Stretching Virtuality

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Deconstructing the Exhibition

If we are to believe Daniel Tyradellis, Deputy Director of the Helmholtz Center for Cultural Techniques, and examine his polemic »Tired Museums,« museums and exhibitions can be seen as »places of resistance against the impoverishment of thought« (2014, 14), »laboratories of the social« (15), and media that »restore a certain corporeality to thought« (17). However, as he continues, they frequently remain trapped within their rigid and self-referential hierarchies, unimaginatively reproducing the same formats over and over again. They shy away from risks and, in their safeguarding maneuvers, strip themselves of societal relevance. The professionalization of curating poses the danger of positioning itself within the field, aligning with standards, and fulfilling the expected, rather than seeking the unexpected. In light of such a diagnosis of the German museum landscape, I argue that non-professionals from other disciplines, with different experiences, can productively engage with the format of exhibiting and, first and foremost, deconstruct the exhibition. → Stretching Spaces, 184

As Object Space Agency (OSA), our interdisciplinary team has done exactly that. Our attempt to bring the complex topic of active matter into a tangible, interactive format did not begin with professionalization in curation and exhibition design. Rather, we asked ourselves what exhibitions might achieve if we did not conceive them as mere showcases of established results but instead as laboratories, where the experimenters dare to step into the view of the visitors, ask questions, inspire, experiment, provoke, fail—and take risks.

»Exhibitions are not mediated—they are mediation,« Tyradellis further asserts (2014, 87), and indeed, exhibitions can become the space where knowledge is exchanged—not unilaterally, not in one direction, not in a simulation of listening but in a truly mediating dialogue. → Intermezzo 5 For it is not only the interested public that stands to gain much from listening to academia (rather than merely admiring or criticizing it in a generalized manner), but academia itself also gains perspectives, questions, connections, and alternative forms of knowledge only when it opens itself beyond disciplinary boundaries.

Our project's predecessor, the Cluster of Excellence *Image Knowledge Gestaltung*, adopted this expansion of disciplinary boundaries as its guiding principle. Its interdisciplinary lab, as

its subtitle »the interdisciplinary laboratory« suggested, lived up to its name, involving over forty disciplines. In this spirit, OSA worked, combining individual and disciplinary perspectives from physics, computer science, design, architecture, cultural studies, art history, German literary studies, and game design. As such a heterogeneous team of curators, it is hardly possible to develop a single, unified narrative line that runs through the exhibition's concept. Thus, a different path was taken, leading to a different conception of both exhibition and curation.
→ Stretching Practices, 49

Fig. 1: *Stretching Materialities* logo

The positions, preparatory work, and interests of the curators could not have been more divergent. Whereas the theme »active matter,« which was to serve as the focal point of the exhibition, was set, its individually selected aspects were so varied that the map of ideas quickly filled entire tables and walls. A competition of ideas ensued, each beginning with its own prerequisites, evolving internally, and converging with other ideas. The more concrete the work became, the more productive the collaboration grew.

We each asked ourselves: which aspect of the overarching theme »active matter« can I best illuminate with my expertise? Can I create something special and unexpected? Can I present something that is conveyed better through showing than through explaining, something that opens up a space for individual discovery? How can I present this in a way that does not exhaust itself in a singular interpretation or statement but includes the unknown and the open-ended? What interactions can I enable with the exhibited objects that allow exploration and experience, play and learning? How does the exhibited object connect with other objects, what relations can be built, and how can these be shown? How does the exhibition space, the context, and the coexistence of other objects alter my object, and how can

I embrace this transformation? What questions do I have about my object, and how might the exhibition help me answer them?
❑ Process, fig. 5, 269

Our idea of an exhibition deliberately did not seek to compile the status quo of knowledge on a subject, to make it visually accessible through objects, and to present it as a »presentation of knowledge.« Instead, we sought to take subjective approaches seriously, aiming for less objectivity and completeness. The exploratory experience was meant to be central, making an exhibition visit a highly subjective experience that would not follow a singular narrative thread. The exhibition space with its architecture, history, and materiality thus became a vital experiential space and a central part of the exhibition itself. The conception evolved from very heterogeneous points and perspectives, converging rather than radiating outward from a single theme. The most important strategy for creating the exhibition was the principle of searching and attempting—for the curators as much as for the visitors. One could say that the exhibition thus became a dynamic experimental arrangement, a series of experiments in the laboratory (fig. 1). And the public served as crucial experimental material.

Merging Virtual and Physical Realms

Museums do not merely house exhibitions; they are exhibition spaces. The spatial aspect enables the juxtaposition of objects and artworks, an arrangement, a dialogue with space, light, perspective, and neighboring elements. In many contexts, it is particularly important that the objects on display are originals. The magic of the exhibit lies in the fact that it is genuine—not a copy or simulation but unique, often historical, and physically present. It is the idea of the object's aura, of the irrefutable presence of the authentic. Walter Benjamin defines the aura of a work of art as »the unique phenomenon of a distance, however close it may be« and attributes it with »inaccessibility, authenticity, and uniqueness.« His essay *The Work of Art in the Age of Mechanical Reproduction* (1935) is nearly a century old. In it, Benjamin explores the question of what remains of the original when mass-produced copies begin to replace it, and how art has developed and will continue to evolve under these conditions.

Today, the technological tools used in and for exhibitions go beyond mere reproduction machines. They have become production tools themselves, enabling the creation of original artworks and objects that could never have been realized without them. The virtual, understood as simulation, as something not real, as an object in an »as if« mode, has been added to the physical. Many significant artworks and objects in museums have already been replaced by replicas to protect the original from the potential risks of exhibition. This does not bother visitors usually, as long as the exhibition environment still manages to highlight the object's uniqueness and offers an enhanced experience that can only be achieved in that particular context.

The original, which we still regard as the most valuable, is also the object that increasingly deteriorates, requiring more elaborate conservation and restoration, and which, due to the need for protection from light, air, and touch, becomes ever more elusive to viewers—not only remaining inaccessible but becoming increasingly difficult to perceive. The relationship we can build with the museum object is hindered by the protective layers of its exhibition.

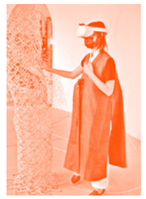
The virtual steps into this gap. The deeper insights it offers increasingly compensate for the fact that it is not real but »merely« virtual. Whether it is through film, which shows an object in activity and its natural context, a 3D model that enables the exploration of all its details and internal structure, or through a reproduction that can be observed and even touched without protective barriers—wherever the original moves away, virtuality comes closer. The knowledge of the originality of the object still retains its value, but the process of appropriation, engagement, and subjective inquiry with eyes, hands, and questions has become ever more important through our daily interaction with media. ❏ Exhibition, fig. 6, 126–127

Just as in an orchestra, where the musicians on stage are only seen as small dots, and the audience's gaze shifts to the large monitors, the exhibited object is divided into the original, contributing its uniqueness and specialness, and the virtual, enhancing visibility, subjectivity, and interaction. Together, they form a new contemporary mode of perceiving objects in exhibitions.

The concept of the virtual is broad and refers to anything that exists in a different form than it appears. Today, when we speak of virtuality, we often mean digital representations of physical objects, processes, or structures. However, exhibiting itself inherently contains something genuinely virtual: the objects on display are removed from their original context and arranged in an artificial space. → Stretching Time, 227

This creates new proximities and with them, new narratives, interpretations, comparisons, and oppositions, which largely determine the reading of the object more than what the object itself inherently expresses. No object can »exist in itself;« its relationships to its surroundings define its meaning, message, and value. → Stretching Practices, 33

Saussurean structuralism emphasizes this relational, structural property of meaning within semiology: *valeur*, the value of any sign—whether spoken word, written symbol, or object—arises through its proximity to other signs. Saussure calls this the »nullité du sème en soi,« the worthlessness and meaninglessness of a sign in itself (Saussure 1967). Meaning emerges in language, society, and the art space of an exhibition through the opposition, proximity, position, and difference of the displayed objects in relation to one another. → Stretching Practices, 27 This fundamental observation shifts the focus away from the object toward the space, from the individual to the relation, from the singular to the plural. In exhibitions, we experience guided interpretations; the object in the arrangement of other objects seems different from how it would appear in other contexts. Virtuality is already present in these arrangements of original objects, in the impossibility of isolated observation.



When we speak of virtuality in exhibitions, we often refer to the use of technologically generated virtuality. ❏ Exhibition, fig. 25, 143 The distinctive feature of virtual objects compared to physical ones is the high degree of freedom in their presentation, interactivity, visuality, and level of detail. Virtuality follows different logics than the physical, as virtual objects are created in a completely different way, have different dependencies and gaps, and thus bring their own digital materiality. This digital material, shaped and animated by digital tools, pushes the boundaries of what is designable, offering insights that cannot be reached through physical originals or replicas. The goal is not to replace or displace the original but to create specific insights that occupy a particular position within the exhibition context and would otherwise be unattainable. ❏ Exhibition, fig. 12, 134

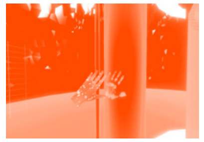
A 3D model of an object, for example, can scale up tiny structures to human proportions, making them visible, or reduce enormous formations to a more manageable size. Extremely slow changes can be sped up, and very fast movements slowed down. → Stretching Time, 211 Objects can regain lost activity, providing glimpses into their interior that would destroy the physical object. They can be observed from every angle and as closely as desired. Visitors can interact with them—opening, moving, activating, or disassembling them. All these possibilities are perfectly suited to explore objects that, rather than withdrawing and needing protection, invite interaction. It is the playful, exploratory character, free from the fear of breaking something, that makes these virtual elements of exhibitions particularly rich. → Stretching Senses, 317

Playing in exhibitions is, in this sense, a highly desirable practice. Play creates a protected space where experimentation and exploration are free from the pressure of potential consequences. The materials used for play are designed for this very purpose, and the players engage with them accordingly. The fear of damaging something, behaving ignorantly, being judged as foolish, not doing the right thing, or failing to meet expectations is greatly reduced in play. Everything that happens in play remains without consequence in the realm outside play. No one fears mishandling or dropping a virtual object. The virtual realm already carries with it the markers of play and invites interaction. The act of interacting itself is the process of creating relations. Just as objects in a room derive their value through their relations to one another, so too do they derive value for visitors through the relations that the visitors are able to draw. A factually correct and objectively written object description fails in this regard: it may withstand the scrutiny of an expert, but it reaches less-informed visitors all the more poorly. The approach of museal objectivity often misses the visitors' need to connect their experience to their personal lives and world. Play, by contrast, does not explain, does not instruct but instead allows for experience and discovery. ❏ Exhibition, fig. 11, 133

Mediated experiences can engage with a wide range of sensory perceptions. One can listen to a story and relive it through inner imagination, touch an object and delve into its form and function, bring forth memories and associations through scent, or move through a room while absorbing its atmosphere. Sensory impressions coalesce into a more or less convincing image, a surrounding world within which individual perceptions are placed. The quality of this immersion into another world—whether ethnological, biological, scientific, technical, or artistic—greatly determines what visitors take away from the exhibition, what they learn and remember. It is no coincidence that the high art of curation includes not only the selection and arrangement of objects but also the design of the exhibition space. Display cases, flooring,

visual design, pathways, and lighting play just as significant a role as they help visitors step out of their everyday perception and fully immerse themselves in the exhibition.

When considering how to combine spaces, atmospheres, and playful interaction within virtual environments, we cannot avoid the advancements made in virtual reality (VR) over the past ten years. Head-mounted displays (commonly referred to as VR headsets) represent a new medium because they allow users to entirely immerse themselves in a virtual space, without showing any »remnants« of the real environment. Unlike large screens or projectors, the virtual world in VR completely surrounds the user. This drastically alters perception, as there is no longer any visible difference between the virtual and the physical space to disrupt immersion. A space of experience can be created where users not only observe from the outside or are led by the camera's movement but are free to fully explore it. ❏ Exhibition, fig. 18, 138



At present, virtual reality is used only sporadically in museums. However, this is likely to change soon. VR is fundamentally a spatial medium. No other medium can render space so intensely and palpably. The combination of virtual and physical spaces in a museum offers an expansion of the exhibition space, the possibility to enter inaccessible spheres, and the ability to explore gigantic or tiny virtual objects and artworks. It removes the inertia of physicality, opening up a realm of expression and experience that allows content, spaces, and works to be explored and experienced. It is anticipated that museums worldwide will soon make significantly greater use of VR, with art being created within VR, and entirely virtual museums finding their way into homes.

The idea behind *Stretching Materialities* was not to integrate a purely virtual experience at a specific point in the exhibition but to layer the physical and virtual exhibition spaces. This overlap was intended to encompass the entire rotunda, allowing visitors to move freely through the space using virtual reality headsets. Rather than a stationary VR application, the VR headset allowed for movement in the virtual world that was achieved through movement in the physical world. Visitors should be able to walk freely through the exhibition space, both physically and virtually, gaining layered impressions of the exhibition's levels. The application was designed to immerse the entire body in the virtual world and, conversely, link the physical with the virtual.

To achieve this, we had to virtually recreate very precisely the rotunda, including passageways, columns, walls, objects, and the central elevator. This model was then aligned so that the virtual rotunda exactly overlapped with the physical one. A step taken in the physical space corresponded precisely to one step in the virtual space, and the distance covered in the virtual rotunda matched exactly that in the physical one. As visitors walked through the rotunda with their virtual reality headsets, they would reach the opposite end and see a virtual wall exactly where the physical one stands. Visitors could stretch out their hands and touch, feel, and explore the virtual wall as if it were the physical one—a merged perception between both dimensions.

Given the basic geometry of the room, several possibilities arose to alter it within the virtual space. Instead of a wall, for instance, there could be an abyss in the virtual world, signaling that the user should not proceed further. The marble columns would maintain the same dimensions and positions in the virtual world but might be made of a different material, perhaps transparent and stretching endlessly skyward. Thus, we could create different virtual spaces using the same geometry, all walkable and each distinct. The physical space defines the possible, sets the boundaries, while the virtual world shapes these potentialities. Using this spatial geometry as the foundation, we created six distinct floors that the exhibition visitors could explore.[1]
→ Stretching Senses, 307

1 This included use of a Virtual Reality app developed for the exhibition. Its source code has been published under an open source license (Stein 2025).

Virtual Physical Exhibition Elements

Elevator Platform—The central elevator connects these floors. Because of the exhibition space's circularity, it has an exact center, surrounded by four columns. → Stretching Practices, 29 We located the Virtual Elevator in this central area, linking the different floors and allowing visitors in Virtual Reality to switch between them. In the physical space, the elevator consists of a round wooden platform on a metal frame, elevated about 12 cm off the ground. A regular step leads onto the platform. The wooden platform is equipped with vibration motors that can set it into a vibrating oscillation. The step that visitors can feel underfoot, combined with the vibration of the platform, makes using the Virtual Elevator a more intense experience, and the transition between floors is accompanied by a physical sensation of movement. In VR, the elevator appears with glass walls extending to the ceiling. Inside, there is a virtual panel where visitors can select the desired floor. With an intuitive hand gesture, one can press a button, the elevator doors close, specially designed elevator music plays, and the platform moves up or down.

VR Headsets—For this purpose, we selected Meta Quest 2 headsets as our hardware platform. These are standalone headsets that function without being connected to a computer, as they include an integrated computer. This allowed using the headsets wirelessly, enabling free movement throughout the exhibition space in the rotunda. The selected headset also offered inside-out tracking, where position and orientation in the room are determined by four built-in cameras. This system tracks head movements through the shift in camera images and their comparison, eliminating the need for an external tracking system, such as those typically using infrared stations. These technologies combined created a large walkable area within the museum space without requiring further modifications, limiting movement, or restricting the number of headsets used. Additionally, the cost of these standalone headsets is about one-fourth that of a computer-based system with external tracking. This cost-effectiveness allowed for the provision of more headsets for parallel use.

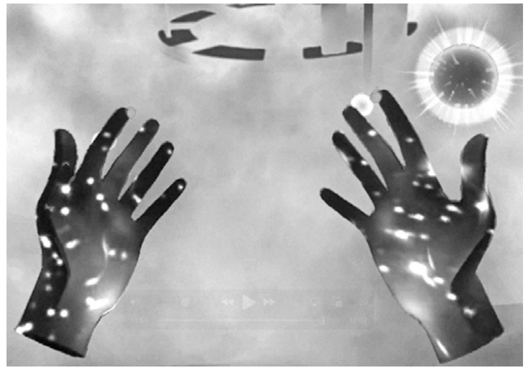
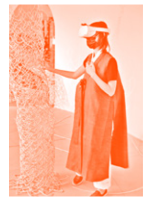


Fig. 2: Camera based hand tracking with »cosmic hands« within the VR headset

Hand Tracking—A significant obstacle to using VR headsets in museums and exhibitions is the need for controllers. While gamers across generations typically have no trouble using VR controllers and quickly become accustomed to them, non-gamers require an adjustment period. ❏ Exhibition, fig. 25, 143 This adjustment can distract from the actual experience and may be perceived as a technological barrier, drawing attention to problems with the technology rather than the experience itself. To avoid this, a controller-free setup was chosen. The Meta Quest 2 headsets have integrated hand tracking, allowing for an alternative control system using the user's own hands (fig. 2). When the hands are within the field of view, they are captured by the



integrated cameras and their position and orientation are accurately transferred to a 3D hand model, which is then represented in the VR headset. Thus, users can see their own hands despite wearing a VR headset. The virtual hands can visually differ from the physical ones. For *Stretching Materialities*, a blue-green pulsating surface was chosen, giving the hands a fascinating, almost »magical« appearance. Due to the system's high accuracy and responsiveness, users immediately recognize the virtual hands as their own, even though their surface looks entirely different. This deliberate alienation effect enables a »re-seeing,« where users are fascinated by their own hands and unconsciously explore the relationship between identity and representation: their own hands are displayed, they feel like their own, their position in space and relative to their body is precisely represented. Users can intuitively press virtual buttons with their fingers or touch objects without needing to learn how. At the same time, their arms aren't visible; the »skin's« virtual representation is entirely different, and the display is still mediated through the integrated screen. Without making it explicit, the experience of one's own body raises questions of virtuality and physicality, material and surface, function and simulation, which are playfully explored. There is no task or explicit discussion of the theme; the reality of the experience itself invites experimentation, exploration, and discussion.

Laser Pointer—A particular challenge was to calibrate the system, which is not designed for mapped use in physical environments. Typically, the starting point in a virtual environment is dynamically set based on the user's current position and can be reset during use. Not only the position but also the neutral orientation of the headset is usually set independently of its location in the physical space. For the scenario we envisioned, however, we needed to achieve an exact overlay of orientation. For this, a custom solution was developed to ensure high calibration precision. While the headset's position could have been determined sufficiently accurately using simple floor marking, this was not enough for orientation. Deviations in the sub-millimeter range would have already caused significant shifts between virtual and physical objects across longer distances. Therefore, we attached a laser pointer to a 3D-printed mount onto the VR headset and used wall markings on the opposite side (fig. 3). This allowed us to align the headset consistently and precisely position

Fig. 3: Custom setup of a VR headset with mounted laser pointer for exact directional calibration

it using the laser point and wall marking. Since the surface of the headsets is rounded and lacks clear edges, attaching the 3D-printed laser pointer mounts differed slightly on each headset. To compensate for this variance, we used color-coded markings on the wall corresponding to the colored markers on the headsets. Thus, each headset was aimed at its corresponding colored mark to achieve exact positioning. For this purpose, we built a specific calibration station on the edge of the rotunda. This station had to be immovably attached to the floor, as any change in position would have rendered the markings and calibrations useless. The station was equipped with firmly mounted perspex blocks, onto which the headset could be pressed despite its rounded shape. The fine-tuning of the calibration was then done manually using the laser point. Once the headset was precisely aligned, its position was reset by pressing a specific button on the controller.

Recalibration— In theory, the headsets remember their position and orientation, restoring this information after deactivation and reactivation. However, in practice, the headsets would often lose their position and automatically reset to the defined center of the experience. The reason for this were the technical limitations of the system, which we used in an unconventional environment, marking one of the first usages of this kind. As previously described, the system determines its position based on four built-in cameras that capture the ceiling and floor. This exhibition scenario posed difficulties for this type of tracking: the lighting in the exhibition area was rather dim, reducing contrast, and both the floor and ceiling were very uniform, offering few visual anchors to serve as distinct positional markers. Additionally, the continuous movements of visitors within the exhibition area created further visual instability. Moreover, the internal Guardian system of the headsets, which restricts the available physical space, was deactivated in a special developer mode to render the entire rotunda walkable. Occasionally, the volume of visual information would overload the internal memory and reset the latter. When this happened, the alignment between virtuality and physicality would break apart, making it impossible to spatially orient oneself.

Using these systems in such an experimental setting, we had to contend with these challenges. Although newer technological developments might have resolved these issues, our goal was to push the boundaries of what was technically possible and offer an experience that exceeded the current state of the art, accepting potential technical glitches along the way. As a result, visitors often reflected on virtuality's functioning, and the constructed nature of their experience became a topic of discussion.

To ensure the exact overlay of the virtual and physical environments, everyone working in the exhibition had to be able to recalibrate the headsets. This knowledge was passed on not only to the project team but also to assistants and museum staff. Therefore, the headsets were typically recalibrated after each use, or as needed, even during use. Occasionally, systems would fail entirely, as they were not designed for such large-scale environments, and the use of unsupported developer functions could cause system errors at the operating system level. In these cases, the entire Guardian system had to be reset, and the internal memory wiped and rebuilt. In some instances, a factory reset of the headset was required. This exploration of the limits of what was technically feasible and operating with very recent, untested developments benefited the exhibition's character. While visitors generally enjoyed a highly immersive experience, occasional errors caused breaks that triggered valuable reflection processes, often leading to conversations with and questions to the exhibition creators, guides, or museum staff. This greatly added to the impression that visitors were not interacting with a finished exhibition product but part of an experimental research lab where they could actively participate and even provide valuable feedback.

Glass Elevator—The central idea of the exhibition design was the glass elevator located in the middle of the exhibition space. Entering and exiting the elevator, as well as the journey within it, was intended to make the transition between different layers of experience palpable, preparing visitors for a new level of perception. The elevator also referenced the historical, mechanical elevator in the very same spot that used to transport animal carcasses from the lower floors of the slaughterhouse to the auditorium. It connected the preparation and storage areas with the presentation rooms. This connection serves as a metaphor for the exhibition, as here, too, process and preparation are linked with presentation and perception.

Inside the virtual glass elevator, visitors would experience a physical sensation that once again made the convergence of the virtual and the physical tangible (fig. 4). The first design element was the platform. Entering the elevator involved stepping

Fig. 4: Inside the virtual glass elevator

up onto a small ledge, which resulted in a slight change in height. The immersion effect was particularly enhanced by feeling the edge with one's foot, as the physical sensation supported the sensory information from the visual experience. Additionally, this created a situation of slight imbalance: trust in the virtual perception was challenged and put to the test. If the visitor felt confident walking around virtual space, stepping up onto the platform could once more challenge one's trust. This moment of testing is crucial, and overcoming it increased the visitor's confidence in the virtual environment's navigability. In the virtual world, the step onto the platform was marked with a large warning sign in yellow and black, drawing attention to the obstacle. Nevertheless, we ensured that this critical moment was typically accompanied by an assistant to prevent falls in practice. → Stretching Senses, 294 Luckily, no one fell or tripped during the exhibition's entire run.

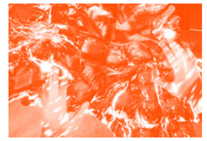
Physical Elevator Button—Initially, we had envisaged a physical elevator button to overlap with the virtual one, offering a tactile element when selecting a virtual floor. This button was produced and mounted on the elevator platform. Inside it, there was a presenter that could send various signals to the server via Bluetooth. We disassembled the presenter and connected its button signals to external buttons. Technically, this setup worked perfectly and would have added another immersive element to the elevator ride. Unfortunately however, the setup was dependent on a millimeter-precise calibration of the headsets. If the calibration was only slightly off, the physical and virtual buttons would be misaligned, leading to irritation rather than increased immersion, ultimately eroding trust in the virtual environment. Despite numerous attempts, we were unable to achieve the necessary precision, so the setup was not used in the end. In the future, it is expected that the inside-out tracking of the headset will be able to detect objects in its environment, allowing for precise alignment. For now, our scheme was ahead of the current technological capabilities (fig. 5).

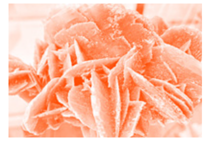
Fig. 5: A physical control station for the Virtual Elevator platform—later replaced by a virtual avatar interface to allow greater freedom of movement with material samples, cloud formations, and dynamic virtual objects

Bass Shaker—We added yet another immersive element beneath the elevator platform. When the elevator »moved« (i.e., pretended to move), four bass shakers were activated, causing the platform to vibrate slightly. This enhanced the sensation of standing in a moving elevator. The vibration started gently and transitioned into a fluctuating pattern that accompanied the »ride.« The bass shakers were activated by an additional server located in the exhibition space. This server was connected to all VR headsets via multiplayer functionality. When someone pressed the elevator button, the server triggered the bass shakers. This was done via a Bluetooth sound connection from the server to a splitter, which divided the signal into four outputs, sending them to four amplifiers, which were in turn connected to the bass shakers. As a result, a uniform vibration was distributed across the entire platform, starting immediately with the elevator's movement.

Object Tracking—For the exhibition, we intended to integrate additional tactile elements. However, at the time of implementation, the Quest 2 headsets were only capable of tracking hands. As a result, we opted for a different tracking system. We wanted to track a 3D-printed stone, which was also physically present in the exhibition for visitors to see and touch, using it as a control element in one of the levels. To achieve this, we created a 3D scan of the stone and printed it in its original size using a Prusa i3 MK3+ in bright green polyactide. This replica was then fitted with a VIVE tracker attached to its backside. The associated Lighthouse system tracks in a manner entirely different from the Quest 2 cameras. Here, detection is based on photodiodes built into the tracker, which are activated by an infrared grid continuously emitted by two base stations. These stations are mounted overhead, ensuring an ideal line of sight between the base stations and parts of the tracker at all times. This setup allows the system to determine the tracker's position in the room by evaluating the infrared grid information. The system updates 60 times per second, enabling very precise tracking without noticeable delay, usually called »latency.« → Stretching Time, 227

Finally, the Lighthouse system's position was integrated into the inside-out tracking of the headsets by connecting the tracking server, so we could place the position data of the 3D-printed stone on one of the virtual exhibition's levels. The stone itself was placed on a pedestal at the edge of the exhibition and became active in the level »Geological Performers.« On (and in) this level, visitors could see, grab, touch, and move the stone both physically and virtually. ❑ Process, fig. 12, 274 The movement of the stone was then translated into the weathering processes of the rocks displayed in the level. Physical movement thus became a control mechanism for a chronological progression. → Stretching Time, 226 ❑ Exhibition, fig. 20, 140





In hindsight, this experimental integration of two different tracking technologies posed a significant technical challenge, as they were never designed to be used together. The proper coordination of the positioning systems, the balancing of discrepancies, the calibration, and the correct activation of all hardware and software components required a complex series of manual steps. As a result, the system was rarely used in practice, and most visitors experienced the exhibition without utilizing this unique tactile component.

Room Configuration—It soon became clear that mapping the space with all its architectural positions was not possible using the building's architectural drawings alone. For an accurate virtual-physical representation, we needed the exact positions of walls, columns, and entrances. When it turned out that the measurements were not accurate enough, we had to initiate a manual correction process. The four columns—seemingly geometrically placed at the exact center of the room—proved particularly challenging. Since our lead developer Marco Garcia was working remotely from Mexico, we connected one evening and spent an entire night in (virtual) TA T, correcting these deviations step by step. With voice communication and a webcam, I moved through the space, noting the necessary corrections in position, edge, diameter, and orientation, which Marco adjusted live in VR. Using this procedure, we were able to precisely adjust each level, while I verified and sensed discrepancies in VR (fig. 6).

Fig. 6: Room configuration at TA T

Material Communication

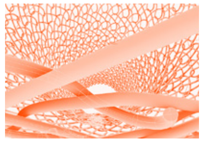
Particularly during the process of adjusting the virtual room model to the actual deviations in the physical space, it became clear that the connection between the virtual and the physical ultimately required meticulous manual work and tedious adjustments. Planning and realization often diverge, just as physical materiality and representational modeling do. When it comes to the details, as in our example, one's perspective on architecture changes: the illusion of geometry becomes questionable, and the shifts and compromises inherent in construction—which permeate any building—become central elements. Some of these deviations are due to measurement inaccuracies, others serve as corrections for certain existing deviations, and yet others respond to circumstances that were not, or insufficiently, considered in the plan. A building no longer appears as the mere realization of a plan but as a flexible framework of materials reacting to and compensating for one another. These materials communicate with each other: they transmit, filter, or block light, acoustic vibrations, electrical charge, pressure, temperature, liquids, and even molecular connections. Similar to verbal communication, material communication can only succeed if it incorporates and bridges ambiguities.

Any material object—and any configuration and spatial arrangement of objects—can be understood as such material communication. The configuration of materials, then, represents a communication network that combines various materials, positions them in relation to one another, and directs their interactions in specific ways. ❏ Process, fig. 7, 270

Materials with different surface textures can have a kind of conversation that materializes spatially. Red sandstone, as seen in the exhibition space's columns and walls, borders against polished granite, creating a material correspondence—a relationship that neither material could achieve on its own. Looking at these surfaces, one can recognize continuities and ruptures, proportions and relationships. Every material present in the space appears differently with other materials present, taking on a role assigned by their configuration. We know this from optical illusions: a gray tone appears lighter when contrasted with dark gray and darker when contrasted with light gray—even when placed directly side by side. Thus, we always perceive materials in context, assign them properties relative to their surroundings, and listen to their intermaterial dialogue. This process occurs not only visually but also haptically and even acoustically. Even though we are rarely conscious of it, we hear spaces and materials and have an unconscious sense of how material spaces sound. Perception happens through the perceptible properties—the surfaces. Just as a thin layer of paint can cover the underlying surface of a wall and create an entirely different material impression, so too material surfaces can deceive. For the exhibition, we chose a red sandstone that would be placed alongside the columns to represent the building's material and make it accessible through touch. We found a particularly treated and colored concrete, whose surface properties closely resembled the real sandstone of the column. Here, the similarity of the surface played a more significant role than the actual materiality.

Specific reactions to external forces can emerge when combining rigid and flexible materials, for instance. Materials such as rubber, fabric, or elastic plastics symbolize adaptability and movement. They can bend, stretch, and deform, visually conveying dynamism and liveliness. In contrast, materials like stone, concrete, or metal represent permanence and immutability, conveying visual calm and stability. The combination of these materials can create a visual tension that makes the space feel vibrant and interesting. The flexible willow structures atop granite in the exhibition space created precisely such tension. Similarly, the cloud, as a highly flexible and ephemeral structure, contrasted with the rigid frame of the Virtual Elevator. ❏ Exhibition, fig. 15, 137 ❏ Exhibition, fig. 19, 139

Virtual and Physical Willow Structures—This form of material dialogue was reflected in virtual space. With the willow structures, however, an element of dissonance emerged for the visitors: while the willow in the physical space was not only flexible but also deviated from its ideal form due to storage, movement, and shifts, its counterpart in virtual space was geometrically perfect. Visitors who, as intended, crawled through the large structure on the floor, feeling it with their fingers and entire bodies, saw it in the virtual space as well but transformed, as it took on its ideal, computer-calculated form in the virtual world. ❏ Exhibition, fig. 17, 138 This dissonance was intentional. It represented the dialogue between the physical material, with its flexibility and adaptability to various factors, and the virtual material, whose structural properties were explicitly calculated and chosen. This material dialogue between the physical willow and the virtual willow was immediately perceptible as a tactile-visual experience. The structural similarity between the two remained apparent, visitors kept identifying them as one and the same structure, yet the differences provoked questions about material identities and specificities.



Any material wears the inscription of its environment(s): temperature, humidity, pressure, and time all exert their influence on its structure and leave their mark. The physical structure, laid out in the exhibition space for several months, was no longer the one that was originally planned and produced after it had absorbed this duration, its location, and the many people climbing through it, showing its transformation over time.

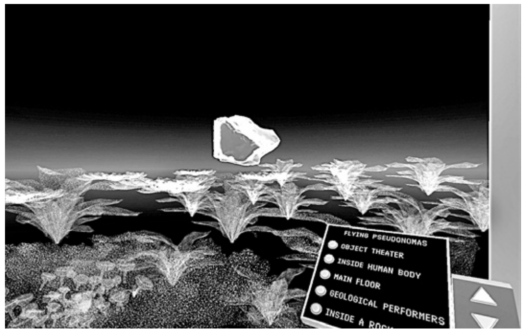


Fig. 7: In the virtual cloud—travelling between microscopic cloud particles in VR

Virtual and Physical Cloud—The cloud also reappeared as a virtual exploration space, with steaming wisps of fog rising up. There was a similar shift between the physical cloud and its virtual twin. When taking the Virtual Elevator to the top floor, one found oneself inside a cloud. The physical cloud was highly reactive—responding to every movement of air, human presence, temperature fluctuations, and even breath, forming unique and unrepeatable shapes—while visitors in the virtual space had been shrunken and were surrounded by large, flower-like cloud particles (fig. 7). Some of these particles hovered dynamically and could be pushed away by hand. The change in scale resulted in a changing perception of the cloud's flexibility and adaptability. Here, in the small-scale virtual environment, the dynamic cloud became rigid; its large particles exhibited a distinct aesthetic. Flexibility and rigidity, as revealed here, are properties that depend on dimensions and relative proportions. How a structure appears, how it moves or can be moved, how it reacts, depends on the observer, their size, and position. In the virtual realm, it is possible to not only alter material but also adjust the observer's position. Scale and perspective can be manipulated, so as to bring what is invisible to a human, tangible scale. Visitors could see, feel, and grasp that material is not merely passive, the execution of a plan: it is living and adaptive matter that reacts, to varying degrees, to countless factors.

Fig. 8: VR-Multiplayer with physical and visual cloud combined on the virtual glass elevator platform

As the physical cloud condensed on the visitor's skin, brushing against their head and becoming palpable, visitors played with cloud particles in the virtual world. Their hand movements, in turn, stirred the physical cloud, changing its shape and form. This interplay was perceptible to an external observer, someone watching from outside the virtual space, who saw the hand movements—seemingly grasping at thin air—and the physical cloud's reaction to them (fig. 8). The swirling, abrupt movements, the currents, and the partial dissolution of the cloud were all visible. The virtual cloud, as seen by the visitor, invited hand gestures, which in turn moved the physical cloud. In this back-and-forth of perspectives and materialities, of observational positions and interactions, a complex set of questions turned experiential, questions that do not easily resolve. → Stretching Practices, 40

Virtual and Physical Wall—Most walls of the rotunda are plastered, but in certain places, the original exposed red sandstone from Saxony is still visible. This sandstone has a unique surface texture, which feels pleasant to the touch and reveals a rough, detailed structure. After touching the wall, one can smell the mineral scent on one's hand, adding an olfactory dimension to the material perception. The wall opens up beneath the usual plastering, offering a kind of insight into the building's material. This material is highly active: it absorbs and releases both temperature and moisture. Thus, the cloud interacts directly with the stone. Every touch of the hand transfers warmth to the wall, which is perceived as pleasantly cool. Through the overlay of the virtual space onto the physical space, this already existing interaction was further expanded.

Technology As a Partner

Typically, we think of technology as a tool, a means to an end that helps us achieve our goals. Technology must not become an end in itself but rather serve a higher purpose. When technology becomes too central and captivates more through its effects than its content, it risks being flashy or used for its own sake. Museums and exhibitions, in particular, strive to place technology in the service of communication, carefully selecting and designing its use so that it best supports the content without becoming too visible in its own right. The tool in this sense is receding into the background as a medium.

In *Stretching Materialities*, we developed a different relationship with technology. Just as the exhibition was meant to reveal the process of exhibiting itself, we also wanted to make the influence and participation of technology as a co-creator visible. Inspired by Actor-Network Theory, we aimed to contextualize the role of the curators, relativizing their absolute position and considering the broader network of human and non-human actors. Technology—or rather, technologies—played a crucial role in almost every aspect of the exhibition. From video installations, measuring devices, and cloud machines to VR headsets and tracking systems, the exhibition consisted of numerous technological arrangements.

Virtual reality was applied here in an experimental mode, with few prior experiences and no reference projects. Working with the technology involved a process of tentative learning, experimentation, failure, rethinking, and letting ourselves be guided by the technology itself. One could describe it as a dialogue with technology, where the outcome was not simply the realization of a vision, but the development of that vision in tandem with the technology.

Technology as a partner in development should not be regarded as a mere instrument that executes human will but as an evolving entity, following logics resembling biological evolution. Technologies emerge, adapt, and sometimes wither, and this process is rarely linear. More often, it unfolds in hidden layers, revealing qualities only when a particular environment appears. Just as an organism's traits may remain invisible until challenged by new conditions, technologies display contradictions, strengths, and weaknesses that lie dormant until circumstances activate them. An interface that seems seamless in one context may turn fragile in another; a function that appears secondary may suddenly become central when conditions shift. Technologies cannot be fully understood in isolation but only in relation to the environments that test and shape them.

To take technology seriously as a partner requires a shift of perspective. Instead of imagining it only as a servant to human ends, we must attend to what it allows and resists. Resistance is not an obstacle to overcome but a signal revealing the technology's internal logic. Rather than pushing against it, it can be more productive to follow it, to ask what it discloses, and to allow it to redirect our plans. The same applies to errors and glitches. What is often dismissed as failure can guide us to hidden structures or overlooked potentials.

Technology is not a transparent medium that disappears behind its effects. It becomes part of the experience, part of the dramaturgy of an exhibition or installation. This reframing makes visible the porous interfaces between human and non-human actors and highlights that we are already engaged in a subtle but profound co-evolution with technological systems. While dominant narratives still present humans as the ones in control, bending tools to their needs, reality is more entangled. Technologies themselves participate in shaping intentions, behaviors, and meanings.

To recognize technology as an active materiality is to acknowledge its dual character. On the one hand, it presents polished features, often marketed as seamless and intuitive. On the other, it harbors concealed architectures, hidden dependencies, and improvised or hacked-in solutions that surface only in particular circumstances. A headset may feel like a gateway into another world, yet behind its sleek design lies a fragile mesh of sensors, code, updates, and workarounds. Such tensions are not flaws to be erased but characteristics to be explored. They remind us that technology is both made and making, both a product of design and an agent of transformation.

Placing technology on eye level requires more than technical skill; it demands a readiness to reconceptualize our ideas in response to what the technology reveals. It involves listening to its rhythms, learning from its resistances, and accepting its capacity to surprise. In experimental VR installations, this means treating the technology not merely as a display device but as a collaborator in meaning-making. The process becomes less about imposing a vision and more about developing that vision in tandem with the possibilities and constraints the technology introduces.

Such an approach embraces uncertainty. It accepts that outcomes may not match initial intentions and that unexpected results can be as meaningful as planned ones. It foregrounds the shared terrain where human intention and technological affordances collide, creating a space of co-authorship. Here, technology is neither background nor spectacle but a participant in the dramaturgy of the exhibition. By acknowledging its evolving, sometimes contradictory character, we allow it to contribute actively to the narrative of active materiality, showing the inseparability of human and non-human forces in shaping experience.

Exhibition As a Game

Exhibition spaces are no longer about displaying pre-existing objects but about dynamic, not fully determinable interactions. When applying this approach, one relinquishes control, risking misunderstanding, failure, or frustration among visitors. The narrative becomes fluid, interpretations multiply, and the points of connection become harder to predict. However, the connections with visitors might also become more intense, personal, and interesting. This shift reframes the exhibition space as a playground, and the visit as a live game with content that can be different each time and with each visitor.

In this sense, curators can learn a great deal from game designers. When designing a game, the focus is on interaction. It's not about telling a finished narrative in a linear way as opposed to film. Rather, it is about creating a specific, characteristic, and unique space that invites exploration, experimentation, and interaction. A game is not successful because the solution is reached; it succeeds when the path to that solution is engaging and interesting. The game designer sets the conditions where motivating interactions are likely, but they leave room for the observations, strategies, interests, and decisions of the players. In this sense, a game is not so much »designed« as it is an open system and a play space where play can take place through the interaction between the player and the game environment.

Similarly, an exhibition visit can be seen as equivalent to playing a game—it is not a predetermined sequence of events but a unique occurrence. How good or intense that occurrence will be depends on how well the play space and the visitor (or player) fit together and what can happen between them. In this sense, visitors, like players, are not static entities to be treated uniformly. Even the classic division by age groups falls short here. Rather, it is important to identify the characteristics of groups as they emerge and manifest within the interaction space—whether it is an exhibition or a game. In some exhibitions, prior experience with digital media may be irrelevant, prior knowledge, conversely, forms different groups. In other exhibitions, reaction speed or the social relationships between visitors might be more decisive. It is essential to recognize different audience groups based on their environment. Once this is achieved, the exhibition can better respond to these varied groups.

There's a notion in game design—»the game looks back«—which means that digital games do not offer a static, unchanging environment. Instead they can subtly adapt to the player's behavior. Games do not simulate a given world; they create a world that adjusts to the player. The difference between simulation and play lies here: a simulation strives to model an external reality as accurately as possible. The quality criterion is realism, the alignment between reality and the model, rather than the player's experience. A game, by contrast, draws parallels with reality primarily on a narrative level, borrowing from experiences with other stories or the physical world to create a world that feels familiar and manageable to a degree. Games often have a physics engine through which virtual objects behave in ways that feel like they adhere to physical laws. Players recognize the similarity with the real world and can therefore interact with the game world more intuitively. But since it's a game and not a simulation, the parameters are often adjusted. The avatar moves faster than in reality to allow for quicker exploration. Objects can be thrown farther or break apart more dramatically to enhance the interaction with the environment. Reality is not the goal; it is an inspiration, and deviating from it is not only allowed but intended.

If we apply these considerations to exhibitions, we see that representing reality is no longer the primary goal. Instead, the aim is to create spaces where access to knowledge can become an individual process, where visitors can find subjective points of connection, and where new questions arise. Even in traditional exhibitions, the curatorial narrative rarely fully comes across. One might wonder how many exhibitions are curated for curators rather than for the average visitor.

Designing exhibition spaces is less about delivering a fixed narrative or a linear progression of knowledge. Instead, the focus is on facilitating an open-ended experience where visitors can engage in dynamic interactions and form personal, subjective connections with the content displayed. This transformation of the exhibition space into a game-like environment allows for a diversity of experiences, where each visitor creates their own journey through exploration, curiosity, and play.

Exhibit: Visitor

From the earliest stages of its conceptual development, one central idea for *Stretching Materialities* had always been clear: it wasn't just about the exhibits themselves, their selection, or their arrangement. Instead, the focus was on placing visitors in the spotlight and making them, and visiting an exhibition, a thematic part of the exhibition. An exhibition without visitors isn't an exhibition. Thus, the act of exhibiting happens in the in-between space, it comes about in the dynamic interaction between objects and visitors. The visitors' knowledge, their expectations, their gazes, their companionship, and their paths through the exhibition all contribute to shaping what is perceived, what leaves an impression, and what proves to be engaging.

Yet, visitors themselves are also observed by others. How crowded is the exhibition? Who is visiting? How do the other visitors appear? What do they focus on, where do they pause, what do they discuss? Visitors might not be aware of it, but they themselves are a part of every exhibition and, in turn, transform it—not only for other visitors but also the space itself. Each person brings vibrations into the room, micro-tremors that affect the exhibition space. They introduce fine particles and matter, which are released into the air, they leave behind dust or material carried in on their shoes. Visitors increase the temperature and humidity of the room, impacting the objects within it. It's a continuous give-and-take, a process of bringing in and taking out, of concentrating and dispersing matter, energy, and meaning. The exhibition space becomes a *trading zone*, a site of ongoing negotiation of meaning and atmosphere.

This concept redefines the exhibition as a shared experience not just between visitors and objects but between all elements in the space. It highlights the fluid interaction of materials, bodies, and perceptions, where each visit is unique, shaped by the visitors who inhabit the space and the way they move through it. Each individual's presence is imprinted onto the environment, both physically and symbolically, creating an evolving network of exchanges between the tangible and the intangible, the seen and the unseen.

Branching

With *Matters of Activity*, the focus has been on rethinking how we perceive matter, especially through the concept of »active matter.« Since 2019, scientists from over forty disciplines have worked together to challenge the traditional view of matter as passive, acted upon only by living agents. Commonly, we think of tools, for example, as inert objects that become useful only in human hands. In reality it is more complex: tools, and non-living matter in general, have their own agency and reactivity, influencing our actions as much as we shape them.

Active matter suggests a view where both living and non-living things are seen as highly dynamic, though these interactions are often too small, large, slow, or fast for us to notice. Rust forming on iron in the presence of water and oxygen is an example of this constant transformation—what we call »matter« is in a continuous state of flux. This also applies to digital matter: enormous data structures constantly grow, react with algorithms, and shape our digital environment, often invisibly. Virtual matter, like physical matter, is active and »alive,« reminding us that we should understand matter as a network of structures that exist and interact in both virtual and physical ways.

One of the key takeaways is that we can no longer maintain a position of simply opposing technology, especially in the arts. Technology is ubiquitous, an inseparable part of postmodern human existence. There is no going back to some idealized »natural« state free from technology. We can only have preferences for one technology over another. A paintbrush is as much a piece of technology as a 3D printer, and a sketchbook is no less artificial than an AI tool. The role of art is to reflect on and repurpose the technological landscape we live in. Technology is not synonymous with its appropriation by capitalism—it is a symptom of our world and it opens new avenues for artistic expression. Art and technology have always been interconnected, and today, this connection is bringing forth fascinating new art forms.

→ Stretching Practices, 36

Fig. 9: Visitors in the Museo Sivori in Buenos Aires, to which the exhibition had traveled from 15 March to 15 April 2023

This exhibition *Stretching Materialities* was a symbolic experiment—an experiment that continued and shifted to an adapted exhibition in Museo Sivori in Buenos Aires (fig. 9). It provided insight into cutting-edge research on active matter, presented through a VR experience that spatialized knowledge and perspectives. It also connected the physical and the virtual. The woven willow structure, made in Berlin, was placed in the center of the exhibition in Buenos Aires. Willow is a particularly active material, responding to pressure, moisture, and temperature, adapting itself to its environment. This willow structure, designed algorithmically and woven by robots, was interwoven with intricate weavings by the Argentinian artist Daniela Castillo Cortez that extended throughout the room. Beneath this, visitors in VR interacted with their surroundings, and their movements and gazes controlled virtual structures that grew into the virtual space. These virtual actions were translated into instructions, which Daniela wove into her physical works. The virtual reached into the physical, and the physical entwined with the virtual. Together, they formed a tapestry of symbolic and material connections, inviting visitors to reflect on how the world truly works.

At Humboldt University, we asked ourselves how we could open up the scientific discourse to the public—in Berlin and internationally. We realized that such global and important questions as those surrounding active matter cannot remain confined to academia. That would be disastrous. Scientists need connections with society and non-academic knowledge, and we must create shared spaces for dialogue. Often, scientific discourse is abstract and incomprehensible to non-academics, leading to its isolation. This can change. We need active dialogue between science and society. Our exhibition experiments are an attempt to give research a different surface, to make it more accessible. In Berlin, we work directly in exhibition spaces that are suitable to engage with the public. Our exhibitions are works-in-progress, invitations to participate in ongoing questions. They intend less to present conclusions and more to encourage inquiry. They are branching out, across borders of mind and space, and connect places on the globe as much as discourses and disciplines. Exhibiting in this sense means opening up, becoming vulnerable, experimental, perceptive—and revealing more than the polished results.

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