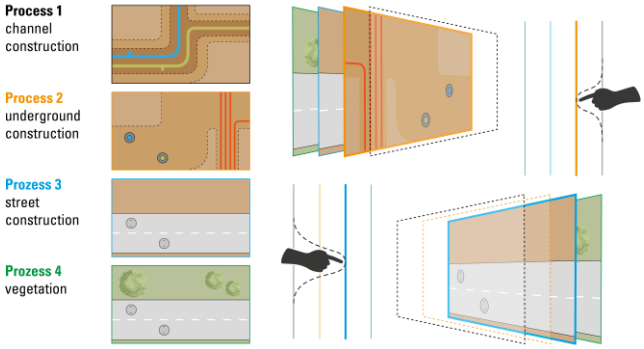

Figure 4: Navigating process layers by surface deformation

Regarding interaction, Zooming/Panning and moving through the process layers are both achieved by pushing into the surface. Adjusting the zoom level is mapped to the depth of the deformation, panning is done via dragging your hand into the desired direction. The same is valid for process layers: starting with the initial process step, pushing into the surface changes the displayed sub-process (Figure 4).
For layer navigation, we integrated magic lenses as tool to separate this operation mode from Zooming & Panning. Thus, we achieved a mixed visualization of zoomable map view in which additional semantic layers can be accessed at any time and position. (Figure 5 left) We employed a physical foot switch to achieve an intuitive and unconstrained way of fast and reliable mode switching between zooming and lens manipulation.

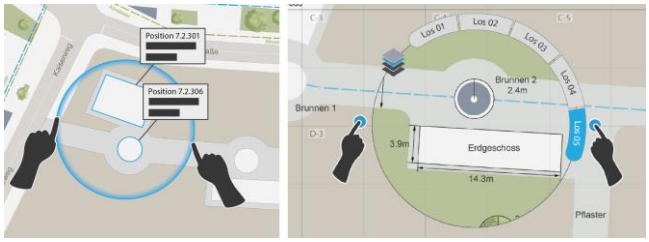

Figure 5: Left: Accessing detailed information about tasks - Right: Providing context information by using the magic lens for semantic zooming.

The lens itself is augmented with information about the currently active mode and provides context-sensitive information about zoom level and/or the current process layer, which is displayed (Figure 5 right).

4.2 Process and Cost Visualization

The visualization of the timeline and cost overview are always visible on the borders of the application. In these compact visualizations - which can be expanded at any time – the most significant information is visible. In the following, we focus on the timeline and project schedule views. Cost overview and cost plan work in similar way and are briefly depicted at the end of this section.

The timeline displays deviations from the original project schedule both regarding specific tasks as well as sum over the whole project phase. Additionally, current state of the construction progress in relation to the planned state is depicted as well as the forecast of the project end (Figure 6).

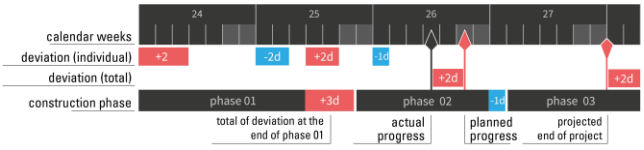

Figure 6: Compact visualization of the timeline as simplified version of the construction schedule including the visualization of delays and early completed processes.

The extent of time savings or delays is color coded, with different shades of blue for savings and red shades for delays.

In terms of interaction, the timeline can also be employed as filter for constraining the map view to the selected time period by adding start and end markers.

The detail-view of the construction schedule consists of a hierarchically organized Gantt-chart. The visualization is grouped into three basic hierarchy-layers which serve as detail-levels: construction phase, construction branch and process. Processes itself can be expanded and collapsed into their specific sub-processes and tasks. The schedule visualizes dependencies using the *Critical Path Method.*

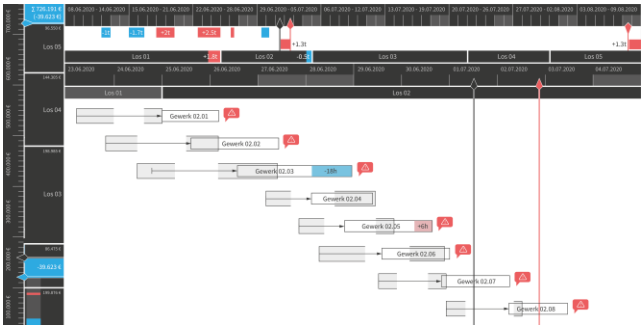

Figure 7: Detailed full-screen Gantt-Chart using techniques from the PlanningLineGlyph [2] concept.

To access detailed process/task information, we use semantic zoom on the items in the Gantt-Chart. By pushing an item, gradually more information is displayed in three zoom layers: By default, it shows the id and name of the task, when zooming in, a short description, quantity (Material or working hours) or prices are displayed. When zooming to the max detail level, the detailed description of the process can be accessed (Figure 8).

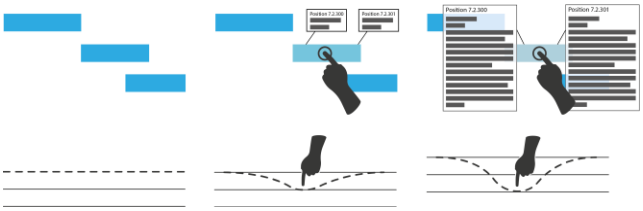

Figure 8: Semantic zoom technique providing additional detail information such as center: process description and right: information about resources/costs.

Additionally, it employs core properties from the PlanningLineGlyph [2] to visualize time tolerances, time shifts, delays and critical changes (changes that lead to conflicts either in context of dependent processes and/or lead to a delay of the overall project schedule (Figure 9, Figure 10).

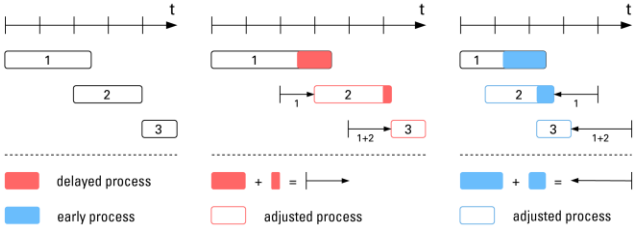

Figure 9: Detailed view on the visual concepts derived from the PlanningLineGlyph [2]

The visualization of the cost overview is similar to the timeline, albeit in a vertical layout (Figure 7): it shows task-based and overall savings and extra costs, as well as the current project

progress in terms of planned and actual costs and forecast of the financial project outcome (Figure 10).

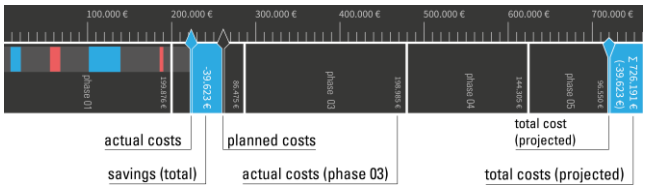

Figure 10: Compact visualization of the cost plan including the visualization of extra costs and savings.

The concepts for the cost plan resemble the schedule visualization. However, instead of horizontal process items, it consists of vertical cost bars. Furthermore, cost margins as equivalent to time tolerances are not visualized, as these numbers are usually not communicated between customer and (sub)contractors. Regarding the construction planning process, we assume that adjusting the project schedule is a more common task than adjusting processes by manipulating cost values; so that we focused on the construction schedule, leaving the cost-plan visualization as tool with minor relevance. However, the overview visualization in the side panel serves as a useful tool to gain a quick overview over cost-related issues, especially, when comparing the feasibility of different conflict solutions.

4.3 Interaction & Gestures

The set of gestures for interacting with the elastic screen starts with simple push gestures. The depth of the deformation is translated to the strength of the desired effect, in regard of layer exploration, it determines which layer is displayed, for zooming it directly translates to the zoom level. This means, that the maximum zoom level is bound to the maximum deformation of the surface. We decided to use direct mapping to zoom layers, which resembles the behavior of the layer exploration. Pushing with a single or both hands determines the type of manipulation: when using a single hand, the action is applied globally, e.g. zooming thew whole map. When another hand is detected the magic lens is displayed between both hands and the interaction is focused on the lens. We used a fixed lens size, as we realized that scaling the lens size while pushing into the surface interferes with zooming/layer exploration and feels very instable, if the lens adjusts all the time. An alternative approach could be to provide different coarse lens sizes, that adjust only when the distance between the hand changes to a large degree.

For manipulation of elements in the process view, we developed a *shift* gesture, which makes use of the physical sensation of deforming the fabric and the rather coarse deformation. It can be used to either move or scale items, similar to dragging in-multi-touch but in an indirect way. So, if the user places his hands on both sides of an item and pushes in the surface with one hand deeper than the other, than he creates a tilted surface. The object now moves, as if it would slide along this tilted area in direction of the deeper spot (and beyond, because it does not use physical simulation, instead the depth difference is just used to determine movement speed).

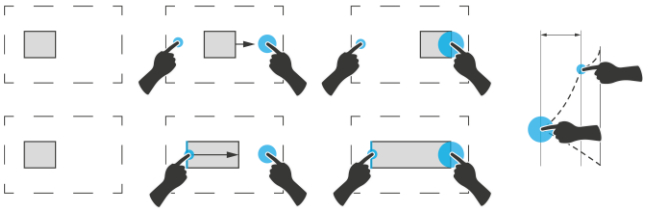

Figure 11: Shift gesture for top: moving objects and bottom: extending ranges.

A second mode of this gesture allows scaling objects. The gesture works the same way, but at the start, one hand is placed on one side of the object. This side is now fixed, and the opposite side moves in direction of the deepest push – expanding or contracting (Figure 11) the elements width (or size in general).

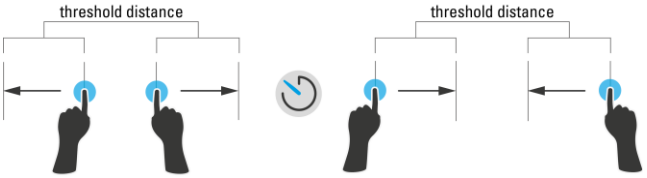

Figure 12: Together-and-apart gesture

Together and apart is another gesture, like a short "open-and-close" pinch gesture: The hand care moved together and apart over a specific distance in a short time. This gesture can be used to activate specific modes or save a specific state - in fact, we tested it for switching between layer exploration and zooming, but found the foot switch more convenient. However, to gain more flexibility, the gesture represents an option for increasing expressivity of the Elastic Display (Figure 12).

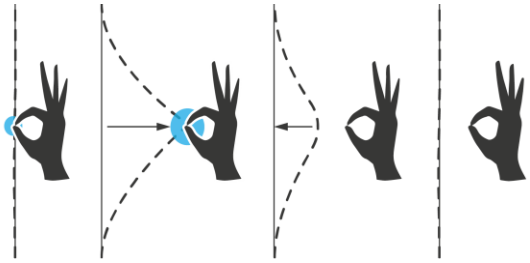

Figure 13: Pull-and-release gesture

Pull-and-Release is a short pull of the fabric into the user's direction. As pulling is not very precise, both in lateral, as well as in depth direction, we used this gesture as reset gesture, to return the application to its initial state, just in case the user got lost or wanted to start over from the beginning (Figure 13).

Task	Gesture
Zooming/Panning	Push
Layer exploration	Push
Mode switch	Foot switch
Freeze/Unfreeze state	Together-and-apart
Manipulate Process Items	Shift
Reset	Pull-and-release
"Natural" Undo	release the fabric - the surface returns to its initial state

Table 1: Tasks and associated gestures

5 Implementation

We implemented a demo application (Figure 1, Figure 14) with the focus on map interaction and the visualization of the magic lens. The process schedule was also integrated, but with limited interactivity. The compact visualization work as described, however, manipulation of process schedule und filtering abilities in the detail-visualization have not been included yet but are subject to future extensions. The basic gestures have also been integrated into the existing tracking framework, both shift and together-and-apart-gesture have been successfully integrated and tested in the demonstrator, as well as the foot switching between zooming and lens interaction. On the technological side, the visualization has been developed based on existing ZUI-demonstrator apps with WPF, using a Microsoft Kinect 2 as depth sensing device.

6 Conclusion & Future Work

We presented a concept and implementation for exploring construction site processes and investigate issues in the context of an on-site construction consultation using Elastic Displays. The developed prototype focuses the construction site map as Zoomable User Interface augmented with a magic lens to integrate the navigation of process layers. Additionally, a timeline widget and cost overview integrate planning tools into the scenario. Furthermore, we investigated gestures that can be used for more complex manipulations of the project schedule.

The integration of these gestures and adding more advanced techniques for problem solving, reordering and configuring the schedule and cost plans represents the next step for the development of the current prototype.

Due to the complexity of the use case we focused on the construction site map, augmented with project schedule and cost plan. This serves as a starting point for integration of advanced concepts like detailed plan adjustments plan or process re-ordering in further development steps. As an extraordinarily complex process, construction planning also involves a very large number of available documents, such as cross sections, contracts, (administrative) regulation, protocols or revision information. Integrating these documents into the scenario to facilitate analysis and decision-making processes, is another viable extension. Exploring other construction branches, and integrating a spatial navigation for the construction map is another research direction (section 4.1) As an example, in skyscraper buildings, internal construction processes take place in different floors in parallel, so diving through the building plan level by level could be a common task, adding another depth-based interaction modality to the map navigation.

An in-depth evaluation of gestures, basic studies about the relation between the physical properties of the fabric and accuracy of gestures, as well as the perceptual limits of depth interaction within Elastic Displays are already actively planned and will be conducted in scope of the research project.

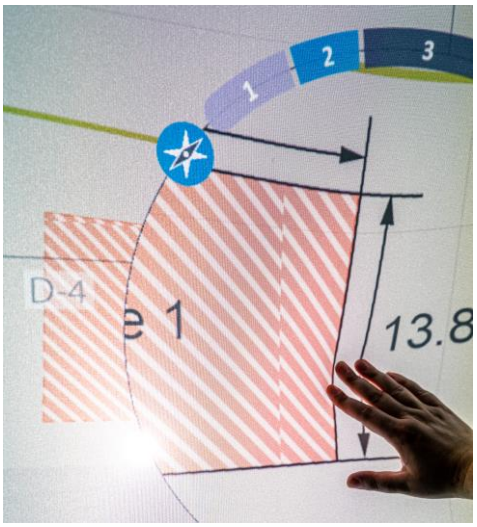

Figure 14: Detail of the magic lens

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