Introduction to Human-Building Interaction (HBI): Interfacing HCI with Architecture and Urban Design

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Buildings and urban spaces increasingly incorporate artificial intelligence and new forms of interactivity, raising a wide span of research questions about the future of human experiences with, and within, built environments. We call this emerging area Human-Building Interaction (HBI) and introduce it as an interdisciplinary domain of research interfacing Human-Computer Interaction (HCI) with Architecture and Urban Design. HBI seeks to examine the involvement of HCI in studying and steering the evolution of built environments. Therefore, we need to ask foundational questions such as the following: what are the specific attributes of built environments that HCI researchers should take into account when shifting attention and scale from "artefacts" to "environments"? Are architecture and interaction design methods and processes compatible? Concretely, how can a team of interaction designers bring their tools to an architectural project, and collaborate with other stakeholders? Can and will architecture change the theory and practice of HCI? Furthermore, research in HBI should produce knowledge and practical guidelines by experimenting novel design instances that combine architecture and digital interaction. The primary aim of this article is to specify the mission, vision, and scope of research in HBI. As the introductory article to the TOCHI special issue, it also provides a summary of published manuscripts and describes their collective contribution to the development of this field.

CCS Concepts: • **Human-centered computing → Human computer interaction (HCI)**; *HCI theory, concepts and models*;

Additional Key Words and Phrases: Human-building interaction

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1 HBI: UNIFYING "HCI IN BUILT ENVIRONMENTS"

For centuries, something as simple as opening or closing a window has provided remarkably sophisticated opportunities to regulate temperature, light, air quality, acoustics, privacy, and even social relations between inside and outside. The introduction of automated ventilation systems, smart lighting, and mixed reality, however, is about to change all of this. What will be the consequences of truly smart buildings on the humans who inhabit them? The scope of such questions not only concerns human experiences in buildings but also extends more widely to public and social environments and urban spaces—what will it be like to live within highly monitored smart cities and in interaction with emerging mobile actors, such as autonomous vehicles and delivery robots?

In recent years, a growing strand of research in Human-Computer Interaction (HCI) has been to understand and shape people's experiences with, and within, built environments. An aspiration is the transition from the "realm of artifacts" to the "realm of architecture." In the vision of Ubiquitous Computing (Ubicomp), this can be seen as a logical extension, a "second transition" succeeding the move from virtual-onscreen objects toward understanding interaction with physical-tangible artifacts.

Human-Building Interaction (HBI) frames HCI research and design within built environments, seeking to sketch the scope of an interdisciplinary area situated at the interface between HCI and the domains of architecture and urban design. Questions addressed have started examining how emerging interactive experiences are "spatiotemporally immersive." By this is meant ones that are not discrete or limited to moments of interaction, but persist over time, and can be enacted at different temporal scales of adaptability [7]. The ultimate goal is to provide a framework that can be used to understand, compare and relate the converging research efforts from the two fields of HCI and Architecture in envisioning and shaping the future of living.

While the "Smart Agenda" for the built environment (e.g., Smart Home, Smart City, Smart Park) has been around for some time, the emphasis has been largely on improving efficiency, cost, and sustainability. In contrast, HBI's focus is on human values, needs, and priorities in addressing people's interactions with such "smart" environments. HBI deals predominantly with questions that embody and reflect the complexity of human interaction and social experiences with and within built environments.

Deepening the collaboration between the disciplines of architecture, urban design, and HCI has already begun. Over the last few years, a number of CHI workshops (in 2014 and 2016 [3, 8]), research papers [2], and books (e.g., Interaction & Architecture, Springer [9]) indicate a growing interest in how HBI can be further explored. The ACM Interactions magazine devoted one of their forums to this area (the Interaction & Architecture forum [17]) in an attempt to bring together contemporary ideas and examples. Many living lab projects have been instigated to provide the shared facilities and collaborative platforms for experimenting interactive architectural design interventions. At the scope of urban, the project CityWare presents one of the earliest attempts to bring together researchers from the domains of HCI and urban sciences, supported by industry (Nokia, Vodafone, HP Labs) to carry out a longitudinal investigation (2005–2009) in the context of the city of Bath, UK [11, 15].

Within industry, Nest Lab's smart thermostats and Amazon's Echo voice assistant have started to scratch the surface of what interactive devices in the home can do to shift people's relationship to the buildings they inhabit. Easy access to the middleware and the software frameworks such as Apple HomeKit are raising questions about who controls the scope and span of the interactive experiences, and indicate a need for more stakeholder inclusive discussion, debate, and exploration.

This special issue is a part of our ongoing attempt to capture, share, and expand what is already known, what is contested, and what are opportunities for a common scientific grounding for prospective dialogues and discourses in the area of HBI. It serves both as a stage for the existing

voices that are centrally and peripherally working on HBI, and a platform for the research area to move forward.

2 HBI– THE MISSION

The shift of focus and scale to the realm of built environments introduces a new set of methodological requirements that stem from the inherent and specific attributes of environments that set them apart from artifacts [1]. HBI needs to fill this methodological gap on four fronts:

1- Developing and re-appropriating frameworks, concepts, vocabularies, and discourses within the domains of architecture and urban design. Questions to ask include the following: what can be learned from the Comfort literature in the scholar domain of Indoor Environmental Quality (IEQ), and how can an HBI perspective capture the interactivity and subjectivity of human comfort to complement the established discourses surrounding comfort-health-productivity [4, 5]? Another example is the potential for HBI to learn from the discourses of "urban public space," rendering insight into the ways in which built environments can support and take advantage of social interaction and cultural diversity [10, 13, 14]?

2- Examining how existing methods of user research developed within HCI and other disciplines can be reappropriated. For example, what can be learned from User Experience (UX) design knowledge in creating buildings that can adapt to their occupants' contextualized needs and preferences? How can the design of interactive experience with ambient intelligence draw on and contribute to the ongoing attempts that further the understanding of Human-AI interaction investigating topics surrounding the explainability of AI components, transparency, trust, and ethics of design? Surveillance is increasingly common for the purpose of providing security. How can the discourses of online data privacy direct the privacy and security concerns that are especially elevated in inhabited environments and that introduce new forms of safety risk?

3- Developing new and novel methods that respond to new emerging phenomena, such as artificial intelligence and new forms of interactivity in built environments. For example, how can HBI designers reconcile the humans' desire to retain control over their environment with the efficiency that the building automation systems promise (e.g., [6])? What services do we expect the buildings to provide seamlessly, and where do we want to be engaged in decision-making, and through what interaction modalities? In a broader view, HBI should proactively engage in guiding the impact of AI in the evolution of built environments. Major projects such as autonomous vehicles and smart urbanity are predominantly led by the tech sector and shaped by technological possibilities. How can HBI create a standpoint in which the sociological conceptions of artificial intelligence emerge – toward truly serving humans and addressing the societal challenges recognized in architecture and urban sciences?

4- Reconciling differences in methods, terminology, and approaches that originate from the different domains of Architecture and HCI. Are architecture and interaction design methods and processes compatible? How do these approaches scale as we shift from artifacts to environments? Concretely, how and when can a team of interaction designers bring their tools to an architectural project, and integrate them into the strict architectural programs and temporal constraints (e.g., [16])? And, importantly, how should we shape the education of future practitioners who operate in this hybrid domain?

3 HBI–SCOPE AND THEMES

Research questions that fall within the scope of HBI are concerned with the relations between human experiences, in a broad sense, covering interactivity and the design of built environments,

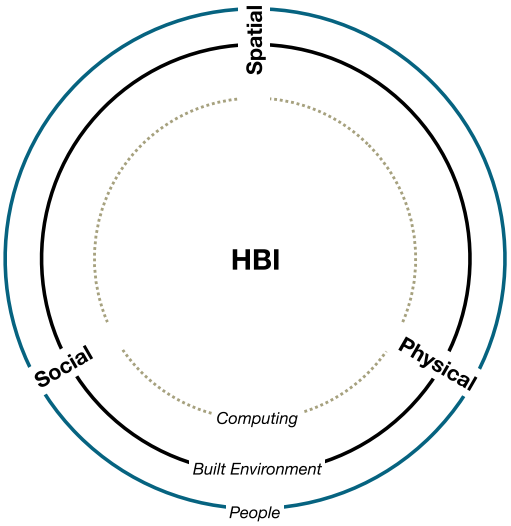

Fig. 1. The schema illustrates the scope of HBI studies answering questions that embody the complexity of *people*'s experiences in *built environments* that integrate *computing* in various forms and to varying extent. Human-Building Interaction is interested in reflections on the multifunctional phenomenon of the building, consisting of three interconnected aspects of the: physical-material, spatial-configurational, and social-cultural.

which may incorporate computing to varying degrees. Buildings with different functions (homes, offices, schools, hospitals, airports, etc.) bring up a range of contextual requirements that entail the development of focused research, whose results might not generalize across these different contexts. Urban experiences, on the other hand, are tied with questions surrounding the future of mobility and transportation, extending the scope of HBI to the consideration of emerging intelligent mobile actors such as autonomous vehicles and urban delivery robots, and particularly their interaction with humans as the trans-scalar actor of mobility.

Figure 1 illustrates an attempt to schematically sketch the scope of HBI research; the three concentric circles of "People," "Built Environment," and "Computing" reflect the three coordinates relevant to HBI questions as we described above. In addition, a classification comprising the interrelated dimensions of Physical, Social, and Spatial, as shown in Figure 1, specify the various but overlapping directions to which HBI research can contribute. This framing is inspired by how the concept of the built environment was proposed by Bill Hillier in his book "Space is the Machine" [12], and reformulated in one of the originating attempts to define HBI [3]:

"Built environments are a construction of physical elements that create and protect a space. Each of these two aspects, the physical and the spatial, carry a social value: the former by the shaping and decoration of elements (with functional or cultural significance), and the latter by providing spatial patterning of activities and relationships. Designing Human-Building Interaction, in that perspective, consists of providing interactive opportunities for the people to shape the physical, spatial, and social impacts of their built environment."

HBI is interested in reflections on the multifunctional phenomenon of the building, consisting of three interconnected aspects of the: physical-material, spatial-configurational, and social-cultural. These aspects, however, are not isolated or perpendicular; many of the topics to be addressed in HBI cover areas that operate between these dimensions. For example, research questions related to human comfort may extend from Physical (environmental condition) to Spatial (visual attributes,

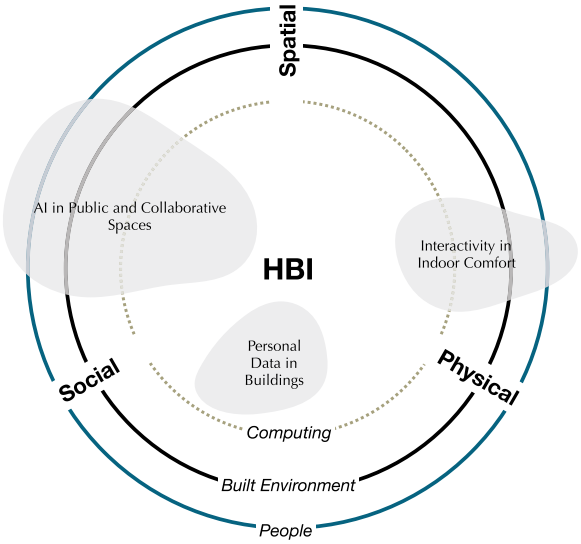

Fig. 2. The three dimensions of HBI research (i.e., Physical, Spatial, and Social) are not isolated or perpendicular; many of the topics to be addressed in HBI cover areas that operate between these dimensions.

such as visual privacy). Figure 2 illustrates a few examples as how the various themes of research within HBI stretch their extent between the three dimensions. Nevertheless, in trying to situate different research themes on such schematic map of HBI, one may observe that while focused research questions can be placed between or on particular dimensions, a comprehensive view of most HBI research topics would entail consideration of all the three. For example, questions related to comfort also touch upon the Social dimension, considering situations in shared spaces where comfort has to be "negotiated," opening a window or changing the thermostat setting is verified with the others who use the same environment.

Each of the papers published in this special issue contribute to the development of knowledge within the HBI scope as outlined in Figure 1. Some of the published manuscripts contribute to the agenda for methodological development on the four above-described fronts. The others help HBI to progress as a design-oriented domain. We expect that in HBI research more design instances will emerge and proliferate, which would serve a dual purpose: first informing design researchers about the effectiveness of those design interventions, and second, contributing to the generalized framework of HBI at the intermediate level of generalizable knowledge (design heuristics, strong concepts, evaluation methods, etc.).

In the next section, we redirect our focus to the special issue, briefly describing its objectives, the selection process, as well as summarizing the studies presented in each of the manuscripts that are selected to be included in the TOCHI special issue on Human-Building Interaction.

4 HBI–THE SPECIAL ISSUE

4.1 Objectives

The primary objective motivating this special issue has been to contribute to the development and recognition of the body of research that can play an increasingly important part in how HCI will engage in envisioning the new ways of living, in relation to the evolution of built environments. The special issue has been planned to serve both as a unifying stage for the existing voices that are centrally and peripherally working on HBI, and a platform for the research area to move forward.

It specifically has sought to capture and share what can construct a common scientific grounding for prospective dialogues and discourses in the area of Human-Building Interaction.

4.2 Selection Process

Following online publication of the call for paper in July 2017, we received 62 abstracts in December of the same year. In January 2018, 26 full manuscripts were submitted to the special issue, among which the associate editors decided that four should be early rejected mainly due to limited relevance to the topics of interest. The 22 papers then underwent the first round of review process, each evaluated by three external reviewers and one of the associate editors of the special issue who acted also as the meta-reviewer. Given the results of the first round of reviews the committee decided to continue with eight of the submissions and reject the remainder. The six papers that are selected to be published in the special issue are the ones that through the next rounds of revision-review could convince the reviewers and the associate editors that are of crucial significance to the HBI special issue and also conform to the high standards of papers published in the TOCHI journal. The final selection decision was made during the committee meeting held in July 2018.

4.3 Selected Papers

This section provides a summary of the six manuscripts published in the special issue. We ordered the papers so that the first two offer framing contributions, the second two report on studies that address specific HBI questions in two specific contexts (children's hospital, workshop environments); the fifth paper describes an HBI design instance and its evaluation, and the last paper focuses on privacy concerns related to the personal data collected in buildings. Except for the framing papers that take broad perspectives, the other presented works are focused upon indoor experiences considering building architecture; this is a limitation for this special issue that HBI studies at the scope of urban settings remain lacking.

(1) Do Architects and Designers think about interactivity differently? It is a paper that elaborates on the way architects and HCI practitioners think about their design problems. According to David Kirsh, the author of this paper, Architects operate with a more embodied and social notion of humans than HCI. Further, he explores how the two fields of HCI and Architecture think differently about "interfaces" and "interactivity." A well-elaborated standpoint and claim in this paper is that both strands suggest that interaction comes in a direct manipulation form and a networked form where interaction is not transparent, and users do not know what and where input devices and sensors are. In addition to this proposal, he concludes that only architects work with a further notion of interface–a more ecological notion–where users/occupants can change the interface in the course of acting. This argument leads up to the proposal of a third conception of interaction–one that adds reflexivity to the intuitive concept that interaction is symmetric and transitive (i.e., mediated).

(2) Temporal Constraints in Human-Building Interaction. It presents a discursive analysis of the divergent temporal constraints in the two domains of interaction design and architecture. As the method of study, they took a desk research approach and grounded their arguments in the literature and description of example projects. The paper is structured at three levels. The first level narrows down the focus to the "Ratoinale," that is the long-term vision that directs the evolution of the fields as well as short-term ways of reasoning that impact design choices. The second level is the "Method" of creation and the third one the "Outcome" of the production process. While recognizing the interplay of Rational–Method–Outcome, the authors structure their discussion of temporal constraints, for each of these topics separately. After outlining the motivation of this study in Sections 1 and 2, the authors elicit and explain what they observed to be the

most influential temporal differences between interaction design and architecture at the level of Rational, Method, and Outcome in Sections 3, 4, and 5, respectively. In the last part of this work, in Section 6, temporal constraints in Human-Building Interaction is discussed, developing arguments as how HBI can find a converging perspectives that is compatible with the rationale, method, and outcome of the two domains. The analysis that this paper offers addresses one of the central challenges in interfacing two design-oriented research domains that have constructed over the years different approaches to design. The question of temporality is both an apparent one when comparing almost any instance of architectural and interaction design works, but also a highly complicated one with a multitude of causes and consequences. This paper has succeeded to instigate a discourse in a way that both connects to mundane examples but also captures the complexity of the matter.

(3) Designing to Distract: Can Interactive Technologies Reduce Visitor Anxiety in a Children's Hospital Setting? It presents an ethnographic study of how Human-Building Interaction can be employed to alter the experience of inhabiting public spaces, in this case the reception area of a pediatric hospital. Patients and their families often experience feelings of anxiety when they stay in these areas, for instance when they await appointments or results from tests. While digital distractions are often portrayed in a negative light, they hold the potential to lessen the state of anxiety and promote enjoyment in such situations. Through the study, the authors demonstrate that it can indeed be beneficial to employ distraction as a design principle to alleviate feelings of anxiety and unease by developing interactive components and embedding them into the physical environment.

The study shows that interactive components, such as a playful interactive floor, can be far better at reducing anxiety than TV screens and large displays, which are an otherwise common feature in such spaces. In addition to increasing our understanding of how to employ distraction as a means of lessening anxiety, the authors therefore also introduce a framework for understanding and designing floor displays that can engage people from multiple perspectives, ranging from initial awareness to immersive interaction. By combining distraction as a design principle with the framework for interactive floors, the authors thus demonstrate how Human-Building Interaction has the potential to expand our repertoire for meaningfully creating or transforming spaces to lessen negative experiences. In addition to the rich case study, this is an eye-opener that invites us to think beyond the ubiquitous TV screens and more carefully consider how to purposefully make use of the potentials of interactive components when we shape the built environment.

(4) Exploring and Understanding the Role of Workshop Environments in Personal Fabrication Processes. It examines a particular kind of building space that has appeared in the last 10 years as a result of the widespread availability and affordability of making technologies, physical computing, and materials–namely, that of fab labs and makerspaces. Every city now and many tech company boasts at least to hosting one of these, providing extensive resources for local people to have a go at designing and prototyping and creating new products. The authors note, however, that they can be permanent or pop-up, large or small, and as such have developed largely from pragmatic constraints. An observational study of 11 such spaces, set up for students and the public to use in urban Toronto, revealed how they are quite different in terms of how the space and surfaces are configured and used, and how the tools, equipment, materials, and furniture are used, stored, and shared. Fabrication, design, and storage areas were also found to be co-located in different ways, depending on the shape and size of the space. A number of insightful observations are highlighted in the paper about how these existing spaces and tools are appropriated by those using them, and how that shapes how their work is done. The authors also describe a number of new practices that were seen to emerge, such as the hoarding of tools and the marking out of a territory. Although the environment was designed to support collaboration through openness in one maker space, it

was found to unintentionally discourage those using it from interacting with each other because they became so engrossed in what they were doing that they were unaware of what others around them were doing.

Based on their findings, the authors propose a number of themes that they propose can inform the design of future makerspaces, which they rename as "hybrid workshops." The reason for this is that, in the future, they hope that these spaces can be augmented with a diversity of other technologies, such as AR, AI, and IoT, not as additional tools to design and prototype with, but as a form of intelligent monitoring and tracking systems that can help with workflows, and take over more of the system maintenance, workshop cleanliness, and maker safety enhancements. By offloading some of these mundane tasks onto the building environment, itself, it is envisioned that responsive architecture will emerge. The utopian vision presented suggests a more personalized "bricolage" space for makers, which will intelligently guide them toward the tools they need at a given time, tailor assistance when needed while encouraging them to develop new skills, thereby enabling them to focus their efforts on learning, designing, collaborating, and being creative.

(5) WindowWall: Towards Adaptive Buildings with Interactive Windows as Ubiquitous Displays. It presents an exploration in the context of interactive smart windows. Drawing on various aspects of previous work in the fields of smart windows, see-through displays, ambient information systems as well as public displays and media façades, the authors envisage the use of interactive smart windows as ubiquitous displays will allow new ways of interacting with buildings in the future. The work extends, and builds on, the vision of adaptive architecture, where elements of smart windows change their features in real time, according to specific aspects such as privacy issues, as well as environmental conditions, e.g., changing transparency from semi-transparent to opaque. More specifically, the paper investigates the design space of interactive and adaptive windows and identifies requirements, constraints and challenges that will help inform future explorations by computer scientists architects and interaction designers. This was achieved through the development of multiple prototypes of a single window with four display elements, and other larger structures including a façade test building. To that end, the authors have built proof-of-concept prototypes of smart windows with established technologies. They consist of fine-grained control of transparency to change the look of the windows dynamically and to use them with integrated ambient information displays. In two studies, the authors carried out an interview study with 12 participants to identify user attitudes toward interactive windows and investigate, with different application scenarios in domestic environments, possible use and benefits of interactive smart windows. This was followed with an exploration of multimodal interactions through and elicited control methods with 16 participants.

Based on the results from the two studies, and to build interactive windows that fit well in everyday environment and become meaningful artefacts, the authors outline design dimensions where they address in details various aspects to be taken into consideration, in future design studies and explorations, with relation to the location of the window and the architectural integration, the support of an active role of users in the content curation, the role of context awareness and context-based adaptation, supporting multimodal interaction (implicit and explicit) and input techniques, and finally, taking into account various social aspects and social dynamics.

Emerging challenges for HCI posed by the explorations and the studies presented in the paper are then presented including the challenges raised though the implementation of in-situ prototypes, how to move on to studies with increased ecological validity and how to address physical and social context of interactive windows as key consideration for users. In this respect, the authors highlighted the need for cross-disciplinary understanding and engagement in a deeper dialogue between HCI and architecture community. Future implementation within the home context, with

potentially prolonged exposure to interactive windows, seems to pose research challenges, where new models of usage need to be developed to take into account activities and presence patterns, and this could also influence the temporal aspect of smart windows content duration and scheduling. Furthermore, interactive windows appear to give privacy and sharing a spatial dimension, which may benefit the interactions but calls for the development of new understanding of privacy and sharing, of how users can effectively define privacy rules and for more advanced controls to fit within the home context. Finally, the authors call for revisiting the notion of "home" in HCI as a place for activity that relate to the artefact (i.e., the smart window), to emphasize the social context and the provision security and control, and perhaps even to reflect the identity and values of the home owners. The work forms the first step toward exploring adaptive walls that use interactive smart windows in a multi-faceted way. It is hoped that the research can stimulate further interdisciplinary exploration and help Architect, designers, and HCI community build a better understanding of future spaces augmented by interactive windows.

(6) Adaptive Buildings and Personal Data. It tackles an issue that is ever-more relevant to Human-Building Interaction, but often overlooked, namely how personal data are captured, stored, and employed by the digital systems that are increasingly embedded into our surroundings. On one hand, the systems we develop to creative adaptive buildings depend on gathering data about the people who visit and inhabit the buildings in order to provide e.g. more accessible, convenient, or information-rich environments. On the other hand, much of this data is collected in ways that are not immediately obvious to visitors and residents, e.g., via sensors and cameras, and it is stored and employed in ways that are not necessarily transparent or comprehensible to them. Recent developments in privacy legislation such as GDPR has underscored the need to take this matter seriously. Balancing the need for data collection to enable meaningful interactions with people's wishes and requirements for retaining control over their personal data has, thus, become a central concern in Human-Building Interaction.

Analyzing a series of envisioning workshops carried out to examine the capture and use of personal data in adaptive buildings, the authors draw out a series of design considerations to help designers and architects gain awareness of the capture and use of personal data, and to develop solutions that strike a proper balance in concrete projects. The authors demonstrate that there are no easy solutions; rather, there exist a series tensions pertaining to temporal, spatial, and inhabitation-related dilemmas for how to capture, store, employ, and provide access to the data. As the technologies for gathering such personal data become more powerful and are increasingly embedded into our environment, these concerns will only grow in prominence.

5 CONCLUDING REMARKS

The primary objective of this introductory article has been to clarify what we talk about when we talk about Human-Building Interaction. We introduced HBI as a growing branch of HCI that seeks to push the boundaries of the field to the realm of environments, to interface with the domain of architecture and urban design, and to be able to address the complexity of human interactive experiences with the built environments of future. This first part of the paper also sought to chart the landscape of HBI research by specifying its mission and sketching the outline of its scope. The second part narrows the focus to the special issue and the six papers that it presents. The objective has been to exemplify rigor in HBI methodological and conceptual contributions as well as opportunities for grounded experiment-based HBI studies.

We see this collaborative work between the authors, reviewers, and the associate editors as a starting point. By proposing and developing this special issue, we aimed to ignite discussions of what could construct a foundation for the future of research and design in HBI, and setting

examples for what should populate within this domain. Through the process of producing this special issue, we noticed the considerable size of the HBI community (62 abstract submissions, as an indicator), and observed signals that suggest its growth in the coming years. We hope that this special issue paves the path for this community to situate HBI among the other sub-domains of HCI and to be able to eventually organize independent scientific events (e.g., annual conferences) dedicated the advancements in Human-Building Interaction.

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