AirClick: Modularized Interactive Inflatables for On-Demand Room Transformation

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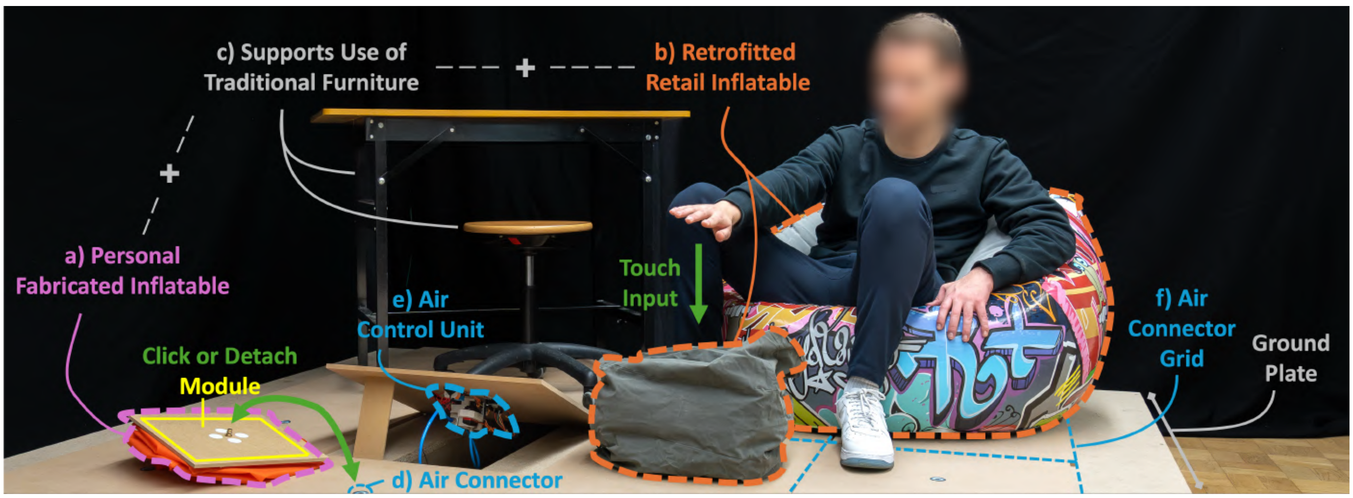

Figure 1: *AirClick* overview. Detachable modules connect to both personally fabricated (a) and retail inflatables (b) and integrate with traditional furniture (c). Each module *clicks* onto an air connector (d) linked to a control unit (e) beneath the ground plate grid (f). This setup enables space-efficient, interactive room transformation through tangible rearrangement and pneumatic actuation.

Abstract

As living and working spaces become scarce and costly, interiors transitioning between living, working, and sleeping configurations while enabling customized setups are in demand. Traditional furniture consumes space and is cumbersome to rearrange. Shape-changing furniture could solve this, yet existing options lack resolution, stability, or adaptability. We present *AirClick*, which facilitates on-demand room transformation using modular interactive inflatables. Our fabrication process supports personally fabricated and retrofitted retail inflatables. The touch-actuated modules connect to a floor-based air connector grid, facilitating interaction while integrating with traditional furniture. In a lab study (N=20) across four scenarios (office, meeting room, apartment room, multipurpose hall), participants rapidly transformed rooms and perceived *AirClick* as significantly more usable with higher intention to use in the everyday scenarios than in the hall, indicating suitability for routine activities with low to medium requirements for robustness. User feedback highlights *AirClick* 's usefulness and scalability in diverse settings, hence showing *AirClick*'s space-saving and customizable design can enhance the functionality and adaptability of living and working spaces.

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CCS Concepts

• **Human-centered computing** → **Ubiquitous and mobile computing**; • **Hardware**;

Keywords
room transformation, shape-changing interfaces, large-scale interactions, inflatables, furniture

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1 Introduction
In recent years, the prices for living and work spaces have continued to rise while the available space has become scarcer [28]. Thus, the available interior space should be used efficiently and effectively to save time, money, and effort. However, traditional manual reconfiguration of interior spaces is time-consuming, as moving large, heavy furniture is cumbersome, and storing unneeded pieces occupies valuable space.

Quick and easy transformations are essential to optimize space usage and enable versatile interiors like meeting rooms and exhibition areas. Extending existing furniture with add-ons rather than complete replacement promotes flexibility and reduces waste. Additionally, shape-changing systems allow furniture to be adapted, making it easier to explore new interior configurations.

While existing systems like pin arrays [8, 15, 25], modular robotic modules [17, 42, 44, 46], and dynamic 3D printing [45] offer on-demand shape change, they primarily cater to haptic feedback in Virtual Reality (VR) environments [52] or tangible prototyping [5] and cannot create the shapes required for practical, aesthetic, and ergonomic furniture like sofas and shelves. Large-scale inflatable approaches, like Printflatables [38], Swaminathan et al. [48], and AirTied [35], provide such shapes that are compact when deflated, yet they struggle with actuation control and hose organization for multiple furniture pieces. Floor-based systems can solve layout, organization, and actuation issues for entire rooms, but pin-based approaches like Elevate [15] require substantial space for their underlying mechanisms. Instead, previous floor-based systems using inflatable modules like LiftTiles [43] and TilePoP [52] solve this space problem but are limited to fixed cuboid shapes, lack robustness (e.g., 10 kg load-bearing [43]), and non-detachable modules, thus offering little flexibility and not supporting the hybrid use of existing furniture.

To overcome these challenges, we present *AirClick*, a system for on-demand room transformation (see Figure 1). *AirClick* employs novel detachable modules, which can connect to arbitrary inflatable shapes while providing sensor and air connections for their interactive actuation. The modules mount personally fabricated and retail inflatables. While personal fabrication enables custom shape creation, catering to specific aesthetic and functional requirements, retrofitting retail inflatables provides accessibility and convenience, leveraging available products. This combined approach allows for various module designs, from simple cuboids to complex, custom shapes for furniture like sofas and shelves. Besides, a ground plate eases module connection while hiding and organizing air hoses and valves in a grid (see Figure 1) connected with a control software to synchronize actuation. Each ground plate grid unit has a circular air connector, enabling one Degree of Freedom (DoF) for module rotations and two DoF for planar movements. Modules can be detached while keeping their inflated state, which can be prolonged by sealing the inlet. The modules cover the floor only when needed, leaving the remaining area available for other uses. Further, compact deflated modules allow space-saving storage.

Following a research through design approach, we built a 2x2 m ground plate with 16 air connectors. To demonstrate the mounting and use of diverse personally fabricated inflatables, we created a chair, cube, room separator, shelf, and air-stack to showcase the modules. Additionally, we retrofitted an inflatable bed, beanbag, and footrest from retail as modules. The prototype underwent a technical evaluation, proving its low space requirements, deployment ease, reasonable actuation speed, and robustness.

To understand how people would use *AirClick* in practice and to probe its applicability to everyday rooms, we conducted a lab study (N=20), where participants freely explored room transformation with *AirClick* in four scenarios: office, meeting room, apartment room, and multipurpose hall. They rated *AirClick* as usable and would use it in the future. While highlighting its versatility, they see challenges regarding robustness and moving object-filled table and shelf modules. The participants' room setups suggest that *AirClick* suits a wide application range, from rearranging meeting rooms to converting bedrooms into home offices.

Contribution Statement:

- The concept and implementation of *AirClick*, a floor-based system for on-demand room transformation.
- Empirical findings from a formative user study (N=20) showing *AirClick* 's usability and versatility across four interior scenarios (office, meeting, apartment, multipurpose hall), revealing interaction patterns with modular inflatables.
- Design implications for everyday room-transformation systems, derived from the study and technical evaluation, guiding future deployments of pneumatic environments.

2 Related Work
AirClick builds on shape-changing interface research (1) conducted at a large scale in entire rooms, (2) with modular designs, (3) using inflatables, or (4) having floor-based applications.

2.1 Large-Scale Shape-Changing Interfaces
Prior work investigated large-scale shape-changing interfaces for interiors, highlighting the benefits of adaptive environments. For example, Hong et al. [12] explored interaction with actuated walls, and Nabil et al. [24] actuated decorative interior artifacts. Moreover, Ori [41] and CityHome [19] provide systems for transforming entire rooms. However, they require rail installations on suitable surfaces, which do not fit every room due to narrow walls and small ceiling height, and need pre-configuration of furniture behavior.

As these prior large-scale systems are primarily designed for specific room layouts [19, 41] and purposes (e.g., decoration [12, 24]), they are limited in adapting or reconfiguring rooms dynamically with custom objects besides walls, beds, and retractable tables. In contrast, *AirClick* focuses on transforming entire rooms with modular inflatable components that can be rearranged on a grid.

2.2 Modular Shape-Changing Interfaces

Modular 3D objects could be used for furniture, as they provide diverse shapes and can be easily rearranged [7, 11]. Researchers have proposed modular systems like SwarmHaptics [17], ShapeBots [46], and RoomShift [42] to build construction kits or provide haptic feedback. However, RoomShift can only move existing furniture and requires at least 30 cm underneath each piece *individually* for robotic module connection, mainly suitable for tables and chairs. In contrast, *AirClick* raises the *entire* floor by 15 cm to allow furniture with less space than 30 cm underneath (e.g., shelves). Moreover, actuators' number [17, 46], size [17, 26, 46], load-bearing [26, 42], and power requirements [49] remain significant challenges when scaling these approaches to furniture.

Besides, self-reconfigurable modular robots (e.g., see [42, 46]), mechatronic surfaces [40], or interactive blocks (e.g., see [11, 34, 37, 45]) create technical complexity due to actuation and communication requirements, imposing a greater risk of technical failures and damages in a large-scale scenario that requires robust furniture. Other works, such as TiltStacks [53] and Tangible Pixels [50], suggested dynamically constructing furniture. However, their electromechanical modules are relatively expensive and limited in size as well as physical representations (e.g., because of the pixel-array layout [53] or weight [50]). Also, the construction time increases with the number of components, posing a challenge for rapid shape generation [45]. To reduce module cost and deployment efforts and increase shape versatility, *AirClick* employs inflatables on modules. In contrast to approaches that require many components for one object (e.g., [17, 37, 45, 46, 58]), this reduces the number of modules, as entire inflatable furniture (e.g., tables or beds), also from retail, can be mounted on modules.

Furthermore, prior work has explored fast and flexible connections between modular units. "Oh, Snap!" [39] introduces a mechanism for rapid attachment and detachment of **small** modules, which aligns conceptually with our goal for swift reconfiguration. Although "Oh, Snap!" does not employ inflatables, the principle of rapid, flexible modularity is central to our approach of deploying entire inflatable furniture on a structured grid.

2.3 Inflatables

Inflatable furniture has existed since the 1970s [14], forming complex shapes [5, 51] and deploying large-scale objects on demand [38] while allowing for compact storage. Moreover, pneumatic actuation offers advantages over hydraulics [23] and low-boiling-point liquid pneumatics [22] due to its safety, energy efficiency, simplicity, low costs, and ease of maintenance. Unlike electromechanical actuation (e.g., [15, 53]), pneumatics is less prone to mechanical issues. Still, inflatables may consist of unappealing material and require inspections for material leaks.

Previous research demonstrated inflatables in diverse shapes and scales. PneUI [56] explored inflatables with diverse curvatures, volumes, and textures, while AeroMorph [31] introduced folding methods to create 3D shapes from 2D inflatable airbags. Regarding applications, PuPoP [51] investigated inflatables as handheld props in VR, and PneuSeries [5] introduced modularized inflatables serial-connected via custom bidirectional check valves to form custom 3D shapes. However, these approaches are too small, not scalable (see [51]), and need to be more robust (e.g., issues with air pressure [5]) to be used as furniture. In contrast, Swaminathan et al. [48], Printflatables [38], and AirTied [35] proposed fabrication methods for large-scale pneumatic structures usable for furniture. Recent work further underscores how inflatables enable versatile, comfortable, and easily stored large-scale objects. Poimo [27] presents an inflatable, lightweight mobility device, and SnapInflatables [55] investigates structural and functional inflatables with seamless on-demand shape transformations while retaining robustness.

However, inflatables that are individually connected to air hoses usually run disorganized on the floor and need separate actuation (e.g., see Printflatables [38] or AirTied [35]). This complicates the inflatables' (automated) actuation control and creates hose clutter, limiting the systems' scalability when rooms require many furniture pieces. To mitigate this, *AirClick* employs an air connector grid on the floor, which organizes hoses and enables centralized and automatic actuation of all modules, facilitating the transformation of entire rooms. Although restricting module arrangement to a grid, we argue that the benefits of simplified use and organized actuation outweigh this.

2.4 Floor-Based Shape-Changing Interfaces

Grid-based air connectors have already been used for large-scale systems that cover the floor to enable effortless actuation for on-demand furniture. They can seamlessly integrate into interiors by hiding and organizing air hoses, cables, and mechanisms.

Leveraging inflatables, TilePoP [52] constructed a floor-based grid of cuboid shapes for human-scale haptics. Similarly, LiftTiles [43] employed grid-based party-horn-like inflatables for large-scale prototyping. However, their deflated modules are permanently fixed to the floor, often unevenly, with gaps. This limits the combined use with traditional furniture. Using small actuated blocks, Elevate [15] provides walkable terrains for VR but lacks modularity (only cuboid shapes) while requiring considerable space for underlying electromechanical systems. Also, prior approaches only support a set of low-resolution cuboids, which are uncomfortable as furniture.

Instead, *AirClick* uses detachable modules that occupy space only when in use, allowing hybrid integration with traditional furniture. The remaining ground plate surface stays usable for movement. Although deflated modules still require storage, their compact size keeps this need minimal. Moreover, *AirClick*'s modules host arbitrary inflatable shapes, either personally fabricated or retrofitted from retail. This enables flexible and efficient interior reconfigurations combining basic shapes like cuboids (see [22, 43, 52]) as dynamic building blocks (e.g., augmenting chair modules with footrests) with more complex shapes (see [38]) for specific furniture like chairs, sofas, and shelves, or serially connectable shapes like air-stack and cubes (see [5, 48]). Besides, unlike previous works, we developed novel detachable modules that process touch input, enabling direct control over furniture actuation.

While our system leverages a grid-based floor integration, an alternative approach is to use mobile robots to carry inflatable modules without requiring fixed air hoses, as explored in Poimo [27] and InflatableBots [9]. These robotic methods do not constrain module placement to a predefined grid and simplify hose management by eliminating fixed connections. However, compared to such robot

Table 1: Comparison of large-scale shape-changing systems regarding on-demand room transformation (see Section 3). *N/A* indicates such a system is not present. Blue indicates the best but comparable capabilities. Green indicates a sole benefit.

		Printflatables [38]	TilePoP [52]	LiftTiles [43]	Swaminathan [48]	RoomShift [42]	Elevate [15]	TangiblePixels [50]	Ori Apts. [41]	*AirClick*
C1	Inactive Module Size	**Low** depending on inflatable size	**Low** 9 cm	**Low** 15 cm	**Low** depending on inflatable size	**High** modules incompressible	**High** max. pin height	**High** 40 cm	**High** modules incompressible	Low min. 5 cm, inflatable size dependent
C2	Module Transport.	**Easy** lightweight inflatables	**Hard** not removable	**Medium** separate module handling	**Easy** lightweight inflatables	**Easy** automated movement	**Hard** not removable	**Hard** not removable	**Hard** not removable	**Easy** lightweight inflatables
C2 -4	Module Deployment	**Hard** separate module air hose	**Medium** automated, not removable	**Medium** automated, not removable	**Hard** separate module air hose	**Medium** automated, 30 cm underneath	**Medium** automated, not removable	**Medium** automated, not removable	**Medium** automated, not removable	Easy click modules at any place
C4	Ground Plate Robustness	*N/A*	**Low** uneven, 6 cm spacing	**Low** uneven	*N/A*	*N/A*	**High** robust, even, thin gaps	**High** robust, even, thin gaps	**High** real furniture	**High** robust, even, seamless tiling
C4	Module Load-Bearing	**High** shape dependent, average male 70 kg	**High** shape dependent, average male 70 kg	**Low** 10 kg	**Low** 7.6 kg for dome, 1.8 kg for canopy	**Medium** 30 kg during actuation	**High** average male 70 kg distributed on pins	**High** average male 70 kg distributed on modules	**High** real furniture	**High** shape dependent, average male 70 kg
C4	Actuation Speed	**Medium** inflatable volume dependent	**Fast** 5 s airbag inflation, 20 s deflation	**Fast** 16 s full extension, 4 s full retraction	**Medium** inflatable volume dependent	**Medium** 1.3 cm/s deployment + 20 cm/s movement	**Medium** 2.9 s for one pin's max. height	**Fast** motor speed dependent	**Medium** motor speed & mod. size dependent	**Fast/Medium** inflatable volume dependent
C5	Shape Complexity	**High** basic and complex shapes	**Low** only cuboids	**Low** only cuboids	**High** basic and complex shapes	**Low** requiring 30 cm underneath	**Low** only cuboids	**Low** only cuboids	**Medium** only bed, shelf, and tables	**High** basic and complex shapes
C6	Manipul.	**Low** only physically moving modules	**Medium** proactive and reactive but only haptic proxy	**Medium** proactive and reactive but only haptic proxy	**High** touch, gesture, and haptic input	**High** touch, gesture, and haptic input	**Low** only haptic feedback	**Medium** touch input and haptic feedback	**Low** only triggering module movement	**Medium** touch input
C7	Reconfig.	**High** separate modules of any shape	**Low** static setup	**Medium** only rectangular module arrangement	**High** separate modules of any shape	**Medium** compatible with tables and chairs	**Low** static setup	**Low** static setup	**Low** static setup	High separate modules of any shape

systems, *AirClick* provides a more direct, robust, and maintenance-friendly setup. By centralizing air supply and reducing mechanical complexity, *AirClick* avoids the cost and operational overhead of multiple mobile units navigating a room. This stationary approach enhances long-term reliability and scalability, as it does not rely on continuous robotic repositioning or navigation systems.

3 Challenges for On-Demand Room Transformation

From a user needs elicitation (see Appendix A) and related shape-changing approaches [5, 38, 42, 43, 52], we identified key challenges (**C1-C7**) in creating an *ideal* room transformation system.

- **C1 Space:** To facilitate dynamic room transformations and efficient single-room space use, furniture must be as compact as possible when not in use [43, 52] (see Table 5 A-E).
- **C2 Deployment:** Furniture must be modular, deployable, and allow quick assembly and disassembly [43, 52]. Modular components should accommodate changing user needs (e.g., see [5, 42, 46] and Table 4 A-E).
- **C3 Low-Cost and Scalability:** Systems must be cost-effective (see Table 6) and scalable to entire rooms, accommodating various furniture shapes, sizes, and interior applications (see Table 4 A-E) [43, 45].
- **C4 Robustness and Speed:** Furniture must (dynamically) form robust structures capable of supporting body weight and other loads [15, 38, 43, 52] (see Table 4 A-E). Rapid and seamless reconfigurations (e.g., see [42] and Table 5 C) are key to adapting to new room purposes (e.g., converting a workspace to a living area).
- **C5 Shape Complexity:** Furniture shapes range from basic cuboids to complex curvatures and cavities. Thus, a room transformation system should support diverse shapes (e.g., see [45, 58] and Table 4 A-E).
- **C6 Manipulability:** Furniture should be manipulable with ≥3 DoF, enabling free movement and rotation of items like chairs and tables (see Table 4 and Table 5 A-E) without being fixated on objects or surfaces (e.g., see [42, 58]).
- **C7 Reconfigurability:** The system should ease reconfiguration of furniture layouts as users' needs and preferences change (see Table 4 A-E), ensuring functionality and comfort in various situations [43].

Table 1 shows a comparison of shape-changing furniture approaches with *AirClick*. While others (e.g., [38, 48]) address at most five challenges, *AirClick* performs well at all seven, underscoring its advantages in overcoming **C1-C7**.

4 The *AirClick* System

Guided by **C1-C7** (see Section 3), *AirClick* enables on-demand room transformation, featuring easy-to-handle modules as bases for diverse inflatable shapes. The detachable modules click into a grid-based ground plate for pneumatic actuation via custom-designed air connectors. A control application coordinates air supply, module identification, and sensor input, providing both automated and manual control of room configurations.

4.1 Design Space and Interaction with *AirClick*

This section outlines the design space underlying *AirClick* 's interaction capabilities, specifying how users can actuate, manipulate, and reconfigure modules through combined physical and digital

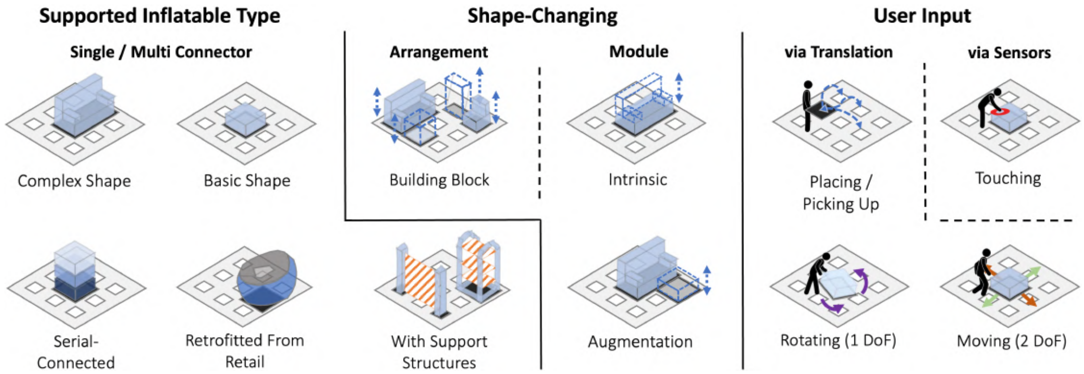

Figure 2: Three-dimensional design space of *AirClick*. The parameters combine freely for on-demand room transformation.

controls. In this work, we use the term *interactive* to refer to both user-driven and system-driven actuation. Interaction with *AirClick* occurs tangibly through physical manipulation and touch input, as well as proactively through automated inflation and deflation triggered by the control software.

Incorporating modularity and diverse inflatable shapes, *AirClick* introduces a novel design space for interactive shape-changing furniture. This draws on concepts from shape-changing interface literature (e.g., large-scale morphing surfaces [12, 24] and modular shape units [7, 11]) but is specifically tailored to *AirClick* 's inflatable and floor-based approach. Rather than being an exhaustive taxonomy of all shape-changing furniture, it highlights the key parameters in our system. This design space has three dimensions: (1) supported inflatable type, (2) shape-change capabilities, and (3) user input (see Figure 2).

Single and *multi-connector* modules can be used in furniture arrangements for one primary use (e.g., table or chair) and as building blocks to create larger structures, augmenting other furniture. We distinguish basic shapes as single air chamber inflatables (e.g., a cushion or footrest), while complex shapes encompass multi-chamber or multi-connector inflatables that can form elaborate furniture (e.g., a multi-segment sofa or shelf with adjustable compartments). Additionally, serial-connected inflatables enable module-intrinsic shape change.

The 3 DoF modules enable lateral and longitudinal movements when disconnected and 360-degree rotations when using a single-connected module (**C6**). They can be inflated/deflated through touch interactions (**C2** and **C6**). Focusing on these direct physical interactions, we emphasize naturalistic, embodied control modalities that link with the physical environment. While alternative inputs such as voice or gesture commands are feasible future extensions, we selected touch sensing as it can be intuitively integrated into rearranging and using furniture.

The identified capabilities guided the module hardware and control software design presented in the following sections.

4.2 Modules

AirClick allows the formation of furniture arrangements from modules that enable quick disassembly, space-saving (**C1**), and adaptability to user needs (**C6** and **C7**). The modularity also facilitates deployment (**C2**), valuable for those who often relocate or need temporary furniture. Modules consist of a baseplate and an inflatable (see Figure 3).

To improve stability (e.g., when sitting) due to the low weight of inflatables, modules use a baseplate (**C4**). This also offers a single connection point for easy deployment (**C2**), manipulation (**C6**), and reconfiguration (**C7**). We mount a spring-based pneumatic plug in the baseplate to connect the ground plate's air supply (see Figure 4). This coupling creates the "click" feedback and ensures the module can withstand lateral forces from objects. Electronic components, like touch sensors, are powered through inductive coils around the connector, eliminating the need for batteries, simplifying deployment (**C2**), reducing weight (**C2**), and costs (**C3**). We used four Mifare Ultralight RFID tags around the air coupling underneath to identify the module's type, function, orientation, and size for automatic actuation. Unlike LiftTiles [43] or TilePoP [52], modules are movable while inflated and disconnected. A manually inserted rubber plug seals the air inlet.

We added a capacitive touch sensor to one side of the baseplate (see Figure 3 b). Double-tapping inflates a module, and triple-tapping deflates it. A single tap cancels or resumes an action. Users must tap and hold for three seconds before detaching a module from the ground plate to avoid accidental disconnection. The touch sensor is fully functional regardless of module rotation, as data is transferred wirelessly and power is permanently received by the inductive coil around the connector inlet.

Mounting Inflatables on Modules. We use inflatables as they are space-saving when deflated (**C1**), lightweight (**C2**), cost-effective (**C3**, e.g., a bed costs $20), and support various shapes, providing a versatile approach for furniture (**C5**). Unlike rigid mechanical modules that are shape-limited [37, 50, 53] or purely deformable surfaces [5, 52] that lack structural stability, *AirClick* merges them by leveraging inflatables for dynamic shapes mounted on stable baseplates for secure connections. This provides a novel, practical room transformation approach without the overhead of robotic mechanisms [42, 46] or permanent fixtures [41]. The mounting process is depicted in (see Figure 4).

Types of Inflatables. AirClick supports **any** *personal fabricated* and *retrofitted retail inflatables*, in sum offering comfortable and aesthetic appealing furniture (**C5** and **C7**). We fabricated inflatables

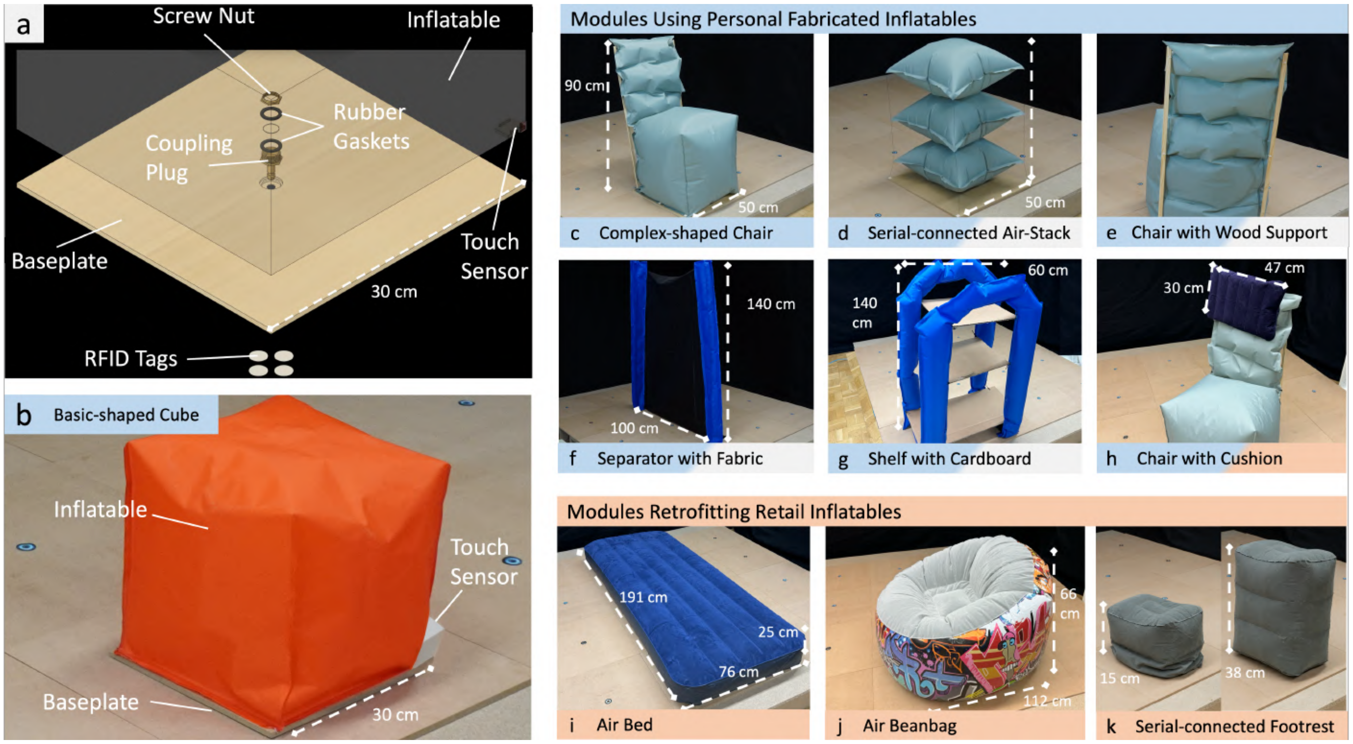

Figure 3: (a) Expansion view of a 1x1 module. (b) Implementation of a basic shape cube module with 30 cm sides. Right: Module demonstration. The modules can accommodate any inflatable shapes-personally fabricated or retrofitted from retail. Also, support structures can increase stability or add texture: (d) Air-stack with strings to avoid tilting. (e) Chair with wooden backrest for increased stability. (f) Room separator with a fabric sheet. (g) Shelf with cardboard dividers. (h) Inflatable cushion.

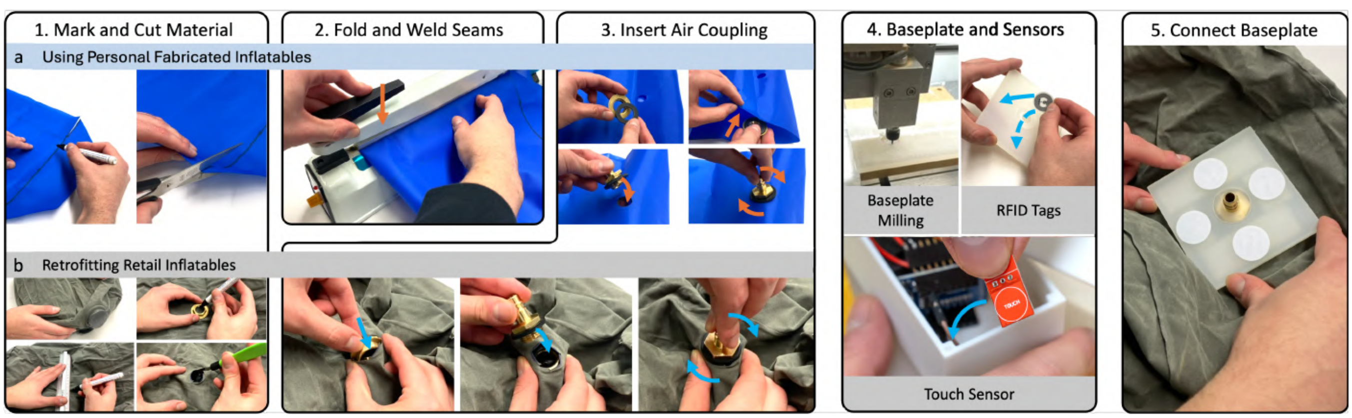

Figure 4: Process of mounting an inflatable on a module. The last two steps are the same for any module.

made of TPU-coated nylon fabric inspired by PneuSeries [5], which could be automated (e.g., see [31, 38, 54]). Based on prior works, we created a chair [38], cube [5], air-stack [52], separator, and shelf (see Figure 3 a-f). Retrofitting retail inflatables promotes resource reuse (**C3**, see Figure 3 g-j) and simplifies the fabrication process for novices. We retrofitted an Intex Airbed, a Bestway Graffiti Air Chair (beanbag), and three Maliton Footrest Pillows, each less than $20 in 2025.

4.3 Ground Plate

The ground plate's grid can scale to any room and eases module deployment (**C2**), allowing for air supply via hidden hoses and valves (see Figure 5). The grid cell size depends on the smallest module, with smaller cells offering higher resolution at a higher cost. In contrast to linear rails [41] or tracks [2] that limit repositioning to one dimension and require carefully planned routes, the grid provides omnidirectional placement freedom. Modules can connect

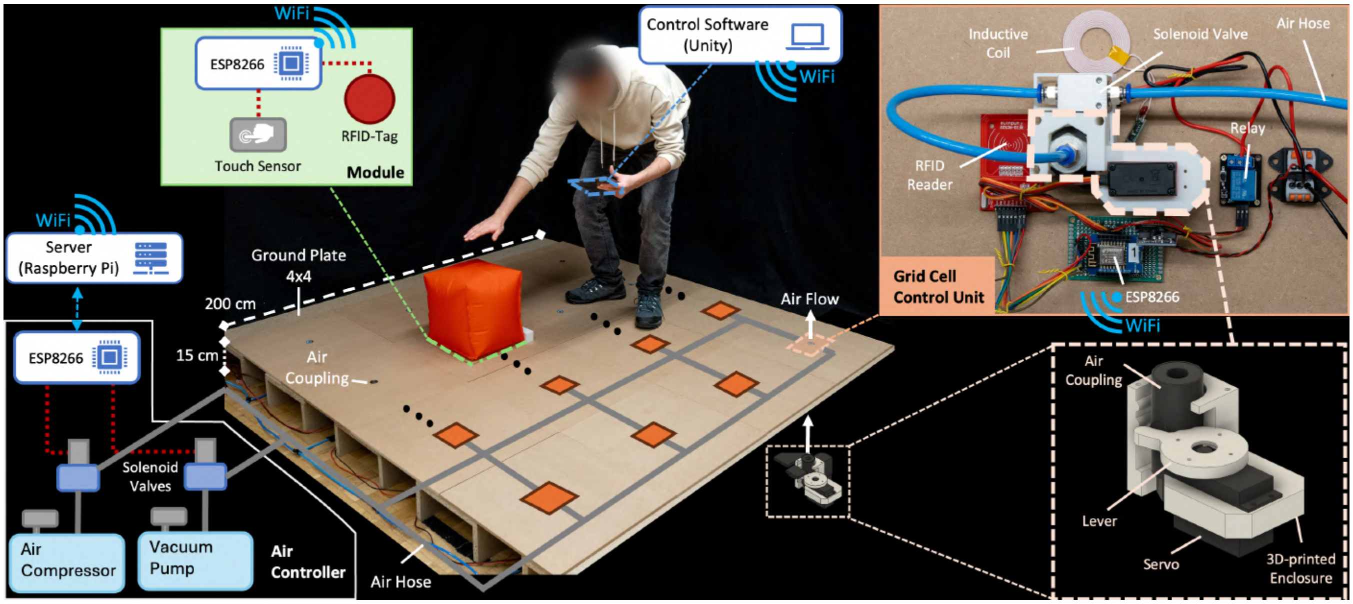

Figure 5: Ground plate system overview. A server sends and receives airflow commands from modules and control software wirelessly. Right, expansion view of a ground plate and control unit with technical components.

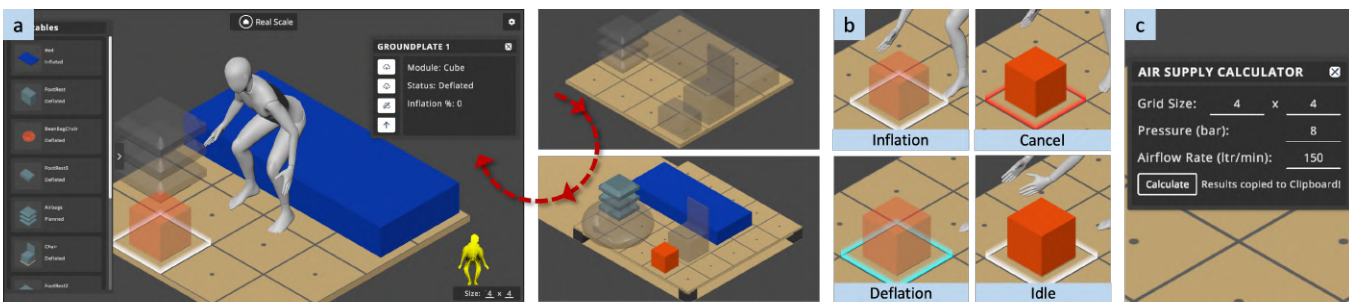

Figure 6: (a) Control software with module catalog and active (opaque) and inactive modules (transparent) visualizing room transitions. (b) Module state representation. (c) Air supply requirement calculator for any ground plate scale, see Appendix E.

to any cell, be rotated, or moved to another cell. This approach also simplifies handling modules simultaneously, as these independently "click" into connectors, reducing mechanical dependencies and enabling truly modular reconfiguration. We created a 2x2 m prototype that holds up to 16 1x1-sized modules.

AirClick integrates with **existing** furniture (see Figure 1), occupying ground space only when needed. Unlike large-scale systems that may create uneven ground surfaces (e.g., see [43, 52]), the ground plate is flat, seamlessly tiled, and robust, made from durable materials like wood (**C4**). This ensures that it complements interior designs without compromising functionality or style. Counterparts for the inductive power connection, microcontrollers for actuation control, and module identification (MRFC-522 RFID reader) are mounted near the hose opening. We used a Hercules Pro-Line Siltek 24 (max. 150 l/min, 8 bar) compressor and a workshop vacuum cleaner as a vacuum pump. The hose layout is depicted in Figure 5.

4.4 Control Software

The open-source control software built with Unity 2022.3.12f synchronizes module states (see Figure 6) and enables mobile device access. The control software can trigger proactive actuation, for example, inflating modules automatically according to pre-defined room layouts or schedules. This enables semi-autonomous transformations, complementing direct, tangible user control.

The virtual ground plate is a 3D system representation. Users can adjust module settings, like timed inflation, and manage inactive modules. They can define custom commands for touch input for each module. The virtual ground plate allows dragging and dropping modules for room prototyping. The software provides a selection of pre-defined modules, each accompanied by blueprints for personal fabrication. The blueprints contain instructions for mounting inflatables to modules, which the community can extend. Figure 7 depicts the iterative usage of *AirClick*.

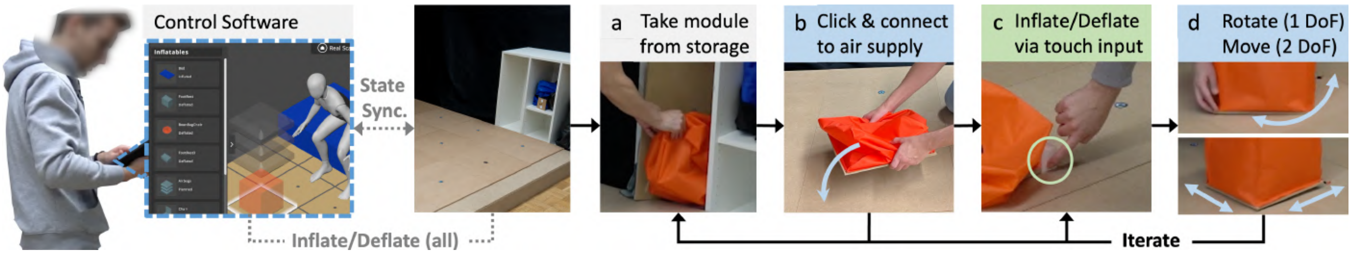

Figure 7: *AirClick* usage process for inflating and handling a module. Before being movable, modules need to be detached. The control software synchronizes the ground plate state and assists in module planning and inflation/deflation. For detaching a module, the control software or a touch at the module is needed to decouple it, with optional deflation prior to storing.

5 Technical Evaluation

Similar to prior works [5, 43, 52], we evaluated the technical capabilities of *AirClick*. Because prior work has already assessed inflatable shapes [35, 38, 48], we focused on the modules' properties and air connection.

(1) We assessed the modules' time for complete inflation and deflation by placing a ruler next to it, indicating the intended height. We recorded the elapsed time in seconds and compared it to the expected time based on the compressor's 192 l/min airflow rate. The compressor was set to 4 bar. **(2)** We also assessed the modules' height after complete deflation to evaluate their compactness. **(3)** To evaluate the inflatable material attachment to the module baseplate, we placed realistic loads on each, accounting for their different use cases. We used 80 kg to simulate an average male, 5 kg for items on a shelf, and manufacturer-intended loads for the retail inflatables. We gradually tilted the inflatables 45 degrees to the left, and we measured lift-offs from the baseplate in degrees. **(4)** To evaluate the module connection's integrity to the inflatable and ground plate, we tested for leakage under the loads from (3). The compressor had 4 bars, and a rigid board distributed the loads evenly. Additionally, to test the module connection's durability, each load was left in place for one week. The compressor was inactive and sealed.

Table 2: Technical evaluation results across modules. *N/A* indicates non-applicable measures. ✔ indicates a successful load-bearing test.

	Chair	Cube	Separator	Air-stack	Shelf	Bed	Beanbag	Footrest
Dimension	1x1	1x1	3x1	1x1	2x1	4x2	2x2	1x1
Connector Type	Single	Single	Multi	Single	Multi	Single	Single	Single
Fabrication Origin	Custom	Custom	Custom	Custom	Custom	Retail	Retail	Retail
Inflation Time (s)	110	20	6	50	25	180	190	33
Deflation Time (s)	215	41	14	112	56	370	385	68
Height-Deflated (cm)	5	4	7	8	10	16	14	5
Hor. Stability (deg)	20	8	N/A	45	11	10	5	13
Conn. Integrity (kg)	80 ✔	80 ✔	N/A	80 ✔	5 ✔	136 ✔	100 ✔	80 ✔

Results. **(1)** Each inflation/deflation time (see Table 2) is suitable for real-world use, enabling timely reconfiguration in line with related inflatable systems [38, 43, 52]. Deflation was slower as the vacuum pump generated less negative pressure. **(2)** All modules were compact after deflation (≤ 16 cm). **(3)** When a one-sided weight is applied, the inflatables' opposite sides have elevated from their baseplate across all tested shapes. A stronger fixation could prevent this, but might overstretch the material. The material around the air connector experienced minimal stress. **(4)** The connectors remained intact for all realistically heavy loads. Yet, additional tests are required to establish the maximum load-bearing capacity. All connectors withstood the loads for one week, implying even longer-lasting integrity.

Scaling to Large Rooms. More powerful compressors enable upscaling the ground plate's hose system, but increase size and noise. Thus, we suggest *AirClick* primarily in small to medium-sized rooms, where space-saving benefits are most needed. For instance, in an average 64 m^2 (8x8 m) apartment in New York City [36], the longest air hose to a grid cell is 16 m. For our prototype's 8-bar, 150 L/min, and 4 mm hose, the pressure drop is too high. A 6 mm hose reduces this to $\Delta P \approx 4.2$ bar, leaving $P_{\text{out}} \approx 2.3$ bar, sufficient to inflate a module but inadequate to sustain 150 L/min. To achieve the target flow, we recommend increasing the hose diameter (≥ 8 mm); the ground plate can cover hoses up to 50 mm.

6 User Study

The study evaluates *AirClick* as an interactive medium for room transformation (**C1**–**C7**, see Section 3), focusing on how users manipulate and repurpose inflatable modules (i.e., combining parameters across the four dimensions, see Figure 2). This was guided by the research questions (RQs):

RQ1 *How do users rate the usability, usefulness, intention to use, and scalability of AirClick after hands-on use?*

RQ2 *What patterns do users employ when transforming a room with AirClick?*

6.1 Participants and Procedure

We recruited 20 participants (11 males and 9 females; *M*=28.23, *SD*=1.67 years; range: 25—35) from our local institution via mailing lists. 12 had a background in computer science, and 8 in psychology. None had prior experience with furniture design. Yet, all held prior experience customizing furniture or interiors (e.g., rearranging living areas and home decoration), and were comfortable with digital tools. Participants received €15 compensation. The evaluation was conducted in a quiet lab room, lasting 90 minutes per session.

(1) Sessions started with a familiarization using a 10-minute show-and-tell of the 1x1 cube module. We explained the ground plate and modules' click, detach, inflate, deflate, and touch input.

(2) Each participant completed four room-transformation tasks, each lasting up to 16 minutes, presented in counterbalanced order. The tasks covered four interiors—office, meeting room, apartment

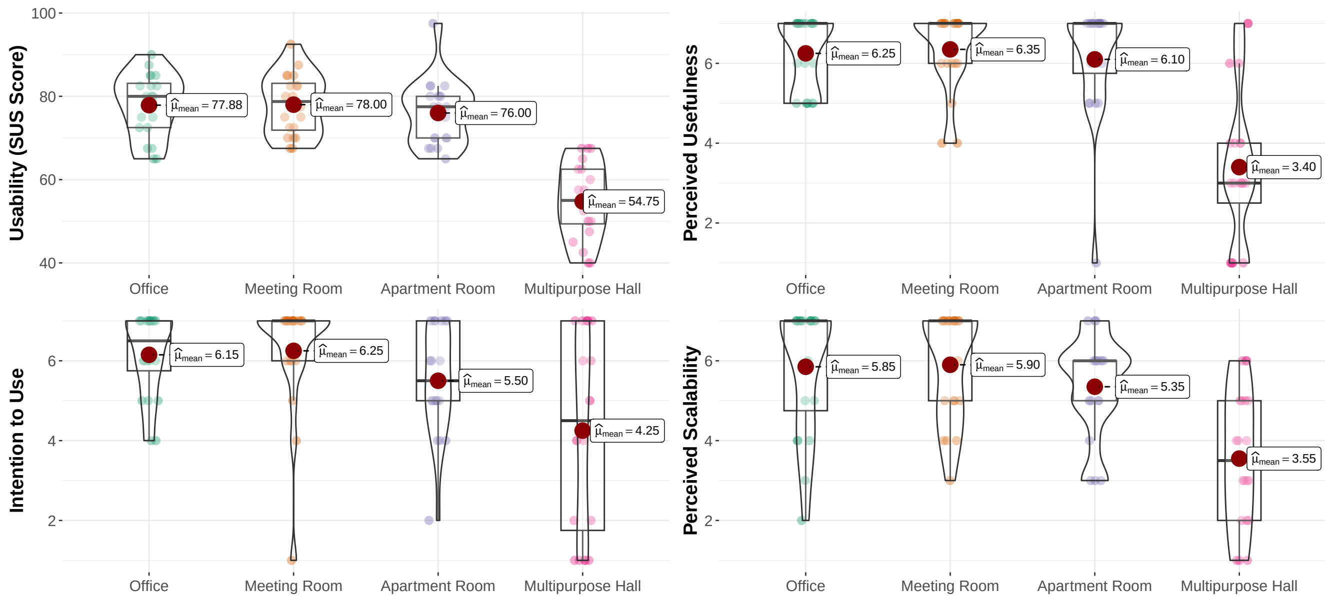

Figure 8: Ratings of usability, perceived usefulness, intention to use, and perceived scalability of *AirClick* in the study (N=20).

room, and multipurpose hall—derived from the needs-elicitation study (see Appendix A). In each task, participants arranged modules to match two target room layouts (e.g., work and meeting setup) within an 8-minute time limit per layout. They could freely inflate, deflate, and relocate any module from the storage shelf (see Figure 3), while the system logged all actions and the experimenter observed and noted behaviors. The predefined base furniture setups are shown in Figure 10.

After every room-transformation, participants answered the System Usability Scale (SUS) [4]; the Technology Acceptance Model (TAM) items *Perceived Usefulness* and *Intention to Use* [6]; and one custom 7-point statement on *Perceived Scalability—"I believe AirClick could be scaled to meet my needs in this scenario."* (1 = Strongly Disagree, 7 = Strongly Agree). This was followed by a five-minute retrospective walkthrough of their interactions.

(3) A semi-structured interview probed open feedback.

The experimental procedure adhered to our institution's ethics committee guidelines, ensuring proper handling of sensitive and private data, anonymization, compensation, and risk mitigation. According to our institution's regulations, no additional formal ethics approval was necessary. All participants provided written informed consent and were briefed about data handling, study purpose, and withdrawal rights before participation.

6.2 Quantitative Results

For the dependent variables (usability, perceived usefulness, intention to use, and perceived scalability), we conducted one–way repeated-measures ANOVAs with *Scenario* (*Office*, *Meeting Room*, *Apartment Room*, and *Multipurpose Hall*) as the within-subjects factor. Figure 8 shows the ratings. We reviewed normality using the Shapiro-Wilk test, and tested for sphericity with Mauchly's test; if sphericity was violated, Greenhouse–Geisser (G–G) corrections were applied. Holm-corrected paired t-tests examined pairwise differences. Only significant effects ($p < .05$) are reported.

Usability. A one-way repeated–measures ANOVA revealed a large main effect of *Scenario* on SUS scores, $F(6, 114) = 32.60$, $p < .001$, $\eta_p^2 = .63$. Holm-corrected pairwise tests showed that *AirClick* was rated as more usable in the *Office* ($M = 77.88$, $SD = 7.56$), *Meeting Room* ($M = 78.00$, $SD = 7.29$), and *Apartment Room* ($M = 76.00$, $SD = 7.74$) scenarios than in the *Multipurpose Hall* ($M = 54.75$, $SD = 9.08$); all $p \leq .016$.

Perceived Usefulness. *Scenario* also influenced perceived usefulness, $F_{G-G}(3.84, 72.99) = 9.66$, $p < .001$, $\eta_p^2 = .34$. Participants perceived *AirClick* as more useful in *Office* ($M = 6.25$, $SD = 0.89$), *Meeting Room* ($M = 6.35$, $SD = 0.98$), and *Apartment Room* ($M = 6.10$, $SD = 1.43$) than in the *Multipurpose Hall* ($M = 3.40$, $SD = 1.92$); all $p \leq .007$.

Intention to Use. *Scenario* had a medium effect on participants' intention to use *AirClick*, $F_{G-G}(3.09, 58.65) = 5.65$, $p = .001$, $\eta_p^2 = .23$. Intention to use was lower in the *Multipurpose Hall* ($M = 4.25$, $SD = 2.46$) than in the *Office* ($M = 6.15$, $SD = 1.03$) and *Meeting Room* ($M = 6.25$, $SD = 1.48$); all $p \leq .014$.

Perceived Scalability. The ANOVA also showed an effect of *Scenario* on perceived scalability, $F(6, 114) = 7.34$, $p < .001$, $\eta_p^2 = .28$. *AirClick* was perceived as more scalable in *Office* ($M = 5.85$, $SD = 1.61$), *Meeting Room* ($M = 5.90$, $SD = 1.39$), and *Apartment Room* ($M = 5.35$, $SD = 1.25$) than in the *Multipurpose Hall* ($M = 3.55$, $SD = 1.70$); all $p \leq .013$.

6.3 Qualitative Results

Room-Transformations and Participant Rationale. Observable in the Figure 9 Sankey plots, inflating (252 times) and subsequent moving (66 times) modules dominated, whereas deflation (43 times) was comparatively rare. The action flows show that participants

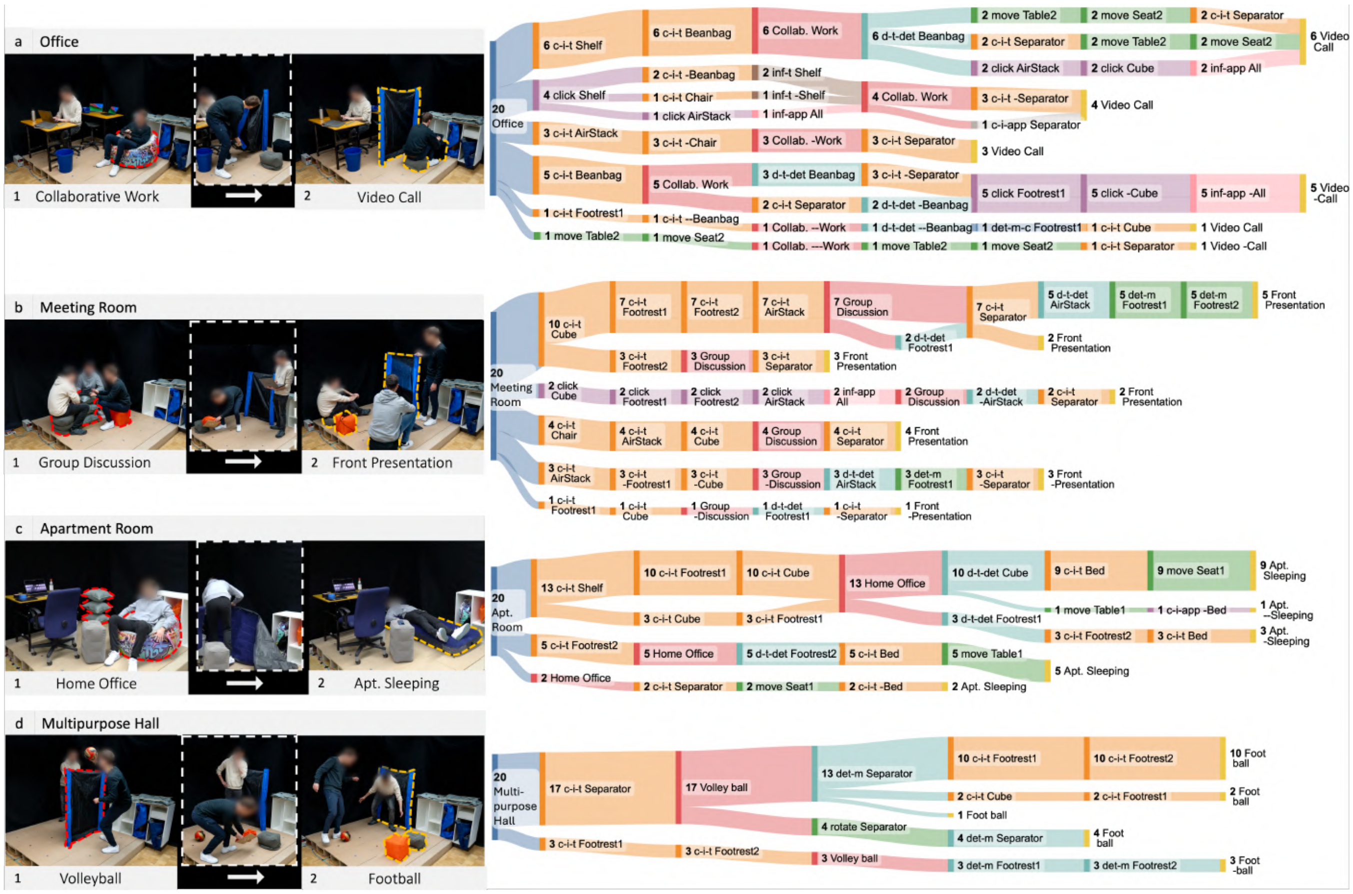

Figure 9: Left: Demonstrations of study participants' most common room setups with multiple example users. (a) 1: Tables with seats and a 2x2 beanbag for relaxation. 2: Video call area divided by a 1x3 separator. (b) 1: Discussion setup with a 1x1 air-stack as table and multiple 1x1 modules as chairs. 2: Presentation setup with 3x1 projection surface, 1x1 chairs, and a 1x1 cube as projector stand. (c) 1: Home office with a table, beanbag, and footrest. 2: Sleeping on a 2x4 bed. (d) 1: Volleyball with a 3x1 net. 2: Football with 3x1 goal and 1x1 audience seats. Right: Sankey plots visualizing participant (N=20) interaction flows with *AirClick* modules and traditional furniture while transforming each scenario's base setup (blue) into the first (red) and the second target room (yellow). Actions are color-coded: c-i-t (click → inflate by touch), d-t-det (deflate by touch → detach), det-m (detach → move), and inf-app (inflate via the control software). Larger ribbons indicate higher participant counts.

preferred to relocate modules while inflated, thereby avoiding additional inflation–deflation cycles. The following summarizes these observations and the retrospective walkthroughs.

For **Office** → *Collaborative Work*, participants inflated a shelf, an air-stack, or a cube as a shared surface, and positioned the separator for privacy; some added a beanbag for relaxed work (see Figure 9 a1). *"I like seeing my collaborator straight on"* (P3); *"The divider gives me a little focus, but I still see my coworker"* (P12). For *Collaborative Work* → *Video Call*, they mainly left the desk in place, detached and moved the separator as a backdrop, and clicked a cube as a laptop stand (see Figure 9 a2). *"I changed as little as possible so I don't need to move the table"* (P5).

For **Meeting Room** → *Group Discussion*, most participants arranged the cube and footrests in a circle around an air-stack "coffee table" (see Figure 9 b1). For *Group Discussion* → *Front Presentation*, modules were moved into a row facing a separator used as the screen; a cube served as a projector stand (see Figure 9 b2). *"The separator is handy if a projection surface is needed"* (P8).

For **Apartment Room** → *Home Office*, participants mainly inflated a 2×1 shelf and clicked a footrest; some added a beanbag for breaks (see Figure 9 c1). For *Home Office* → *Apt. Sleeping*, they inflated the 2×4 bed, repurposed the separator as a privacy screen, and either moved or deflated the desk to clear space (see Figure 9 c2). *"I only moved the pieces I needed so my work setup stays intact for tomorrow"* (P4).

For **Multipurpose Hall** → *Volleyball*, participants inflated the separator as a "net" (see Figure 9 d1) and some marked corners with small modules. *"The separator might not be robust, but easy to rearrange"* (P4). For *Volleyball* → *Football*, they moved and repurposed the separator into a 3×1 goal, and moved seats to the sidelines (see Figure 9 d2). *"I liked the flexibility of the separator"* (P8); *"Reusing the same modules helps"* (P21).

Open Feedback. In the final semi-structured interview, participants shared positive opinions on *AirClick*: *"Room separators are super helpful, especially with the distractions and all in busy spaces…"* (P6). They found the detachable modules effective for small rooms, emphasizing *"…having movable furniture instead of big, bulky stuff…. those pop-up tables are handy for space management when you're switching modules around."* (P11). Besides, large modules like the air bed were a clear favorite: *"…better for freeing up space than deflating a shelf full of things."* (P18). Regarding sports applications, they were skeptical, *"It's really more suited for making quick sports markers or cones, not so much for the serious sports gear. Durability's a bit of a question…"* (P14). Still, they appreciated the ability to change rooms quickly: *"…but changing things up is so easy."* (P7). An interesting suggestion was also made: *"What if we used AirClick for emergency housing? Like, in disaster zones, to quickly set up shelters with inflatable walls and cubes."* (P9).

7 Discussion

In the following, we discuss findings from the technical evaluation and user study to articulate design insights for on-demand room transformation systems using modularized inflatables.

7.1 On the Applicability of *AirClick* in Everyday Room Scenarios

As demonstrated in the user study (see Section 6), *AirClick* supports on-demand room transformation, addressing **C5** and **C7**. Besides, **RQ1** is answered positively for the room scenarios. Participants rated usability, perceived usefulness, intention to use, and scalability significantly higher in the office, meeting, and apartment scenarios than in the multipurpose hall. Also, in the office, meeting, and apartment scenario, the usability was *acceptable* (SUS scores: 76—78), while *marginal* in the hall (54) [3]. A likely reason is that the current module inventory and the office, meeting, and apartment target rooms mostly resembled people's needs at work or at home.

Technical results (see Section 5) further support the applicability of *AirClick*. Modules inflate/deflate in practical times; are compact after deflation (≤16 cm); and their connectors held realistic loads for one week. Table 1 summarizes how *AirClick* addresses the identified room-transformation challenges (see Section 3) and shows its benefits compared to prior floor-actuated [43] or rail-mounted systems [41]. However, compared to conventional space-saving furniture such as collapsible beds, tables, or inflatable mattresses with electric pumps, *AirClick* trades structural stiffness and tactile comfort for automated actuation, shape diversity, and low module cost and weight. While this enables flexible, automated room transformation, everyday usability (e.g., stable load-bearing or long-term seating) remains more limited than with rigid furniture.

Besides, applicability drops in high-impact or large-area activities that exceed our prototype's scale or robustness (e.g., ball sports). Participants voiced concerns about impacts and collisions; perceived scalability was also lower when the activity area clearly exceeded the 2x2 m ground plate prototype. Load-bearing and stiffness requirements for some furniture roles (e.g., heavily loaded shelves, kitchen counters) remain above what soft inflatables alone provide. However, high-stiffness, lightweight systems (e.g., TrussFab [18]) could complement soft inflatables as support structures.

Across scenarios, participants reported that the limited inventory reduced usability, while they still saw *AirClick*'s potential if more module types were available, hence, relatively higher usefulness and intention to use scores despite the constraints. These observations align with prior demonstrations that inflatables can be engineered for everyday use when built from structural textiles (e.g., *poimo* mobility devices [27]), and with work on pneumatic structures that lower control complexity at larger scales (e.g., *PneuMesh* truss actuation [10]). Providing this flexibility in attaching any kind of inflatable with options for support structures is a unique strength of *AirClick* compared to other floor-based systems regarding everyday use and transforming entire working and living spaces.

Daily use presents further challenges. For example, damaging or incorrect operations, such as sharp objects like cutlery on a table module, may puncture the inflatable, or the inflatable may tear off its baseplate. As our user study had a single-day lab setting, future research should explore longitudinal use of *AirClick* in daily settings at home and work. Moreover, to reduce the overhead introduced with frequent re-arrangement and **C2**-deployment, the modules could be made "robotic", that is, programmable as done by Suzuki et al. [42] and Kim and Follmer [17]. This could be included in prior home automation approaches and be determined based on rules (e.g., morning/evening presets).

7.2 Interaction Patterns for Room Transformation with Modular Inflatables

We found four patterns in the qualitative results (see Section 6.3), answering **RQ2**:

(1) Users kept modules inflated while moving them and only deflated when necessary.
(2) Users transformed the room primarily into "activity areas" and often used separators to zone these.
(3) Users repurposed small modules to switch between roles (e.g., seat, table, stand).
(4) Users preserved traditional furniture and large modules in place and transformed the room around them.

These patterns may explain the observed interactions (many inflations, few deflations, minimal movement of traditional furniture). While the inflation-deflation imbalance is expected, given the initially empty room, this pattern's persistence for the second room targets with non-empty room setups still reveals that users tend to maximize furniture availability over minimizing space use. We argue this reflects a "growth-first" user strategy found in related adaptive environments [29, 42].

Re-use of modules (patterns 1, 3, and 4) might suggest extending the module inventory. Fabrication pipelines for custom inflatables (e.g., *AeroMorph* [31], *Printflatables* [38]) can supply diverse-shaped modules for multiple roles. Moreover, these patterns align with prior work that aims for quick furniture reconfiguration through moving existing artifacts [42] or placing partitions [29], which is, in contrast, difficult to achieve with floor-based actuation systems that change ground geometry [43, 52]. Our findings also align with rail-mounted systems [19, 41] by suggesting the use of a few anchored, load-bearing units where structure is needed, and a few detachable inflatables for the rest.

7.3 Practical Implications for On-Demand Room Transformation Systems

Based on the patterns, we see the following practical implications for on-demand room transformation systems that use *AirClick*-alike modular inflatables.

Support relocate-while-inflated operations. Systems should minimize "state churn" (e.g., unnecessary deflate–inflate cycles) to shorten room transformation. For this, modules should enable low-effort relocation without deflation using, for instance, low-friction bases, graspable edges/handles, and quick mechanical locks.

Module inventories should contain many small "role-fluid" and few large, specialized modules. Small modules that can switch roles (seat <-> table <-> stand) provide higher value relative to adding another large, specialized shape, suggesting module inventories should bias toward versatile small modules with only a few larger modules (e.g., origami shell [20] support structures).

Ensure interoperability with traditional furniture rather than a fully shape-changeable room. Traditional furniture has unique benefits, such as robustness and comfort. To preserve these, they should be augmented by inflatables only on demand. Thus, future systems should assume heavy/traditional items remain in place and provide interfaces that let modules augment tables, shelves, and walls; thereby supporting "hybrid rooms" where inflatables augment traditional furniture or anchored furniture on rails [19, 41].

Offer scenario-specific presets. Common room transformations (e.g., video call, front presentation, sleeping) should be packaged as presets that combine traditional furniture with detachable modules; enable optional automation by time/rules/sensors where it demonstrably reduces effort [17, 42]. Moreover, there should be (mixed-reality) tools (e.g., [33]) similar to our control software (see Section 4.4) that help users preview placements, set activity-specific presets (e.g., video call, presentation, sleeping), and recall them later.

Beyond the tested room scenarios, the findings may inform the broader design of interactive inflatable furniture. The observed preference for small, role-fluid modules and hybrid integration with rigid elements could extend to other soft, reconfigurable furniture concepts, such as responsive seating or adaptive partitions. Thus, *AirClick* may serve as an initial example within this emerging class of computationally actuated furniture systems.

7.4 Limitations and Future Work

Although *AirClick* demonstrates the feasibility of modular pneumatic furniture, it remains an early functional prototype. The study used a small ground plate, a limited module set, and short, fixed tasks. Hence, results cannot be generalized to full apartments or large venues. Still, the identified *interaction patterns*—what users inflate, move, and preserve—are largely scale-independent and can guide future room-transformation systems.

Ecological Validity. Conducted in a controlled lab with a 4 m² prototype, the study did not capture real-world factors such as spatial constraints, daily routines, or existing furniture. Future work should examine use in real apartments or micro-homes, for example, through a Wizard-of-Oz setup, to complement controlled findings with in-situ data.

Room Setup Requirements. Installing *AirClick* currently requires a ground plate with embedded valves and connectors, demanding 15cm elevation for the hose and valve layer. In small-height rooms, such an elevation can conflict with accessibility and aesthetics. Future iterations could use distributed low-profile valve clusters or wireless air modules to reduce required floor volume. Hence, while *AirClick* improves modularity and reusability compared to prior floor-integrated systems [43], height overhead remains an open design challenge.

Technical Scalability. *AirClick* partly addresses **C3**-scalability, as, according to fluid dynamics, there is an upper limit for the room size when using our prototype's air supply due to increased hose length and friction. While, according to our technical evaluation, the current setup suffices to accommodate medium-sized rooms where *AirClick*'s space-saving capabilities are primarily needed, larger air supplies and increased hose diameter would enable scaling to entire halls. However, due to the required air supply size and noise levels, future work should explore systems with multiple air supplies and revised hose layouts to improve airflow.

Stability and Load-Bearing. Some use cases require higher structural capacity (e.g., TV shelf, kitchen counter). Inflatables inherently have lower stiffness and load limits than traditional furniture [49]. Our technical evaluation confirmed this (see Table 2). Thus, *AirClick* partially addresses **C4**-robustness. Yet, we argue that this drawback is tempered by modules' compactness, low weight, and shape change (addressing **C1**, **C2**, **C6**, **C7**). Also, compatibility with existing furniture via the ground plate is an advantage over prior floor-based approaches, which can create uneven surfaces and hose/cable clearance issues around traditional furniture [43, 52]. Even when arranged around existing furniture, their module height can lead to impractical, non-aesthetic elevation.

Actuation Speed and Operating Noise. Our prototype uses a compressor and vacuum pump at ~150 l/min with up to 60 dB. The air-supply calculation (Section 5) suggests these devices could serve an entire apartment; off-the-shelf compressors at ~300 l/min with similar noise (60 dB, 8 bar) cost ≈ $270 [1]. However, 60 dB, similar to conversation-level noise, can be undesirable [30]. The air supply should, therefore, be placed in a separate room or a sound-insulated case when space is tight. Yet, we argue that *AirClick* 's space saving may still result in a net space gain. Besides, participants perceived actuation speed as improvable (partly addressing **C4**; see Section 6). Future work should balance faster inflation/deflation with acceptable noise and measure user thresholds for both.

Sustainability. *AirClick*'s modularity encourages rearranging existing modules and retrofitting inflatables, potentially repurposing old furniture (e.g., inflating a footrest instead of buying a new sofa), and may help in reducing material demand. However, limitations include electronics for actuation/sensing (see Section 4.1) and plastic use. Energy consumption is likely modest as pumps run mainly during state changes or to maintain pressure (e.g., twice daily), but future work should quantify energy, materials (plastics/electronics), and fabrication costs.

User Interaction. Our prototype enables touch input to address **C6**-manipulability. However, we argue that future work should evaluate different interaction concepts. For instance, pressure sensors on the inflatable surface could sense weight changes, enabling proactive inflation/deflation. Moreover, Wi-Fi signals could enable gesture recognition throughout a building without additional room instrumentation [32]. Additionally, future work could design a control software for mixed-reality devices to improve users' spatial imagination when designing rooms with *AirClick* (e.g., see [42, 52]). Besides, future studies may target specific applications (e.g., health-promoting furniture, see Appendix F).

8 Conclusion

We present *AirClick*, a system for on-demand room transformation using modular, interactive, large-scale inflatables. The novel detachable modules mount both personally fabricated and retrofitted retail inflatables, supporting shapes from simple cuboids to curved, furniture-like geometries. A flat, seamless ground-plate grid provides air and connectivity to modules, enabling hybrid configurations with traditional furniture. This presents a solution to the rising challenges of limited and costly living and workspaces by activating furniture on demand and storing it compactly. A technical evaluation confirmed a compact deflated footprint, practical actuation times, and connector robustness.

In a lab study (N=20) spanning office, meeting room, apartment room, and multipurpose hall scenarios, participants individually explored room transformations and reported that *AirClick* was usable and applicable in most scenarios. However, the study also surfaced current limitations in scalability and module robustness. Together, these findings indicate that *AirClick* could transform the use of living and working environments by offering a cost-effective, space-saving, and customizable solution. With this work, we aim to inspire further research into on-demand room transformation and shape-changing interfaces that meet the ever-changing needs of users in living and work spaces.

Open Science

All materials are openly available at https://github.com/Pascal-Jansen/AirClick. The repository includes assembly plans for the *AirClick* ground plate, air connectors, and modules, as well as 3D-print source files and the control software code.

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References

[1] Amazon. 2025. *Scheppach Cylinder Compressor, Oil-free, Maintenance-Free – Product Page*. Scheppach. https://www.amazon.de/-/en/Scheppach-Cylinder-Compressor-Oil-free-Maintenance/dp/B08X4NDVFQ Accessed: 7 Aug 2025.

[2] Antidark. 2024. Designline Track. https://antidark.dk/en/product/designline-track/. Accessed: 2024-12-11.

[3] Aaron Bangor, Philip Kortum, and James Miller. 2009. Determining What Individual SUS Scores Mean: Adding an Adjective Rating Scale. *J. Usability Studies* 4, 3 (may 2009), 114–123.

[4] John Brooke. 1996. Sus: a "quick and dirty'usability. *Usability evaluation in industry* 189, 3 (1996), 189–194.

[5] Yu-Wen Chen, Wei-Ju Lin, Yi Chen, and Lung-Pan Cheng. 2021. PneuSeries: 3D Shape Forming with Modularized Serial-Connected Inflatables. In *The 34th Annual ACM Symposium on User Interface Software and Technology (UIST '21)*. Association for Computing Machinery, New York, NY, USA, 431–440. doi:10.1145/3472749.3474760

[6] Fred D. Davis. 1989. Perceived Usefulness, Perceived Ease of Use, and User Acceptance of Information Technology. *MIS Quarterly* 13, 3 (1989), 319–340.

[7] Aluna Everitt and Jason Alexander. 2017. PolySurface: A Design Approach for Rapid Prototyping of Shape-Changing Displays Using Semi-Solid Surfaces. In *Proceedings of the 2017 Conference on Designing Interactive Systems* (Edinburgh, United Kingdom) *(DIS '17)*. Association for Computing Machinery, New York, NY, USA, 1283–1294. doi:10.1145/3064663.3064677

[8] Aluna Everitt, Faisal Taher, and Jason Alexander. 2016. ShapeCanvas: An Exploration of Shape-Changing Content Generation by Members of the Public. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems (CHI '16)*. Association for Computing Machinery, New York, NY, USA, 2778–2782. doi:10.1145/2858036.2858316

[9] Ryota Gomi, Ryo Suzuki, Kazuki Takashima, Kazuyuki Fujita, and Yoshifumi Kitamura. 2024. InflatableBots: Inflatable Shape-Changing Mobile Robots for Large-Scale Encountered-Type Haptics in VR. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 423, 14 pages. doi:10.1145/3613904.3642069

[10] Jianzhe Gu, Yuyu Lin, Qiang Cui, Xiaoqian Li, Jiaji Li, Lingyun Sun, Cheng Yao, Fangtian Ying, Guanyun Wang, and Lining Yao. 2022. PneuMesh: Pneumatic-driven Truss-based Shape Changing System. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 260, 12 pages. doi:10.1145/3491102.3502099

[11] John Hardy, Christian Weichel, Faisal Taher, John Vidler, and Jason Alexander. 2015. ShapeClip: Towards Rapid Prototyping with Shape-Changing Displays for Designers. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (Seoul, Republic of Korea) *(CHI '15)*. Association for Computing Machinery, New York, NY, USA, 19–28. doi:10.1145/2702123.2702599

[12] Jiayi Hong, Xiyao Wang, Aluna Everitt, and Anne Roudaut. 2023. Interacting with actuated walls: Exploring applications and input types. *International Journal of Human-Computer Studies* 172 (2023), 102986.

[13] Hikaru Ibayashi, Yuta Sugiura, Daisuke Sakamoto, Natsuki Miyata, Mitsunori Tada, Takashi Okuma, Takeshi Kurata, Masaaki Mochimaru, and Takeo Igarashi. 2015. Dollhouse VR: A Multi-View, Multi-User Collaborative Design Workspace with VR Technology. In *SIGGRAPH Asia 2015 Posters* (Kobe, Japan) *(SA '15)*. Association for Computing Machinery, New York, NY, USA, Article 24, 1 pages. doi:10.1145/2820926.2820948

[14] IKEA. 2023. Great mistakes - Inflatable dreams and stinky sofas. https://ikeamuseum.com/en/explore/the-story-of-ikea/great-mistakes/ Online; Accessed: 01.02.2024.

[15] Seungwoo Je, Hyunseung Lim, Kongpyung Moon, Shan-Yuan Teng, Jas Brooks, Pedro Lopes, and Andrea Bianchi. 2021. Elevate: A Walkable Pin-Array for Large Shape-Changing Terrains. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems (CHI '21)*. Association for Computing Machinery, New York, NY, USA, 1–11. doi:10.1145/3411764.3445454

[16] KS Jung, JH Jung, TS In, and HY Cho. 2020. Effects of Prolonged Sitting with Slumped Posture on Trunk Muscular Fatigue in Adolescents with and without Chronic Lower Back Pain. *Medicina (Kaunas)* 57, 1 (Dec 2020), 3. doi:10.3390/medicina57010003 PMID: 33374520; PMCID: PMC7822118.

[17] Lawrence H. Kim and Sean Follmer. 2019. SwarmHaptics: Haptic Display with Swarm Robots. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems* (Glasgow, Scotland Uk) *(CHI '19)*. Association for Computing Machinery, New York, NY, USA, 1–13. doi:10.1145/3290605.3300918

[18] Robert Kovacs, Anna Seufert, Ludwig Wall, Hsiang-Ting Chen, Florian Meinel, Willi Müller, Sijing You, Maximilian Brehm, Jonathan Striebel, Yannis Kommana, Alexander Popiak, Thomas Bläsius, and Patrick Baudisch. 2017. TrussFab: Fabricating Sturdy Large-Scale Structures on Desktop 3D Printers. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems* (Denver, Colorado, USA) *(CHI '17)*. Association for Computing Machinery, New York, NY, USA, 2606–2616. doi:10.1145/3025453.3026016

[19] Kent Larson, Hasier Larrea, and City Science Group, MIT Media Lab. 2014. City-Home. Project page. https://www.media.mit.edu/projects/OLD_cityhome2/overview/ Project active 2011–2016.

[20] David Melancon, Benjamin Gorissen, Carlos J. Garcia-Mora, Chuck Hoberman, and Katia Bertoldi. 2021. Multistable inflatable origami structures at the metre scale. *Nature* 592, 7855 (2021), 545–550. doi:10.1038/s41586-021-03407-4

[21] Robin C Moore. 2017. *Childhood's domain: Play and place in child development.* Vol. 6. Routledge, 2 Park Square, Milton Park, Abingdon, Oxfordshire, OX14 4RN, UK.

[22] Takafumi Morita, Ziyuan Jiang, Kanon Aoyama, Ayato Minaminosono, Yu Kuwajima, Naoki Hosoya, Shingo Maeda, and Yasuaki Kakehi. 2023. InflatableMod: Untethered and Reconfigurable Inflatable Modules for Tabletop-Sized

Pneumatic Physical Interfaces. In *Proceedings of the 2023 CHI Conference on Human Factors in Computing Systems* (Hamburg, Germany) *(CHI '23)*. Association for Computing Machinery, New York, NY, USA, Article 212, 15 pages. doi:10.1145/3544548.3581353

[23] Takafumi Morita, Yu Kuwajima, Ayato Minaminosono, Shingo Maeda, and Yasuaki Kakehi. 2022. HydroMod: Constructive Modules for Prototyping Hydraulic Physical Interfaces. In *Proceedings of the 2022 CHI Conference on Human Factors in Computing Systems* (New Orleans, LA, USA) *(CHI '22)*. Association for Computing Machinery, New York, NY, USA, Article 393, 14 pages. doi:10.1145/3491102.3502096

[24] Sara Nabil, Aluna Everitt, Miriam Sturdee, Jason Alexander, Simon Bowen, Peter Wright, and David Kirk. 2018. ActuEating: Designing, Studying and Exploring Actuating Decorative Artefacts. In *Proceedings of the 2018 Designing Interactive Systems Conference* (Hong Kong, China) *(DIS '18)*. Association for Computing Machinery, New York, NY, USA, 327–339. doi:10.1145/3196709.3196761

[25] Ken Nakagaki, Daniel Fitzgerald, Zhiyao (John) Ma, Luke Vink, Daniel Levine, and Hiroshi Ishii. 2019. inFORCE: Bi-directional 'Force' Shape Display for Haptic Interaction. In *Proceedings of the Thirteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '19)*. Association for Computing Machinery, New York, NY, USA, 615–623. doi:10.1145/3294109.3295621

[26] Ken Nakagaki, Yingda (Roger) Liu, Chloe Nelson-Arzuaga, and Hiroshi Ishii. 2020. TRANS-DOCK: Expanding the Interactivity of Pin-Based Shape Displays by Docking Mechanical Transducers. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction* (Sydney NSW, Australia) *(TEI '20)*. Association for Computing Machinery, New York, NY, USA, 131–142. doi:10.1145/3374920.3374933

[27] Ryuma Niiyama, Hiroki Sato, Kazzmasa Tsujimura, Koya Narumi, Young ah Seong, Ryosuke Yamamura, Yasuaki Kakehi, and Yoshihiro Kawahara. 2020. poimo: Portable and Inflatable Mobility Devices Customizable for Personal Physical Characteristics. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology* (Virtual Event, USA) *(UIST '20)*. Association for Computing Machinery, New York, NY, USA, 912–923. doi:10.1145/3379337.3415894

[28] OECD. 2022. *Housing Taxation in OECD Countries.* Organisation for Economic Co-operation and Development (OECD), 2, rue André Pascal, 75775 Paris Cedex 16, France. 140 pages. doi:10.1787/03dfe007-en

[29] Yuki Onishi, Kazuki Takashima, Shoi Higashiyama, Kazuyuki Fujita, and Yoshifumi Kitamura. 2022. WaddleWalls: Room-scale Interactive Partitioning System using a Swarm of Robotic Partitions. In *Proceedings of the 35th Annual ACM Symposium on User Interface Software and Technology* (Bend, OR, USA) *(UIST '22)*. Association for Computing Machinery, New York, NY, USA, Article 29, 15 pages. doi:10.1145/3526113.3545615

[30] World Health Organization et al. 2011. *Burden of disease from environmental noise: Quantification of healthy life years lost in Europe.* World Health Organization. Regional Office for Europe, Avenue Appia 20, 1211 Geneva, Switzerland.

[31] Jifei Ou, Mélina Skouras, Nikolaos Vlavianos, Felix Heibeck, Chin-Yi Cheng, Jannik Peters, and Hiroshi Ishii. 2016. aeroMorph - Heat-sealing Inflatable Shape-change Materials for Interaction Design. In *Proceedings of the 29th Annual Symposium on User Interface Software and Technology (UIST '16)*. Association for Computing Machinery, New York, NY, USA, 121–132. doi:10.1145/2984511.2984520

[32] Qifan Pu, Sidhant Gupta, Shyamnath Gollakota, and Shwetak Patel. 2013. Whole-Home Gesture Recognition Using Wireless Signals. In *Proceedings of the 19th Annual International Conference on Mobile Computing & Networking* (Miami, Florida, USA) *(MobiCom '13)*. Association for Computing Machinery, New York, NY, USA, 27–38. doi:10.1145/2500423.2500436

[33] Chuhan Qu and Leila Aflatoony. 2023. An Augmented Reality Design Tool to Guide Furniture Arrangements at Home. In *Proceedings of the 34th Australian Conference on Human-Computer Interaction* (Canberra, ACT, Australia) *(OzCHI '22)*. Association for Computing Machinery, New York, NY, USA, 254–259. doi:10.1145/3572921.3576216

[34] Hayes Solos Raffle, Amanda J. Parkes, and Hiroshi Ishii. 2004. Topobo: A Constructive Assembly System with Kinetic Memory. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (Vienna, Austria) *(CHI '04)*. Association for Computing Machinery, New York, NY, USA, 647–654. doi:10.1145/985692.985774

[35] Lukas Rambold, Robert Kovacs, Conrad Lempert, Muhammad Abdullah, Helena Lendowski, Lukas Fritzsche, Martin Taraz, and Patrick Baudisch. 2023. AirTied: Automatic Personal Fabrication of Truss Structures. In *Proceedings of the 36th Annual ACM Symposium on User Interface Software and Technology* (<conf-loc>, <city>San Francisco</city>, <state>CA</state>, <country>USA</country>, </conf-loc>) *(UIST '23)*. Association for Computing Machinery, New York, NY, USA, Article 57, 10 pages. doi:10.1145/3586183.3606820

[36] RentCafe. 2025. *Average Rent in Manhattan, NY.* RentCafe. https://www.rentcafe.com/average-rent-market-trends/us/ny/manhattan/ Accessed: 21 Aug 2025.

[37] A. Roudaut, D. Krusteva, M. McCoy, A. Karnik, K Ramani, and S. Subramanian. 2016. Cubimorph: Designing modular interactive devices. In *2016 IEEE International Conference on Robotics and Automation (ICRA)*, Vol. 1. IEEE, New York City, 3339–3345. doi:10.1109/ICRA.2016.7487508

[38] Harpreet Sareen, Udayan Umapathi, Patrick Shin, Yasuaki Kakehi, Jifei Ou, Hiroshi Ishii, and Pattie Maes. 2017. Printflatables: Printing Human-Scale, Functional and Dynamic Inflatable Objects. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems (CHI '17)*. Association for Computing Machinery, New York, NY, USA, 3669–3680. doi:10.1145/3025453.3025898

[39] Martin Schmitz, Jan Riemann, Florian Müller, Steffen Kreis, and Max Mühlhäuser. 2021. Oh, Snap! A Fabrication Pipeline to Magnetically Connect Conventional and 3D-Printed Electronics. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (Yokohama, Japan) *(CHI '21)*. Association for Computing Machinery, New York, NY, USA, Article 420, 11 pages. doi:10.1145/3411764.3445641

[40] Anthony Steed, Eyal Ofek, Mike Sinclair, and Mar Gonzalez-Franco. 2021. A mechatronic shape display based on auxetic materials. *Nature Communications* 12, 1 (Aug. 2021), 4758. doi:10.1038/s41467-021-24974-0 Number: 1 Publisher: Nature Publishing Group.

[41] Ori Design Studio. 2023. Ori Expandable Apartments. https://www.oriliving.com/. Accessed: 2023-12-12.

[42] Ryo Suzuki, Hooman Hedayati, Clement Zheng, James L. Bohn, Daniel Szafir, Ellen Yi-Luen Do, Mark D. Gross, and Daniel Leithinger. 2020. RoomShift: Room-scale Dynamic Haptics for VR with Furniture-moving Swarm Robots. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems (CHI '20)*. Association for Computing Machinery, New York, NY, USA, 1–11. doi:10.1145/3313831.3376523

[43] Ryo Suzuki, Ryosuke Nakayama, Dan Liu, Yasuaki Kakehi, Mark D. Gross, and Daniel Leithinger. 2020. LiftTiles: Constructive Building Blocks for Prototyping Room-scale Shape-changing Interfaces. In *Proceedings of the Fourteenth International Conference on Tangible, Embedded, and Embodied Interaction (TEI '20)*. Association for Computing Machinery, New York, NY, USA, 143–151. doi:10.1145/3374920.3374941

[44] Ryo Suzuki, Eyal Ofek, Mike Sinclair, Daniel Leithinger, and Mar Gonzalez-Franco. 2021. HapticBots: Distributed Encountered-type Haptics for VR with Multiple Shape-changing Mobile Robots. In *The 34th Annual ACM Symposium on User Interface Software and Technology (UIST '21)*. Association for Computing Machinery, New York, NY, USA, 1269–1281. doi:10.1145/3472749.3474821

[45] Ryo Suzuki, Junichi Yamaoka, Daniel Leithinger, Tom Yeh, Mark D. Gross, Yoshihiro Kawahara, and Yasuaki Kakehi. 2018. Dynablock: Dynamic 3D Printing for Instant and Reconstructable Shape Formation. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18)*. Association for Computing Machinery, New York, NY, USA, 99–111. doi:10.1145/3242587.3242659

[46] Ryo Suzuki, Clement Zheng, Yasuaki Kakehi, Tom Yeh, Ellen Yi-Luen Do, Mark D. Gross, and Daniel Leithinger. 2019. ShapeBots: Shape-changing Swarm Robots. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST '19)*. Association for Computing Machinery, New York, NY, USA, 493–505. doi:10.1145/3332165.3347911

[47] Saki Suzuki, Ilan Mandel, Stacey Li, Wen-Ying Lee, Mark Colley, and Wendy Ju. 2023. AdVANcing Design: Customizing Spaces for Vanlife. In *Proceedings of the 15th International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (Ingolstadt, Germany) *(AutomotiveUI '23)*. Association for Computing Machinery, New York, NY, USA, 256–266. doi:10.1145/3580585.3607175

[48] Saiganesh Swaminathan, Michael Rivera, Runchang Kang, Zheng Luo, Kadri Bugra Ozutemiz, and Scott E. Hudson. 2019. Input, Output and Construction Methods for Custom Fabrication of Room-Scale Deployable Pneumatic Structures. *Proc. ACM Interact. Mob. Wearable Ubiquitous Technol.* 3, 2, Article 62 (jun 2019), 17 pages. doi:10.1145/3328933

[49] Faisal Taher, John Vidler, and Jason Alexander. 2017. A characterization of actuation techniques for generating movement in shape-changing interfaces. *International Journal of Human–Computer Interaction* 33, 5 (2017), 385–398.

[50] Wen Yen Tang, Sheng Kai Tang, and Yuzn Zone Lee. 2012. Tangible Pixels: Interactive Architectural Modules for Discovering Adaptive Human Swarm Interaction. *eCAADe* 2 (2012), 7.

[51] Shan-Yuan Teng, Tzu-Sheng Kuo, Chi Wang, Chi-huan Chiang, Da-Yuan Huang, Liwei Chan, and Bing-Yu Chen. 2018. PuPoP: Pop-up Prop on Palm for Virtual Reality. In *Proceedings of the 31st Annual ACM Symposium on User Interface Software and Technology (UIST '18)*. Association for Computing Machinery, New York, NY, USA, 5–17. doi:10.1145/3242587.3242628

[52] Shan-Yuan Teng, Cheng-Lung Lin, Chi-huan Chiang, Tzu-Sheng Kuo, Liwei Chan, Da-Yuan Huang, and Bing-Yu Chen. 2019. TilePoP: Tile-type Pop-up Prop for Virtual Reality. In *Proceedings of the 32nd Annual ACM Symposium on User Interface Software and Technology (UIST '19)*. Association for Computing Machinery, New York, NY, USA, 639–649. doi:10.1145/3332165.3347958

[53] John Tiab, Sebastian Boring, Paul Strohmeier, Anders Markussen, Jason Alexander, and Kasper Hornbæk. 2018. Tiltstacks: composing shape-changing interfaces using tilting and stacking of modules. In *Proceedings of the 2018 International Conference on Advanced Visual Interfaces (AVI '18)*. Association for Computing Machinery, New York, NY, USA, 1–5. doi:10.1145/3206505.3206530

[54] Junichi Yamaoka, Kazunori Nozawa, Shion Asada, Ryuma Niiyama, Yoshihiro Kawahara, and Yasuaki Kakehi. 2018. AccordionFab: Fabricating Inflatable 3D

Objects by Laser Cutting and Welding Multi-Layered Sheets. In *The 31st Annual ACM Symposium on User Interface Software and Technology Adjunct Proceedings (UIST '18 Adjunct)*. Association for Computing Machinery, New York, NY, USA, 160–162. doi:10.1145/3266037.3271636

[55] Yue Yang, Lei Ren, Chuang Chen, Bin Hu, Zhuoyi Zhang, Xinyan Li, Yanchen Shen, Kuangqi Zhu, Junzhe Ji, Yuyang Zhang, Yongbo Ni, Jiayi Wu, Qi Wang, Jiang Wu, Lingyun Sun, Ye Tao, and Guanyun Wang. 2024. SnapInflatables: Designing Inflatables with Snap-through Instability for Responsive Interaction. In *Proceedings of the 2024 CHI Conference on Human Factors in Computing Systems* (Honolulu, HI, USA) *(CHI '24)*. Association for Computing Machinery, New York, NY, USA, Article 342, 15 pages. doi:10.1145/3613904.3642933

[56] Lining Yao, Ryuma Niiyama, Jifei Ou, Sean Follmer, Clark Della Silva, and Hiroshi Ishii. 2013. PneUI: Pneumatically Actuated Soft Composite Materials for Shape Changing Interfaces. In *Proceedings of the 26th Annual ACM Symposium on User Interface Software and Technology* (St. Andrews, Scotland, United Kingdom) *(UIST '13)*. Association for Computing Machinery, New York, NY, USA, 13–22. doi:10.1145/2501988.2502037

[57] Yan Yixian, Kazuki Takashima, Anthony Tang, Takayuki Tanno, Kazuyuki Fujita, and Yoshifumi Kitamura. 2020. ZoomWalls: Dynamic Walls that Simulate Haptic Infrastructure for Room-scale VR World. In *Proceedings of the 33rd Annual ACM Symposium on User Interface Software and Technology (UIST '20)*. Association for Computing Machinery, New York, NY, USA, 223–235. doi:10.1145/3379337.3415859

[58] Yiwei Zhao, Lawrence H. Kim, Ye Wang, Mathieu Le Goc, and Sean Follmer. 2017. Robotic Assembly of Haptic Proxy Objects for Tangible Interaction and Virtual Reality. In *Proceedings of the 2017 ACM International Conference on Interactive Surfaces and Spaces (ISS '17)*. Association for Computing Machinery, New York, NY, USA, 82–91. doi:10.1145/3132272.3134143

A User Needs Elicitation for Shape-Changing Furniture

We elicited user needs using an online survey to derive requirements for enabling on-demand furniture change. The following elicitation research questions (E-RQs) guided the survey design:

E-RQ1 Which use cases do users envision for an on-demand furniture system?

E-RQ2 What capabilities do end users expect of a furniture system?

E-RQ3 Which aspects of on-demand furniture change might they consider challenging?

Procedure and Measurements. After giving informed consent and answering demographic questions[1], participants were asked about their usage of furniture, i.e., how often they change its arrangement in their home and work environment, and how often they buy new furniture. Additionally, they were asked to rate whether they have interior and furniture design knowledge on a Likert scale (1=*strongly disagree* to 7=*strongly agree*). If they had not designed their furniture yet, they were also asked whether they would design one in the future and how that decision would be affected by tools supporting them during the process. On the same Likert scale, to answer **E-RQ2**, they were also asked to rate which aspects of furniture they consider more or less important, i.e., its flexibility, extensive design variations, fast setup, and ability to change interiors.

To answer **E-RQ1**, participants were shown five use cases, including example images: **meeting room**, **office**, **multipurpose hall**, **living room**, and **camper**. For each use case, they first wrote down different scenarios they could imagine that would require a quick and easy furniture change. As in **E-RQ3**, they were also asked which challenges they could imagine when using the furniture in this use case, i.e., while, for example, reconfiguring or rearranging it. Then, they were presented with a scenario for that use case (see Appendix B). They were then asked to write down the expected challenges in this scenario (see **E-RQ2** and **E-RQ3**). Finally, they ranked the use cases they had seen by the importance of the possibility for quick and easy furniture change.

In the end, participants could share any additional thoughts. The survey also contained two attention checks.

General Results. We recruited N=41 participants (29 female, 12 male, and 0 non-binary) for this online survey via Prolific with a remuneration of £2.15. Participants were aged between 18 and 73 years (M=40.17, SD=14.36). Most participants preferred consistency in their home furniture arrangements. Specifically, 24 participants arrange furniture annually, while 13 make less frequent changes. Only four individuals reported making monthly adjustments. This trend towards infrequent change was also reflected in purchasing habits, with 20 participants buying new furniture yearly and 19 doing so less often. Similar patterns emerged in the context of work environments. Sixteen participants rearranged their work furniture annually, while 21 did so less frequently.

Regarding expertise, participants had limited interior and furniture design knowledge (see Table 3). Interestingly, while only six participants (14.63%) have designed their own furniture, there was a notable shift in interest when considering future possibilities. The remaining 35 participants would design their own furniture if they were more familiar with the necessary tools (see Table 3). Lastly, when rating furniture attributes, participants were neutral towards the importance of flexibility, the availability of extensive design variations, and the ease and speed of setup and modification. Table 3 presents further details on these preferences.

Use Cases Implications. We presented the use cases (A) meeting room, (B) office, (C) multipurpose hall, (D) living room, and (E) camper. From the participants' feedback, challenges appeared consistent across various use cases. Appendix C details the coded scenarios and challenges, referencing individual participants.

(A) For **meeting rooms**, the main scenarios include accommodating different meeting types and sizes, rearranging seating arrangements, dividing the room, and hosting after-work events. Challenges include moving large meeting tables, heavy and inflexible furniture, and limited space. (B) For **offices**, the scenarios involve staff changes, rearranging desks or cubicles, dividing spaces, improving ergonomics, and hosting parties or after-work events. The main challenges are limited space, managing cables, moving heavy furniture, and storing additional furniture. (C) In **multipurpose halls**, scenarios include accommodating different events, such as sports, parties, and concerts. The main challenges are storing unused furniture, the time and manpower needed for reconfiguration, and the potential for damage to the hall's floor. (D) For **living rooms**, scenarios include hosting gatherings, accommodating guests, changing living arrangements, and remodeling. Challenges involve storage space for unused furniture, moving heavy furniture, limited space, and ensuring comfort and visibility. (E) For **campers**, participants reported the same challenge as in living rooms. However, they highlighted the transition between daytime and nighttime furniture setups (also see [47]).

Overall, the common challenges across these settings include limited space, storage for unused furniture, and the time, coordination, and manpower required for rearranging furniture. Some

[1]Questions and selectable items from SurveyMonkey (21.08.2025)

Table 3: Results of the Likert scale questions (1=*strongly disagree* to 7=*strongly agree*) in the online survey related to furniture design and user needs for furniture features.

Variable	n	Min	q_1	$\tilde{x}$	$\bar{x}$	q_3	Max	s	IQR
I have knowledge of interior design.	41	1	2	4	3.73	5	6	1.61	3
I have knowledge of furniture design.	41	1	2	4	3.46	5	6	1.48	3
I would design my own furniture	35	1	3	4	4.20	5	7	1.68	2
I would design my own furniture if I knew my way around the tools needed.	35	1	5	5	5.09	6	7	1.72	1
Furniture should be flexible.	41	1	3	3	3.37	4	5	0.97	1
Furniture should enable extensive design variations.	41	1	3	3	3.24	4	5	0.86	1
Furniture should enable fast setup and change of interiors.	41	2	3	4	3.44	4	5	0.95	1

participants suggested using flexible or collapsible furniture and stackable chairs to address these challenges.

Ranking of Use Cases. After identifying scenarios for on-demand furniture change and challenges that come with them in all the use cases above, participants were asked to rank these use cases depending on where they consider on-demand furniture change most important. The multipurpose hall (use case C) received the highest ranking, and the camper (use case E) was ranked lowest. Participants explained that the ranking mostly considered the frequency of needed change. However, as a camper has to be arranged often, the ranking most likely also implies their own frequency of experiencing the use cases.

Importance of Furniture Aspects. Participants rated the importance of different furniture aspects (e.g., attractiveness, cost, individuality, robustness, and reusability) for their homes and a public environment. In general, for all aspects, we found that they were more important in a private setting (e.g., at home). For descriptive values, see Table 6.

B Use Case Descriptions

Meeting Room. "A meeting room at a university is used for two events that take place right after each other: After the weekly meeting of all members of an institute at a university, a thesis presentation is held in the same meeting room. Because only a few people are left in the room, the remaining chairs and tables should be removed."

Office. "A new person starts working at a company. Therefore, the open-plan office has to be reconfigured: The existing tables have to be put closer together, and a new table has to be installed in the newly created space."

Multipurpose Hall. "Directly after a gymnastics lesson for students, the multipurpose hall gets used for an information event of the local city administration where people can sit and watch a presentation."

Living Room. "After having lunch, a family wants to prepare their living room for a birthday party. Therefore, they need to put more chairs and tables into it and remove an armchair and a smaller coffee table because of the limited space in the room."

Camper. "Inside a small camper, there is only enough space for a bed OR a table to sit and eat at. Therefore, these [two] pieces of furniture have to be exchanged every morning and evening."

C Scenarios and Challenges for Shape-Changing Furniture in Various Settings

In the user needs elicitation (see Section A), participants were shown five use cases: meeting room, office, multipurpose hall, living room, and camper. Table 4 summarizes the results regarding the scenarios participants could imagine requiring a quick and easy furniture change. Table 5 summarizes the results regarding the challenges participants could imagine when using such furniture in the respective use cases.

D Comparison Furniture Aspect Importance in Private and Public Settings

Table 6 summarizes the results of the user needs elicitation (see Section A) regarding the importance of different furniture at home and in public environments.

E Air Supply Calculation

Upon entering the ground plate dimensions $n \times m$ and the grid cell distance, the calculation starts with a default pressure and flow rate (8 bar, 150 l/min). **(1)** It calculates the pressure drop in the current hose segment, beginning with the main hose leading to the first branch. The pressure drop ΔP is approximated using a modified Darcy-Weisbach equation:

$$\Delta P = \lambda \cdot \left(\frac{L}{D}\right) \cdot \frac{v^2}{2} \cdot C \tag{1}$$

With friction factor λ (approximately 0.06 for a 4 mm PE hose[2]), hose length L, and hose diameter D. The flow velocity v is the current volumetric flow rate divided by the cross-sectional area of the hose. The compressibility factor C adjusts the pressure drop calculation to account for changes in air density (1.0 to 1.2 for 8 bar at room temperature[3]). **(2)** If an outlet's valve is open, the valve's airflow rate (3.38 SCFM for our prototype's valves) is subtracted from the current flow rate. This is repeated for the branch's m outlets. **(3)** The subsequent branch's starting conditions are the remaining flow rate after splitting a branch and the cumulative pressure drop. This procedure is repeated for all n branches. **(4)** Finally, the application identifies the layout's minimum pressure and airflow rate. If these

[2]https://www.engineeringtoolbox.com/pe-pipe-pressure-loss-d_619.html; Accessed: 21.08.2025
[3]https://www.engineeringtoolbox.com/ideal-gas-law-d_157.html; Accessed: 21.08.2025

Table 4: Envisioned scenarios for different use cases (A-E) based on participant feedback in the online user needs elicitation (N=41).

Use Case	Envisioned Scenarios	Participant References
A Meeting Rooms	Accommodating different types and sizes of meetings	P1-P2, P4, P6, P9, P14, P17, P19, P21, P28-P30, P32-P33, P35
	Rearranging seating arrangements	P2, P12, P14-P15, P17, P20, P23-P24, P32, P35-P36, P39
	Dividing the room	P3, P20, P24, P30, P37
	Hosting after-work events	P3, P6, P10, P11, P19, P21, P22, P26, P30, P31, P41
B Office Rooms	Staff changes	P1, P11, P16, P18-P19, P22, P29, P33, P39
	Rearranging desks or cubicles	P2, P9-P10, P20, P23-P24, P28, P35-P36
	Dividing spaces	P27, P37
	Improving ergonomics	P12, P14, P25, P27, P30
	Hosting parties or after-work events	P3, P13, P19, P24, P26, P31
C Multipurpose Halls	*Accommodating different events, such as*	
	... sports	P1, P14, P19-P21, P27, P39
	... parties	P3, P19, P22, P36
	... concerts	P20, P22, P26
D Living Rooms	Hosting gatherings	P1-P3, P11, P19-P23, P27, P31, P33, P35
	Accommodating guests	P14, P16, P20, P24, P36-P37
	Changing living arrangements	P6, P27-P28
	Remodeling	P6, P14, P22, P26-P29
E Campers	*see Living Rooms*	P4, P6, P8, P12, P14, P19, P24, P30, P37

Table 5: Challenges anticipated in various use cases (A-E) as highlighted by participants of the online user needs elicitation (N=41).

Use Case	Envisioned Challenges	Participant References
A Meeting rooms	Moving large meeting tables	P1-P4, P6, P8-P9, P14-P15, P20-P22, P27-P31, P33, P35-P36, P41
	Heavy and inflexible furniture	P1, P10-P12, P24, P29
	Limited space	P2, P11, P17, P22-P23, P26, P30, P38-P40
B Office rooms	Limited space	P2, P7, P12, P15, P20-P23, P26, P29, P35-P36
	Managing cables	P4-P5, P8-P10, P13-P16, P21-P22, P29-P30, P36, P41
	Moving heavy furniture	P1, P3, P5, P14, P16, P24, P29
	Storing additional furniture	P1, P19, P24, P30
C Multipurpose Halls	Storing unused furniture	P1, P14, P17, P19, P23, P33, P35-P37, P41
	Time needed for configuration	P5, P7, P9-P10, P18-P19, P30, P36
	Manpower needed for configuration	P10, P20, P22, P26
	Potential damage to floor when rearranging	P17, P24, P27
D Living Rooms	Storing space for unused furniture	P1, P4, P9, P19, P27, P30, P35
	Moving heavy furniture	P12, P14, P29-P31, P34
	Limited space	P5, P11-P12, P18-P20, P23, P36
	Ensuring comfort	P1, P4, P16, P19-P22
	Ensuring visibility	P19-P21, P24, P34
E Campers	Transition between daytime and nighttime setups	P4, P6, P8, P12, P14, P19, P24, P30, P37

values are below a set threshold (see Section 5), it incrementally raises the compressor's input airflow rate and pressure, performing the four steps until the desired inflation speed for the ground plate's far end. Users then receive the required air supply specifications in bar and l/min.

F Application Examples

While we focused on overall module arrangements for room transformation in the user evaluation (see Section 6), *AirClick* also provides specific interior applications, which we created to demonstrate further parts of the design space covering the dimensions *D1: inflatable type*, *D2: shape-changing*, and *D3: user input* (see Figure 2).

Posture Correction. Unlike previous floor-based approaches [43, 52], a chair's backrest can be inflated to enhance lumbar support if the user exhibits slouching behavior (see Figure 11 a). We employ a chair with *(D1) serial-connected* chambers: the backrest and the

Table 6: Online survey results regarding the importance of different aspects of furniture at home (top half) and in a public environment (bottom half).

Variable "that they/you ..."	n	Min	q_1	$\widetilde{x}$	$\bar{x}$	q_3	Max	s	IQR
... match	41	1	3	4	3.68	4	5	0.93	1
... have an attractive/appealing design	41	2	4	4	4.20	5	5	0.81	1
... are individual	41	1	3	3	3.00	4	5	1.00	1
... are cheap	41	1	3	3	3.05	4	5	0.92	1
... are high-quality	41	2	3	4	3.83	4	5	0.70	1
... are robust	41	1	3	3	3.37	4	5	0.94	1
... are easy to clean	41	2	4	4	4.00	5	5	0.95	1
... are easy to handle for relocation (e.g., transportable, easy to break down and set up)	41	1	3	3	3.44	4	5	1.00	1
... fit into your environment (e.g., the measures of a corner)	41	2	4	4	4.17	5	5	0.86	1
... can reuse some pieces	41	2	3	3	3.32	4	5	0.99	1
... match	41	1	3	4	3.63	4	5	0.86	1
... have an attractive/appealing design	41	2	3	4	3.76	4	5	0.73	1
... are individual	41	1	2	3	2.61	3	5	1.20	1
... are cheap	41	1	2	3	2.71	4	5	1.05	2
... are high-quality	41	2	3	4	3.78	4	5	0.79	1
... are robust	41	2	3	4	3.68	4	5	0.99	1
... are easy to clean	41	2	4	4	4.32	5	5	0.79	1
... are easy to handle for relocation (e.g., transportable, easy to break down and set up)	41	1	3	4	3.76	5	5	1.02	2
... fit into your environment (e.g., the measures of a corner)	41	1	4	4	4.10	5	5	0.97	1
... can reuse some pieces 2	41	1	3	4	3.66	4	5	1.11	1

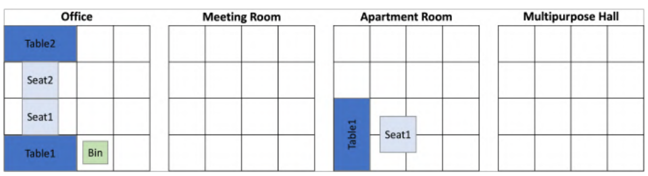

Figure 10: Schematic of the 2x2 m *AirClick* prototype used in the user study. Each panel shows a 4x4 ground-plate grid with the default arrangement of traditional furniture for the four scenarios: office, meeting room, apartment room, and multipurpose hall. The meeting-room and hall scenarios began with an empty grid. The drawn furniture blocks are scaled to roughly match their real-world dimensions.

seating area. Users may only inflate the seating area for a temporary chair. However, extended seating often leads to posture degradation [16]. The pressure sensor within the chair's baseplate identifies the irregular *(D3) weight distribution*. Upon detection, the backrest inflates, offering added support (*D2 intrinsic shape-change*) and correcting the user's posture.

Physical Disability Support. In case of arm or leg injuries, healing advice may suggest keeping limbs straight and immobile to alleviate pain and support blood circulation. Yet, many households lack readily available footrests or armrests to aid this process. With *AirClick*'s comfortable yet versatile *(D1) basic and complex shapes*, a combination of an air-stack and a cube module can be attached next to a chair (*D2 module augmentation*), serving as an armrest or footrest (see Figure 11 b). Users can trigger the inflation by touch. A *(D3) gesture* can determine the ideal inflation height when a user's arm injury prevents them from reaching the baseplate.

Exercise Assistant. *(D1) Basic shape* modules can inflate to form soft structures that assist in various physical exercises or yoga poses. Users may inflate a chair as a yoga prop, a cube as an Aerobic stepper, or an air-stack module for punching exercise (see Figure 11 c). In this environment, a user wants to perform a plank at varying difficulty levels but is uncertain about the correct adjustments. The user places their legs on a deflated cube module to solve this. By detecting the body pose (*D3 gesturing*), *AirClick* adjusts the difficulty by controlling the cube's inflation, modifying the plank's incline and challenge level (*D2 intrinsic shape-change*).

Mood-based Environment. Dedicated relaxation or focus work areas are rare in many smaller companies due to the costs and setup effort. *AirClick* offers a solution by enabling the quick setup of mood-responsive personal spaces (see Figure 12 a). Unlike prior large-scale shape-changing interfaces [38, 43, 52], *AirClick*'s easy-to-handle *(D1) complex shape* and *(D2) building block* modules facilitate users to tailor rooms to their emotional state. For example, stressed users can inflate the room separator, chair, and footrest modules, creating a secluded area (*D3 via translation and touching*). Replacing the footrest with a table-shaped module can quickly convert this into a focused work area.

Modular Play Area for Children. Children typically dislike limited play space [21]. *AirClick* can help children and parents establish an additional play area (see Figure 12 b) in the living room. While previous large-scale shape-changing approaches [38, 43, 48, 52] lack module shape diversity and do not support *(D1) retrofitting retail inflatable* toys, with *AirClick*, modular play areas can be tailored based on the number of children and the intended game type (*D2 arrangement*, *D3 via translation*). For example, a versatile playground fortress can be constructed using *(D1) single/multi-connector* room separator, cube, chair, and air-stack modules.

Prototyping Architectural Spaces. Designers and architects can assemble and reconfigure detachable modules with various (*D1 single/multi-connector*) shapes to test different spatial layouts, visualize architectural concepts, and collect feedback from potential users (see Figure 12c). By integrating with existing furniture and retrofitting larger objects (unlike [38, 43, 48, 50, 52]), *AirClick* enhances design versatility and cuts down on development time, eliminating the need to construct an entire interior from shape-changing modules alone (*D2 building block, module intrinsic and*

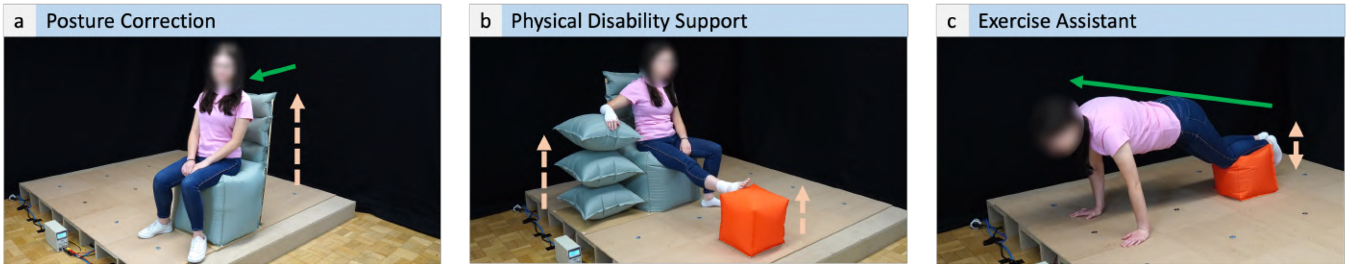

Figure 11: Health-promoting furniture application examples. (a) Automatic posture correction using a 1x1 chair with a separately activatable backrest. (b) On-demand support for arm and leg injuries using a reactive 1x1 cube and air-stack as arm and footrest. The cube inflates upon touching, and the air-stack inflates by holding the arm above the module. (c) Exercise assistant supporting a plank exercise by proactively inflating/deflating the module to adjust the difficulty.

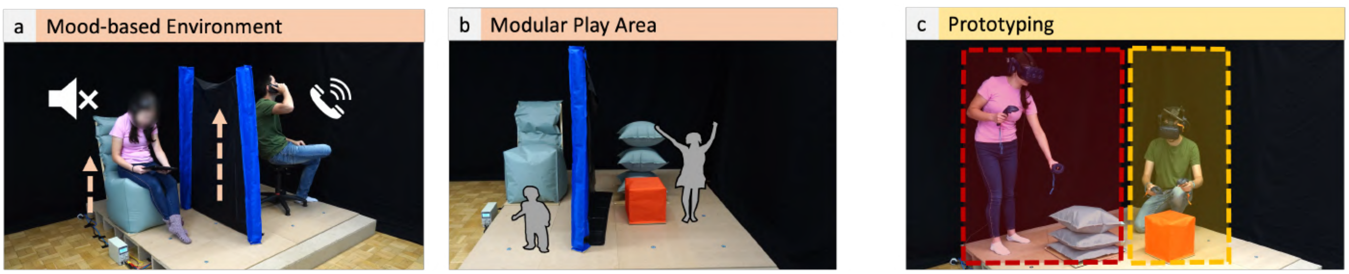

Figure 12: (a) On-demand mood-based environment with 1x1 chair, and 2x1 wall modules. (b) A dynamic play area for children using a chair, cube, air-stack, and wall module to create a small playground fortress. (d) Synchronized shape-change in collaborative VR for prototyping architectural spaces with haptic proxies.

augmentation). Besides, *AirClick* is not restricted to specific shapes (unlike [38, 48, 57]), thereby increasing the design's expressiveness. Designers and clients might remotely co-design a new office space at two separate *AirClick* systems (e.g., see Dollhouse VR [13]). When the designer alters the furniture (*D3 via translation and sensors*), the remote location's modules inflate or deflate to reflect the changes, synchronizing the ground plates in the control software.