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A FRAMEWORK FOR CENTRALIZING ETHICS IN THE DESIGN ENGINEERING OF SPATIAL COMPUTING ARTIFACTS

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ABSTRACT
Creating Spatial Computing (SComp) artifacts (including Virtual Reality, Augmented Reality, Mixed Reality, and Ambient Intelligent artifacts) is a rapidly-emerging domain in need of new design methodologies. In this paper, we examine whether and how ethics are procedurally integrated into the creation of SComp artifacts. After an introduction to terminology—including a reframed definition of Spatial Computing—findings of interviews with Spatial Computing practitioners are shared. The interviews indicated an awareness among professionals about the inordinate vulnerability of SComp artifacts, and about the need for—and the lack thereof—processes and tests to mitigate negative effects of SComp artifacts. Results from the domain expert interviews are integrated into a proposed framework: The Framework for Ethical Spatial Computing Design Engineering. Our framework serves to support researchers and practitioners in devising new methodologies unique to Spatial Computing by highlighting considerations central to the creation of ethical artifacts. The framework integrates the findings from the in-depth interview study and builds on existing models in Design Process, Methods, and Human-Computer Interaction (HCI) Research that highlight important barriers and opportunities between research and practice. It maps the three-phases journey consisted of (1) Enablers, (2) Synthesizers, and (3) SComp Artifacts. We trust that our work sheds light on considerations necessary to the creation of ethical Spatial Computing artifacts.

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1 INTRODUCTION
In Spatial Computing (SComp), the space on and around the user becomes the interface. SComp comprises a combination of both digital (software and data) and physical (hardware) artifacts, which together we refer to as SComp Artifacts [1]. SComp Artifacts are made possible by an abundance of sensors gathering data from users and actuators acting on that data. The automated gathering of user data from sensors and the use of such data to imitate autonomous processes or train artificially intelligent models (most often in the form of Machine Learning (ML)) is fundamental to the effective functioning of SComp Artifacts. Therefore, it is important that SComp is understood as inherently comprising of Autonomous Processes and/or Artificial Intelligence (AI), what we will refer to as Auto/AI hereafter. The collection and use of such data for Auto/AI powered SComp raises significant ethical questions concerning privacy, equity, and personal agency, among others [2]. AI-powered SComp is especially vulnerable to these kinds of concerns over exclusively Autonomous Process-powered Scomp, as (1) AI relies heavily on data collected from users who may not have control over how their data is being used, and (2) AI creates ever-evolving outcomes [3] which increase the risk of unintended [4][1] (negative) consequences.

Take, for example, a recent study conducted at Stanford University [6] where—after participants used the HTC Vive Virtual Reality headset and controllers—the system was able to correctly identify ninety-five percent of users from their movement

[1]For further discussion on the conflation of "unintended" and "unanticipated" see Zwart [5].

data alone, raising ethical concerns that even when data is "de-identifed" as promised in the terms and conditions, *"in practice taking one's name of [sic.] a dataset accomplishes very little"* (p. 1). To say this was an intentional work-around data privacy, would be brazen. Rather, what this example highlights is that SComp Artifacts rely on a mix of Auto/AI which can produce outcomes that were both unintentional and unwanted from the perspective of the design engineering team that conceived the artifact. Or take another little-studied concern which deals with an ethical issue in terms of its underlying assumptions about the users in a given environment: the increasing prevalence of "sound-aware" environments (e.g. voice-activated smart homes). SComp Artifacts created for a sound-aware environmental condition presupposes that the user can (1) speak to their device and (2) hear the device respond. This, of course, is blatantly inaccessible to deaf and hard of hearing users and users with dysarthria [7–9]. Should this mean voice-activation is axed for its inherent lack of universal accessibility? No. Rather, this limitation should be on the radar of SComp design engineers ("design engineers" [10, 11] is the term we use to refer to practitioners in the SComp field hereafter) as a limitation with ethical import. These two examples in no way represent an exhaustive list of examples of SComp's ethical gray zones, but rather highlight the types of concerns that fall in the purview of this research.

Just because there are many significant unanswered and critical questions around in design engineering does not mean this is a un-researched domain. Ethics as it relates to technology, is becoming increasingly mainstream. This general movement towards the centralizing of ethics is signaled by an increasing prevalence within legislation and governance. Notably, in Europe, the General Data Protection Regulation (GDPR) is indication that there is growing awareness of the significant consequences of ethical impact going un-examined and un-regulated [12]. Researchers are especially concerned with examining and proposing frameworks where outcomes of technological artifacts (especially those that involve Auto/AI) are hard or impossible to predict [13, 14]. Given this glaring issue of unpredictability, chains of responsibility becoming a critical element of technological artifacts with changing outcomes is an emerging area of research [15]. Researching design methods for integrating ethics (and their limitations) in the design engineering process is not a small task [16–18]—and there is no guarantee that ethical frameworks created for one domain will be well-suited to another. Therefore, explicit ethical methods for the design and development of SComp are needed lest we use outdated tools which end in potentially negative (unintended) consequences.

Our guiding research inquiry is, *whether and how are ethics procedurally integrated into the creation of Spatial Computing artifacts*. Based on our research findings, we propose a framework for SComp design engineers to systematically consider ethics by highlighting the centricity of synthesis and underlining the opportunity for iteration (see Fig. 4).

Artifact Type	Examples
Virtual Reality (VR)	Facebook's Oculus, Sony's Playstation VR
Augmented Reality (AR)	Google Glass, Facebook's Aria
Mixed Reality (MR)	Magic Leap 1 and Microsoft's HoloLens
Ambient Intelligence (AmI)	Google Home, Amazon Alexa, Nest Thermostat, Philips Hue, Tesla Autopilot

TABLE 1. Types of Spatial Computing (SComp) artifacts.

2 RELATED WORK

This paper relies on knowledge from three domains: Spatial Computing (Sec. 2.1), Autonomous Processes (Sec. 2.2), and Ethics (Sec. 2.3). In this section, we introduce terminology significant to each of the three domains. To standardize the domain-specific lexicon for design engineers working in this field, we also identify commonly (and possibly incorrectly) used terms amongst SComp professionals (see Table 2)[2]. Because of the many terms used interchangeably in this field, and to support precision, we offer a new working definition of SComp adapting and integrating existing definitions [21–24]:

2.1 Spatial Computing

We define Spatial Computing (SComp) as computing where interaction with a machine works by the machine (1) *understanding* the physical world and the biological, virtual, and mechanical subjects that move through it; (2) *knowing* and (3) *communicating* the subjects' (selected) relations to places in that world—and the subjects' quantifiable experiences within it; and (4) *navigating* through those places (whilst leveraging other artifacts therein).

SComp creates immersive, digitally-augmented experiences that rely on the communication of a user's location in space and uniquely identifying details about or from their person (movement, voice, other biometrics) to be realized. Tangible outcomes of SComp include Extended Reality and Ambient Intelligence.

[CB:

]*Extended Reality (XR)* is the umbrella term given to the combination of real and virtual environments generated by wearable technology, and encompasses all related human-machine interactions [25]. XR comprises Virtual Reality, Augmented Reality, and Mixed Reality [26, 27]. *Virtual Reality (VR)* is a digital environment that completely immerses a user's visual fields and partially immerses a user's audio and tactile fields. Faecebook's Occulus

[2]Ubiquitous Computing (UbiComp), Pervasive Computing, and Spatial Computing are often used interchangeably. UbiComp is when computing is found everywhere; Pervasive Computing is when computing is diffused through everywhere [19]. Spatial-, mobile-, laptop-, and tablet- computing all fall under UbiComp. [20].

and Sony's Playstation VR are commercial examples. *Augmented Reality (AR)* is the paradigm where the real world is overlaid with digital content (through some kind of physical mediator). Google Glass and Facebook's Aria are commercial and research examples, respectively. *Mixed Reality (MR)* is when content overlaid on the physical environment, and objects in the physical environment, can also interact with the digital world (through some kind of physical mediator) [28]. Magic Leap 1 and Microsoft's Hololens are commercial examples. *Ambient Intelligence (AmI)* is when the real physical environment itself becomes the interface through which users (un-)intentionally interact with (increasingly invisible) computing. [21, 29, 30]. Amazon Go, Google Home, Amazon Alexa, Nest Thermostat, Philips Hue, Tesla Autopilot are all commercial examples (see Table 1).

At first glance, it might seem odd to house XR and AmI in the same field of computing. While XR artifacts have obvious hardware components the user has to contend with (i.e. different kinds of screens: headsets, glasses, phones, and tablets). AmI artifacts, on the other hand, are often much less hardware-heavy in so far as how the user interacts with them. However, the underlying motivation of the domains are the same. Our research found practitioners work across these domains more than the apparent difference between commercial products would suggest (i.e. the commercial product divisions may suggest a greater disconnect between practitioners then there is).

Ultimately, all of the artifact types of SComp explore how to centralize the human user as the main interface whilst overlaying different digitally-augmented and spatially-contextual experiences. Because of the centrality of the user in SComp, Human-Computer Interaction (HCI) is a field from which much relevant knowledge can be found. In the creation of our proposed framework, we drew on Zimmerman et al.'s HCI model [31] which visualizes interaction pathways amongst "Interaction Design Researchers" and "HCI Researchers." Using the case of a complex smart home scenario, they show how HCI artifacts are the result of integrating theoretical knowledge with technical opportunities across multiple research domains. They highlight the significance of cyclical ideation, iteration, and critique of prototypes as a necessary part of ensuring HCI practitioners "make the right thing" [31, p. 5]. Our research identified a similar trend for which we a propose new framework in Sec. 5, the Framework for Ethical Spatial Computing Design Engineering (Fig. 4) .

2.2 Autonomous Processes

Spatial Computing relies on a combination of both Automation and Artificial Intelligence (AI). While in principle there can be exclusively automated SComp artifacts, mostly, SComp artifacts are the result of an overlap between the two technologies. Demystifying the extent to which SComp artifacts are actually "intelligent" or simply "automated" is critical to a correct understanding of the field [32]. *Automation* is the act of using machines to perform tasks humans used to do, and increasingly, tasks that humans would be unable to do [33]. *Artificial Intelligence (AI)* comprises two main categories, Weak AI and Strong AI [34]. *Weak AI*, aka *Artificial Narrow Intelligence (ANI)*, is machine intelligence created to perform a single task. This is the AI already around us, includes SComp use cases like smart lights turning off when you leave the house and self-driving cars stopping when a ball rolls into the street. *Strong AI*, aka *Artificial General Intelligence (AGI),* is machine "intelligence" that is in line with general human intelligence. This kind of AI does not yet exist, but can be seen in media speculations like the humanoid robot, Ava, in the film *Ex Machina* [35, 36]. Some argue there is also a third category, Artificial Superintelligence, where machine "intelligence" categorically exceeds human intelligence in "virtually all domains" [37]. In this document, any reference to AI is a specific and exclusive reference to ANI. When discussing Autonomous processes and AI, a gradient of "intelligence" emerges [38–40], we refer to this as Auto/AI. Most of the research on these gradients between varying levels of Auto/AI is, however, in the field of business and manufacturing [39, 41, 42]. We therefore propose a new gradient for the categorization of intelligence in SComp artifacts in Sec. 6.

2.3 Ethics

Fundamentally, SComp only works with the support of sensors automatically gathering data from users, often without their explicit consent. This raises significant ethical questions, to which the designer must be not only sensitive, but also, well-educated in. While we focus on taking an exogenous position on applied ethics, there must be explicit fail-safes for mediating the potential in any design engineering artifact to be technologically determinant un-/intentionally. This is where a comfort with theoretical or normative ethics is important for design engineers. *Theoretical and Normative Ethics* is an analytic or philosophical approach to examining ethics [43]. In this way of examining ethics, the very nature of design is questioned, e.g., *"do designed artifacts inherently influence human actions?"*, and if so, *"is it immoral to influence human action?" Applied Ethics* is the application of moral considerations in practice. *Ethics by Other Means*, an applied ethics theory, assumes designers aim to influence human behavior by explicitly mediating human experience with the artifacts they create [44]. *Technological Determinism* says that each individual designer intentionally imparts values in artifacts [44, 45]. Whereas, to hold an *"exogenous position"* (as we do) in ethics is to say that society influences how humans are influenced by technology, including the way they choose to use a given technological artifact [46]. Finally, *Humanistic Intelligence (HI)* [47], *Postcyborg Ethics* [48, 49], and *Prophetic Technorealism* [48] all offer ethical frames specifically addressed at how to respond critically to technologies that augment our nature as humans, which SComp does, and centralize the importance of accountability "from both innovators and the sociopolitical struc-

Role	Experience (years)	Company	SComp Type	Terms used
(0) Founder	10+	Startup	VR, AR	*N/A*
(1) Senior Designer	5+	Major Tech	VR, AR, MR, AmI, Auto/AI	*Spatial Computing (SComp), Pervasive Computing, Immersive Computing, Ubiquitous Computing (UbiComp), Ambient Intelligence, Architectural Technology.*
(2) Research Director	10+	Startup	VR, MR	*Spatial Computing (SComp), Immersive Computing*
(3) Head of Design	15+	Major Tech	MR, AmI, Auto/AI	*Spatial Computing (SComp),Internet of things (IoT) or Artificially Intelligent Internet of Things (AIoT), Ambient Intelligence, Ambient Computing*, Persistent Computing*, Persistent Ambient Computing*, Spatial Intelligence**
(4) Head of Design	25+	Major Tech	AR, MR, AmI, Auto/AI	*Spatial Computing (SComp), Immersive Computing, Ambient Intelligence, Architectural Technology, Spatial-Related Computing*, Spatially-Oriented Computing*, Contextual Computing**

TABLE 2. Expertise and Practice Domain of Participants (*indicates spoken by participant during interviews)

tures" [48, p. 290].

3 METHOD

Our research was geared towards understanding when, if, and how ethics is considered and integrated in the SComp design engineering process. We sought to unearth a framework which could support teams responsible for design engineering SComp artifacts in formalizing their design engineering processes within industry, especially. Given the implications of SComp having unforeseen ethical consequences because of Auto/AI, approaching the research in this way allowed us to understand how ethics remain high-valued and centralized in the design engineering of SComp artifacts.

We followed a Sequential Mixed Methods Procedure comprising two components, a survey and an structured interview. This was proceeded by a pre-test which comprised a semi-structured interview. The Sequential Mixed Methods Procedure was conducted with four participants who filled out the survey before doing the interview in all but one case, when Participant 4 answered the survey after the interview.

All participants are decision-making SComp professionals working as designers, engineers, and (intra-organizational) design engineering consultants (see Table 2). Three of the participants work for major technology corporations producing SComp artifacts. The other two work at startups; one is software-focused and works with major consumer product brands to create bespoke XR e-commerce experiences, the other is hardware-focused and works with SComp-producing major technology corporations. Together they have a combined working experience of 73 years, or an average of 14.6 years. Because of the nascence of this field, we were only able to interview a select few experts, but hope this research can serve as a road map for further and more extensive research.

3.1 Pre-Test

We conducted informal, semi-structured, exploratory interviews focused on the topic inquiry, "what are the bottlenecks in considering ethics in the the design/development process of AR/VR/MR/AmI tech," with three industry insiders (Participants 0,1, and 3). Interviews were conducted on Zoom, lasted between 0.5 and 1.5 hours, and were recorded with hand-written notes which served as the foundation for the construction of the research design.

3.2 Survey

After the pre-test, we sent Participants 1,2,3, and 4 a 43-item survey which comprised three sections.

Section One of the survey asked for professional-demographic information on expertise-domain(s) (*"Augmented Reality (AR)," "Virtual Reality (VR), "Mixed Reality (MR)," "Ambient Intelligence (AmI)," "[related] Automated Processes or Artificial Intelligence"*) and terminology used to describe expertise-domain(s) (*"Ambient Intelligence," "Architectural Technology," "Immersive Computing," "Internet of things(IoT) or Artificially Intelligent Internet of Things (AIoT)," "Pervasive Computing," "Spatial Computing (SComp)," "Ubiquitous Computing (UbiComp)," "Other"*).

Section Two focused on five factors that participants in the pre-test considered as relevant while considering ethics in the design engineering process (*"Time," "Money/Budget," "Designating Responsibility," "Stigma," "Familiarity"*). The first three factors were presented in a two part format: (1) does factor come up? yes/no; (2) how often does the factor come up? five-point Liker scale, Always to Never. The fourth factor, "Stigma," also presented in a two part format: (1) is there a stigma towards ethics? yes/no; (2) how ethics is perceived? multi-select, Positive/Neutral/Negative).The fifth factor, "Familiarity," comprised one single question on a five-point Liker scale, Agree to Strongly

Disagree, *"How much do you agree or disagree with the following statement: 'Designers are deeply aware that their design artifacts can lead to ethical issues'?"*

Section Three inquired about types of diversity in two different situations: within the design engineering team composition, and in terms of defining who the potential users are. The diversity types were products of interviews in the pre-test (*"Age," "Culture," "(Dis)Ability," "Employment Status," "Ethnicity," "Gender," "Intro-/Extro-version," "Living Situation," "Neuro(a)typicality," "Privacy Index[3]," "Race, Religion/Spirituality," "Sexuality,"* and *"Socio-Economic Class"*). Participants were asked to indicate how often each particular type of diversity came up in the design engineering process on a five-point Likert scale.

3.3 Interviews

The survey was succeeded by a structured qualitative interview. Interviews were semi-formal, structured, and focused on the topic inquiry, "whether/how/when is ethics procedurally integrated into the creation of Spatial Computing artifacts?" Our goal was to understand industry best practices for integrating ethics in the SComp design engineering process and verify our assumption that considering ethics in the design engineering process led to "better" downstream outcomes. Interviews were conducted on Zoom, lasted between 0.75 and 1.5 hours, were recorded and transcribed (consent was asked for in the survey and confirmed before recording started, recording was stopped whenever a participant wanted to discuss something off the record). Thereafter, transcriptions were analyzed by two (2) coders using Grounded Theory [51]. Interview questions were clustered on the following topics: Automation/AI and design engineers, research-practice barriers, design engineering processes, ethics in the design engineering processes, comparative downstream outcomes.

4 RESULTS

Given the small sample size, we opted to present the raw data of both the surveys and interviews clustered together based on salient Grounded Theory [51] codes produced in the data analysis of interviews. The raw data of the surveys is presented as distributions of responses; while in the case of the interviews, the raw data is presented as quotes.

We also present the processed and coded interview data in Table 3. Codes were decided on by two (2) reviewers using the Grounded Theory Methodology to analyze the transcriptions of the recorded interviews. The reviewers are experienced in design research on processes, methodology, theory, and Human-Computer Interaction (HCI). They independently coded each paragraph of the transcripts. Codes were compared and when consensus wasn't initially achieved, discussion and review of data followed until raters reached an acceptable inter-rater reliability (IRR) score of 0.77 (see Table 3 for coding examples, descriptions, and corresponding exemplar responses).

[3] Privacy Index is a diversity type based on work by Dr. Alan Westin mentioned in interview conducted in the pre-test [50].

4.1 Spatial Computing (S)

Our literature review found overlap in terminology used to describe similar (if not the same) domain concepts. We also found an infrequent usage of the term "Spatial Computing" in academic literature, but seemingly more frequent usage within industry and media publications. The survey thus sought trends in terms used by participants (see Table 2)."Spatial Computing" was the only term used to refer to the range of artifact types we discuss in this paper (XR and AmI) by all participants. "Immersive Computing" and "Ambient Intelligence," named by three participants, came in second place. Within the context of individual interviews, there was much terminology variation, (and several additional terms were identified, see Table 2),

> *"...but **persistent ambient computing**, and especially mixed reality and augmented reality...when we have **ambient computing**...when we introduce **persistent computing**...the line over into things like ambient data collection, or persistent data processing of AI or **spatial computing**..."* [Participant 3]

> *...I can talk a little bit about the **immersive computing** in [project name redacted]...if you're talking about **spatial-related computing**...and **contextual computing**...if you limit to **the spatial-oriented in a specific computing area**...without a specific interface to interact in the AR and VR space, you could say that **ambient intelligence** is detected"* [Participant 4]

(S) Identity. Interviews indicated identity of self and harm to others' identities as a complexity of SComp,

> *"in the early days of chatting [you could] anonymously chat with other strangers [and] hide your identity...maybe it's part of to human nature, trying to express other sides of yourself in different environments...we probably have to become more conscious about this anonymized effect and what human behavior associated with it."* [Participant 4]

(S) Measurement. While, in the interviews, all participants noted testing as requisite in ensuring ethical outcomes, none outlined objective measures for evaluating outcomes,

> *"You want to mitigate [negative effects] as much as possible. If 2.0 percent of users [are effected negatively] compared to 0.1 percent...[do] we find that acceptable or not? [Is it] something we think we can correct?..Or is it a result of other things out of our control?...If I'm*

Code & Description	Coded Examples
Spatial Computing (S)	
(S) Identity: SComp has an effect on your performed identity of self.	*"[In] the early days of chatting...you anonymously chat with strangers...you hide your identity, and [sabotage] others...maybe [it's] part of to human nature—trying to express side[s] of yourself in different environment[s]."*
(S) Measurement: Ways of measuring and evaluating outcomes SComp use.	*"[We're] taking our best guess. But the fact that we've had very limited product cycles [makes it] very difficult to separate signal and noise from ethical considerations."*
(S) Process: The order of activities when design engineering SComp Artifacts.	*"We try to come up with a hypothesis [of the] concept or problems that we see. That requires research, [the we test in] environment, then [we try] to understand the effects [through] an ethnography study."*
(S) Research: How research is separate from practice in SComp, and the implications of that.	*"Accuracy drops in the real world. Why? Because there are massive discrepancies between training data, benchmark set, and real world operating conditions."*
(S) Vulnerability: Whether SComp is ethically more vulnerable than other artifacts.	*"Short answer, yes [SComp is more vulnerable to ethical concerns than other design artifacts.]"*
Ethics (E)	
(E) Challenges: Types of roadblocks to integrating ethics in SComp.	*"[Ethics has] introduced all sorts of hiccups...[namely,] that, it always adds more time. And we always find out stuff that we weren't prepared for."*
(E) Diversity: How diversity is considered in the creation of SComp Artifacts.	*"[It's] difficult to design a product that will work as well in Asia as [in] Western Europe. Beyond just the human factors, there's a huge...cultural mismatch."*
(E) Process: When and how ethics is an explicit part of the creation of SComp.	*"It should [not] be a checklist at the end, because you're just trying to meet that criteria vs. preemptively looking at considerations you may have not otherwise have thought of, [had you gone] through a proper design process."*
(E) Role of Company/Culture: What it is when it comes to ethics.	*"[Organizational beliefs are limiting in terms of prioritizing ethical considerations] not necessarily out of malice, it's just sort of out of inertia."*
(E) Role of Designer: What it is when it comes to ethics.	*"If I don't spend this privilege, [what] am I doing with it. [because] it's not okay to put [the] burden on people from marginalized communities [alone] to carry all of the work [towards ethical outcomes]."*

TABLE 3. Qualitative codes established from the interviews and examples of each from the interview transcripts.

> *failing 2.0 percent of people, that's significant to me, other humans may say, that's fine...so [it's] subjective."* [Participant 1]

(S) Research. Distinctions between types of research and their relative function in industry were noted,

> *"I want to make a clear distinction between user research, or Human Centered Design research, versus research...like research science, theoretical research, academic research, more broadly, literature review, landscape analysis. There's obviously tons of overlap...[In] the fundamental research space, novelty is the primary driving incentive. And therefore from the jump, you have huge discrepancies with practice."* [Participant 3]

(S) Process. While all participants indicated their teams follow processes to produce and test SComp artifacts, no processes unique to SComp were discussed,

> *"It is kind of a general UX approach: understanding user flow, who the user is, pain points, and all that."* [Participant 4]

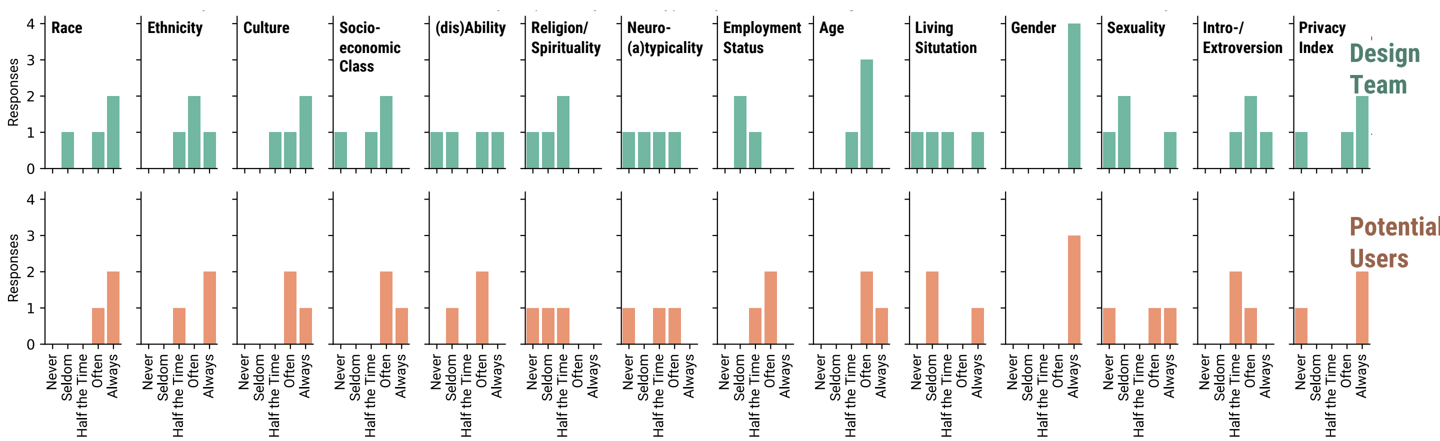

FIGURE 1. Participants' answers to: *"Select the option that reflects the frequency with which considering that particular type of diversity occurs."*

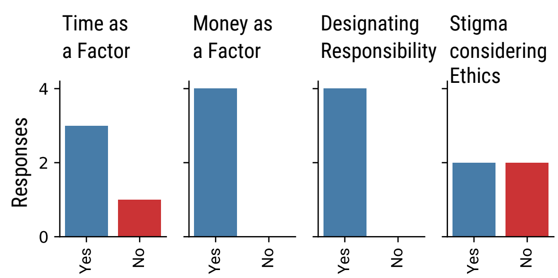

FIGURE 2. Participants' perceptions on whether or not certain factors "come up" in the consideration of ethics in design engineering.

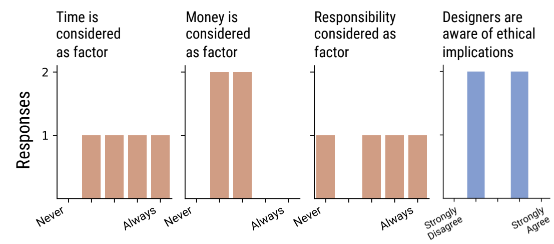

FIGURE 3. Participants' perceptions on the extent to which certain factors "come up" in the consideration of ethics in design engineering, and their opinion on whether or not designers are aware of ethical considerations.

(S) Vulnerability. All participants indicated SComp is more vulnerable to "ethical mishaps" than other design engineering artifacts,

> *"I think [yes] but not necessarily because of the core of the industry. I think ethical questions are driven by...second and third order questions that aren't being well considered yet [especially] consent...what I do to someone in the physical world is different than what I do to someone in a digital world."* [Participant 2]

> *"Different types of emerging spatial intelligences [allow one to] unintentionally...wiretap and surveil people, but [people act like] 'oh, it's just disperse point clouds.' [And I'm] like, 'Uh huh. Basically you've just created biometric data.' So how is that not something that we need to be cognizant of?"* [Participant 3]

4.2 Ethics (E)

(E) Challenges. The survey (see Fig. 1) found that Money and Designating Responsibility "comes up" for all participants. For Money, answers regarding how often there is enough money "to consider ethics" was split evenly between "seldom" and "half of the time." For Designating Responsibility, answers regarding responsibility being designated were distributed equally across "never," "half of the time," "often," and "always." Time "comes up" for most participants, and answers were distributed equally across "seldom," "half of the time," "often," and "always." Interviews expanded on these findings:

> *"It comes down to money. Some would say...it's a luxury to look at ethics, [on the other hand ethics could] actually prove some bad stuff...[But, if it does show something bad, we can't have] identified [that and not] say anything, that's unethical."* [Participant 1]

Finally, the survey found participants were split down the middle in terms of whether Stigma 'comes up," and in terms of how ethics is perceived were distributed equally "Positive, "Neutral, "Negative" (where one participant answered all three, and the rest were equally divided). Interviews expanded on these findings:

> *"[Ethics] can be perceived negatively, because it can*

impede innovation at times, or people perceive it that way...Positive [perception] is...especially on the consumer side, [centers on] privacy...[and] on the creator side, [ethics is] great, because you feel good that you are creating something that makes people happy." [Participant 1]

(E) Diversity. The diversity type section of the survey(see Fig. 1) showed three primary things. First, Gender was the only diversity type that was considered with the same frequency in both team composition and potential users, namely as, "always-considered."

"We [try to be] conscious about showing...different types of people because we sell worldwide...but still, we're not quite there ...[so we ask ourselves], 'what are the ways that we can make [our illustrations of] people more inclusive [so users are] not left out?' And we don't have a right answer yet." [Participant 4]

Second, diversity types are considered more than half the time. In design teams, that is the case for 55.76% of diversity types; and in potential users, for 68.29% of diversity types.

"I love the split you provoke between design team and end user, that itself is really appreciated. Because...if we ourselves are not the reflection of the diversity and the change that we seek to bring about in the world, then who are we to bring about that change?...I strive to continuously be building a more diverse team...[The challenge is in] continuing to feel like we can act with confidence...even though we don't represent every, every facet of the wonderful diversity range that you have in your in your survey." [Participant 3]

Finally, participants also highlighted three diversity types missing from our survey: Language, Human Factors, and Situational Limitations (e.g. *"mother holding a baby [therefore] only has one hand at that moment"*).

(E) Process. In the interviews, participants indicated ethics should be integrated early and often in the design engineering process of SComp artifacts to mitigate unethical outcomes,

"it should happen at the beginning...and I've been on both sides of that process, where it's the very first thing that we're looking at...then a lot of other times it comes at the end, it's a checklist saying 'okay, does your design meet this criteria?' Check, check, check, or not?" [Participant 1]

"The earlier you can bring these sorts of ethical questions in and make conscious decisions...intelligently...and with eyes open make good questions, that, to me, would would be a very helpful tool set." [Participant 2]

(E) Role of Company/Culture. Participants addressed ways in which culture effected product choices,

"When and why we invest in something as a product...the starting point is because there are people in very, very significant positions of monetary or budget decision making, saying, 'I want that.' " [Participant 1]

(E) Role of Designer. Participants were asked to rate their agreement with the following statement, *"Designers are deeply aware that their design artifacts can lead to ethical issues,"* Answers were split evenly between "Agree" and "Disagree."

"Junior designers defend [their] designs [too] much...I see that in in some of the product managers too...their assumptions are incorrect, or based on 'the research.' " [Participant 4]

(E) Challenges. There was agreement that considering ethics always revealed something, sometimes problematic, but not always. When problematic discoveries emerge, however, so too does liability (see Sec. 6.2 for more discussion).

"It's not that we [are guaranteed to find ethical issues], it's that [if we do,] we're liable [and] have to do something about it. If you don't investigate it, you can't diagnose it. If you can't diagnose it, you can't ameliorate it." [Participant 3]

5 FRAMEWORK DEVELOPMENT

The lack of best-practice methodologies for ensuring design engineers remain cognizant of (and concerned with) the impacts of their Spatial Computing artifacts, creates a higher risk of unknown negative impacts to (primarily) human subjects[4]. To combat the lack of methodologies for supporting the creation of new SComp design methods, we propose a framework (see further discussion in Sec. 6.1). The framework is informed by qualitative analysis of semi-structured interviews conducted with expert practitioners in the field of SComp in decision-making roles at their organisations. The Framework for Ethical Spatial Computing Design Engineering (Fig. 4) is aimed at supporting design engineers in understanding their role in creating SComp Artifacts. It maps the journey of contextualizing, researching, creating, implementing/testing, and iterating on SComp Artifacts; the stages of creating ethical outcomes in SComp highlighted by industry professionals in our research.

[4]As we describe in our definition of SComp (Sec. 2.1), SComp works by tracking not only human users, but also other biological, virtual, and mechanical users/subjects. Prioritization between them will become of increasing importance.

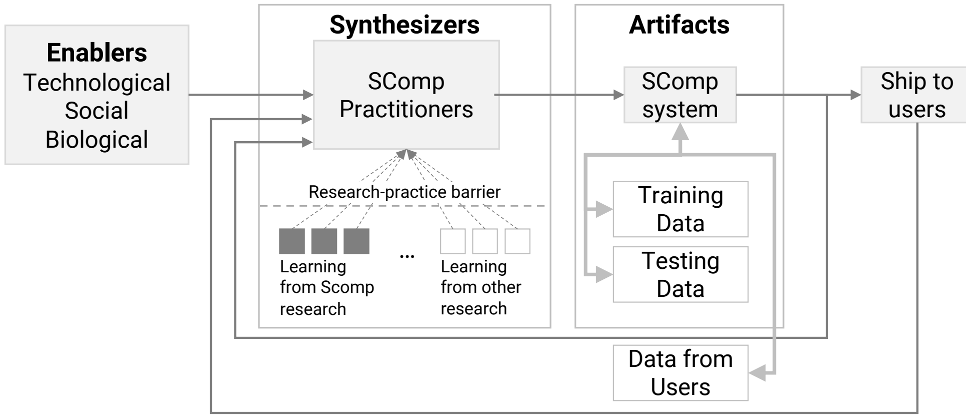

FIGURE 4. Framework for Ethical Spatial Computing Design Engineering. The Framework is based on our research findings and borrows from Zimmerman et al.'s model of the Research-Practice Barrier in the field of Human Computer Interaction (HCI).

5.1 SComp Design Engineering Framework

The framework we propose emerges from the data collected which underscored that ethical SComp artifacts follow a three-phase process. Phase one highlights the importance of beginning the design of an SComp artifact with a rich understanding of what types of opportunities exist, which we name "Enablers." This is followed by a multidisciplinary research phase based on Zimmerman et al.'s work [31] comprising of many types of "researchers" and "practitioners," which we name "Synthesizers" [5]. Finally, the last section of the framework, "SComp Artifacts," impresses the complicated nature of SComp Artifacts as both tangible and intangible. The framework also highlights that the result of creating an SComp Artifact can lead to three outcomes: (1) informing the enablers, (2) returning to the act of synthesis (aka adjusting based on testing), and/or (3) shipping to the user. Additionally, the framework highlights the three kinds of data that emerge from varying resolutions of an SComp Artifact: (1) training data, (2) testing data, (3) data from end users.

Enablers. Seen on the left side of Fig. 4 in detail, Enablers are the factors that coalesce to allow for SComp artifacts to exist. Enablers come in three categories: (1) Technological, (2) Social, and (3) Biological. As arriving at the moment of design engineering is—under ideal conditions—itself an act of synthesis, it is critical that design engineers of SComp have a wide-ranging familiarity with the enablers of SComp both within and beyond the myopic silo of their own discipline.

1. **Technological Enablers** include sensors/actuators, computing power, 5G / network speed. Mechanical Enablers are the hardware, software, and technical infrastructure that allows for Social Computing to be realized.
2. **Social Enablers** include: societal readiness, social science including environmental/social psychology. Social Enablers are possibilities rooted in societal, social/psychological, and sociological domains.
3. **Biological Enablers** include neuro/cognitive science, human physiology. Biological Enablers are characterised by neuroscientists and cognitive scientists as both opportunities and challenges for the brain and body.

Synthesizers. Understanding how to employ enablers is the work of—for now—human synthesis. The center of Figure 4 highlights the complex and interactive nature of departing from the realm of what-is-possible given the Enablers that exist (as synthesized by researchers, domain researchers, and domain practitioners), into the realm of what-will-actually-be-designed given the fact that those Enablers exist, as they have been synthesized by the design engineer in the form of SComp Artifacts. We based this section on Zimmerman et al.'s work [31], and would like to highlight that one can understand the entirety of the left side of their model to be found below our Synthesizer section.

SComp Artifacts. This section of the framework highlights that SComp artifacts are both tangible (in so far as they interface with the user explicitly through interfaces and hardware) and intangible (in so far as they are also algorithmic data-collecting, processing, and outputting artifacts). Distinguishing between the different types of data helps to address the gap between research conditions and real world conditions that was addressed by our participants.

1. **Training Data**—Training data is the first kind of data that is used to teach the SComp Artifact, and is the first touch point for ethical consideration when one should as questions like: *what data am I using to train my model and does it reflect the*

[5] "Synthesizers" visualization adapted from Figure 4, "Research through design within HCI" [31].

vectors of diverse accessibility important to our end users?

2. **Testing Data**—Testing data is what emerges once the Auto/AI algorithms are tested by the developers (alpha tests) and end users (beta testing). Design engineers should aim to test in as life-like conditions as possible and consider such questions as: *how can we use testing data to build-in self-perpetuating checks and balances based on what we have seen so far?*
3. **Data from Users—**This kind of data is the most precarious, as (1) it is data from real people who (likely) know next to nothing about how the technology is working, and (2) will produce vast amounts of data over the course of its use. When considering this kind of data, questions to be considered can include: *What data will be collected?*, *How will the user be informed?*, and *How will we use this information to continually refine the product towards making it ethical?*

6 DISCUSSION

Our research with domain experts leads us to advocate for integral "in-action" socio-ethics starting at the beginning and continuing through the entirety of the Spatial Computing design engineering process [43, 45, 52]. We see any ethical processes in the domain of SComp as needing to be highly practicable, responsive, and situated in the Third Paradigm Human Computer Interaction (HCI) [53] where design engineers are active stakeholders in the ethics evaluation and design engineering is understood as explicitly embodied and mediated by human meaning-making. We reject ethical processes that accept the design engineer to be a wholly neutral arbiter of a highly rational or mechanical process for "printing" "ethical" outcomes. People, including design engineers, are naturally fallible, and the ethical processes designed to help them make morally-just artifacts, should be cognizant of the limitations of remaining ethical throughout the entirety of a design engineering project. In addition to introducing the Framework for Ethical Spatial Computing Design Engineering as a tool for creating new design engineering methods for SComp, this paper also functions as a call to action: should we not promptly create new methodologies, we run the risk of seeing a proliferation of problematic ethical outcomes of SComp.

6.1 Unintended Unethical Outcomes

As Spatial Computing Artifacts become increasingly smaller, and invisibly embedded in the physical environment, the only things that will remain visible are user interfaces [29]—which themselves have a range of tangibility, from the ultra-tangible Virtual Reality (VR) headset to the relatively intangible invisibility-in-computing that Ambient Intelligence (AmI) strives for. This, most of the participants agreed, makes them more vulnerable to "ethical mishaps." But what (or who) is at fault should outcomes of the design engineering of SComp lead to the perpetuation of oppressive biases (e.g., the SComp not recognizing a black person, or calling a transgender person by the incorrect pronoun, or not opening the elevator doors for someone in a wheelchair)?

The important question is not only "what are the unintended outcomes that might emerge?" but also, "where, or with whom, does the fault lay?" Our research found that "designating responsibility" always came up in the design engineering—but when asked if that responsibility was designated things changed with only one participant saying, "always." We did not ask or discuss, however, where that responsibility was designated. One might suggest deferring responsibility to the umbrella organization that employs a design engineer, but looked at another way, this could instead obfuscate the design engineer's sense of personal responsibility. Regardless, unless design engineers and organizations agree on a custody of ethical responsibility—as the saying goes, "no-one ever sued a methodologist for a design that didn't work out" [54, p. 170]—there is a high chance that ethical mishaps will continue. SComp design engineers must be trained to formally avoid unethical outcomes. To do this, morality must be impressed. Our research showed that what is seen as ethical and what isn't is still highly subjective in organizations, and the methods for evaluating ethical issues are "subjective" with one interviewee likening it to, "licking the stamp and seeing if it sticks...[or the] spaghetti approach." And while our participants were split 50/50 (2 agreed, 2 disagreed) on whether or not "designers are deeply aware that their design artifacts can lead to ethical issues," none went so far as to "strongly agree" which given the import of unethical consequence, seems critical.

We argue SComp design engineers *must* understand there is an ethical fault when negative unexpected outcomes emerge or when use reveals bias whether they be racist, ableist, or privacy issues, i.e., outcomes that lead to exclusion, alienation, repression, or oppression. Notably, we were not able to find examples of unethical outcomes teams discovered in research or after shipping, *"I have a very specific example that, but I can't talk about it,"* or *"I'm pretty sure I can talk about this. One second, I'm trying to think about the right abstraction...[essentially] the thing we found is really dark."* While this classified nature of company insights is not unique to SComp, this, in addition to the findings that money and time seem to limit teams from pursuing explorations into possible unethical outcomes, seem to be important systemic limitations. Designating responsibility, creating methodological evaluation and comprehensive standards for what constitutes harm, and delivering organizational support seem to be important factors in centralizing of ethics in SComp creating organizations.

When design engineers are not well-versed in the nuanced, inevitable, and complex fact that their artifacts are self-adjusting systems—as noted by participants be the case, especially amongst young practitioners who either make assumptions or do research incorrectly and accidentally validate their assumptions—they run the risk of creating and perpetuating ethical problems. Similarly,

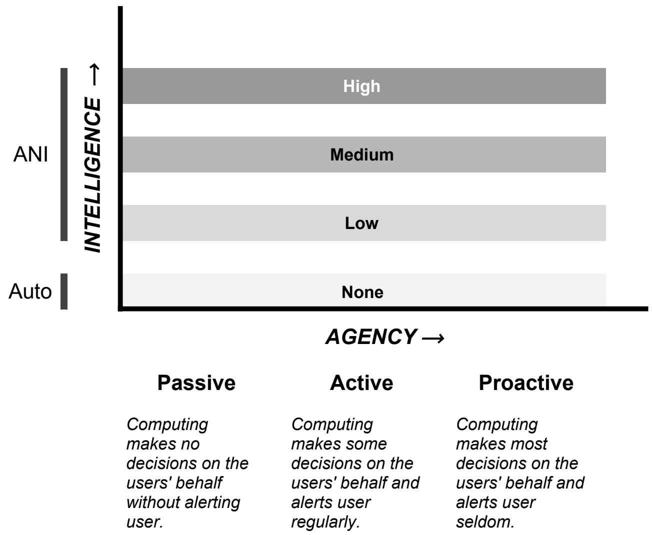

FIGURE 5. Gradients of Intelligence and Agency in SComp Artifacts.

when organizations do not devote resources (be they monetary, temporal, or cultural) to systematically seeking ethical outcomes, idealism is in place to become the main driver behind creating artifacts which do not oppress users. Or as one participant said, "there's a limit to idealism in any space. ...hopes and aspirations can only exist in a very narrow range...hopes and dreams that your product will change the world, not necessarily that you are going to change your products for the world." It seems to follow that an organization creating SComp artifacts must both (1) create artifacts that add to users' experience, but also (2) make sure those artifacts are adapted to users' experience.

Additionally, though not mentioned by participants, important research needs to be done in so far as prioritization of subjects. SComp is from preceding design engineering fields in that it is designed for not only human- but also non-human subjects. Other biological subjects such as animals or ecosystems could be affected by SComp, as can mechanical subjects such as robots. While there is a relatively reasonable assumption that human subjects will be prioritized in SComp designs, SComp is complex in that there might be scenarios where other biological or mechanical subjects might be intentionally or unintentionally prioritized over certain groups of humans by a design. We thus need to be vigilant and concerned that prioritization aligns with long-term ethical values.

6.2 Intelligence & Agency of SComp Artifacts

The Framework for Ethical Spatial Computing Design Engineering, formulated based on the insights from our research, extends on Zimmerman et al.'s work [31] and highlights SComp Artifacts are both tangible and intangible in that the essential nature of a SComp artifact is that of a system, not an artifact in the historical "product" sense [1]. Whether automated and made to feel artificially intelligent, or actually artificially intelligent to some extent, the SComp artifact is complex and ever-changing once use begins.

The three possible steps after the SComp Artifact stage, highlight how the fidelity of the SComp Artifact is variable (anything from a prototype to a market-ready product can be a SComp artifact). Our participants impressed upon us the importance of "prototyping," "testing," and "iterating"—therefore, the three possible steps after the SComp Artifact stage highlight different depths of returning to re-conceive of the artifact based on learnings in the SComp Artifact stage. It is important to notice that "shipping" is not an exit from the SComp Design Engineering Framework, but rather, an opportunity to evaluate anew. Design engineers should be mindful of which stage in the framework they hope their insights from shipping lead their teams to return back to. The framework also highlights that SComp artifacts comprise and produce three distinct types of data, and distinguishing between how to deal with the different data types is important.

SComp Artifacts are reliant on Auto/AI, which is to say, SComp Artifacts have varying levels of machine intelligence and agency. It is important that while SComp design engineers learn to defer increasingly to the capacity of Automation and AI, they are also trained to confront a likely confirmation bias in designing that could emerge when designing Auto/AI: that the human is hierarchically in deference to the Auto/AI. If they don't, the design engineering process becomes vulnerable Auto/AI processes disappearing from design engineers' field of awareness or understanding. This only serves to further obfuscate the importance of the end user [55].

We therefore propose further research into an intelligence/agency axis (Fig. 5). We intend our proposed axis to be able to help formalize an understanding of two main themes that seem to confound and confuse poorly understood elements of the burgeoning field of SComp: how "intelligent" is an artifact (in an artificially intelligent sense) and how much agency does the artifact have. Agency was a particular concern of participants. Mostly agency was discussed in terms of the invisibility of the technology powering the tangible part of SComp artifacts to end-users. As Participant 1 put it, *"[VR is] easier to control, because you're still looking at a singular screen...you don't have as many variables...and as many inputs, compared to ...IoT sensors...[which makes the user] more passive. When you look at those types of cultural Artifacts, the more passive ones can be a lot more dangerous, because you're not aware...[or a computer camera] when you start a meeting [and you're undressed you say to yourself,] 'I['m] naked right now, I'm not going to turn on the camera.'...Issues of having an active user versus passive [are] substantial...[Or a checkout-less smart store which is] measuring where you're at [but] now, it is more of an active position, because you're entering that space and you know...that you are now being observed...And how that's communicated to someone, that's* *also incredibly important...I think it comes down to the active or passive, and notifying the users [that is] incredibly important."*

Another way of supporting design engineers in avoiding deference to Auto/AI as inherently superior, is to ensure design engineers have some theoretical grounding in the difference of problem finding and problem solving as two (often co-evolving) ways of approaching design [56]. Creating for Auto/AI means the objective is not to design engineering solutions, which is the work of the Auto/AI engine, but rather to design engineer "problem-solving loops" [57]. The unique opportunity when designing Auto/AI is in framing the problem that Auto/AI can solve and/or address (and considering what kinds of inputs that Auto/AI will rely on to produce its outcomes at all three data stages from the SComp Design Engineering Framework). Much more research is needed on the axis of agency and intelligence that we propose, especially on how it helps practitioners in the field conceptualize their Artifacts and communicate the levels of intelligence and agency of an artifact to a variety of stakeholders. The axis pulls from two domains. The y-axis of intelligence borrows heavily from literature on intelligence in business and product manufacturing, which uses the terms Robotic Process Automation (RPA) [41], Complex Process Automation (CPA) [39], and Intelligent Process Automation (IPA) [39, 42] to describe increasing levels of "intelligence" in autonomous processes. On the x-axis of agency, we borrow from literature in mixed-initiative interaction and suggest that "active" can be understood as closely related to the concept of mixed-initiative interaction [58].

6.3 Implications for Practice

Given that participants indicated that there was a general tendency and preference to address ethics early on (and often throughout) the design engineering process, there are two approaches in practice to addressing ethics in the design engineering of SComp Artifacts. Strategy one is to address ethics *after* a technology exists. Strategy two is to address ethics *before* the technology exists. The benefit of addressing ethics once the technology exists is that one can learn from both observable interactions and historical data. The limitation is that once the technology exists, biases may be too entrenched at the point of the analysis: perhaps too many (monetary or temporal) resources have been invested, or society already holds limiting beliefs that analysis can not look beyond. Likely, the furthest outcome of analysis that occurs once the technology exists is that modification recommendations can be made, but the whole premise is unlikely to get completely re-evaluated or discarded. On the other side, addressing ethics before the technology exists, what are called "emerging technologies" [43], while only speculative, presents the opportunity for ethical observations to be potentially independent of bias. The limitation here is that all examinations of ethics are speculative. The main concern is that some might find time and resource investments necessary to exploring ultimately speculative scenarios to be a tall ask. While others might strongly see this as an ultimately cost-and-time saving endeavor, in the long run. Strategy one might be thought of as defensive, while strategy two can be seen as offensive.

What emerged from our research, was the concept of "trade offs", as one interviewee remarked, *"The second you bring [accessibility] into your design space, trade-offs need to be made... those trade-offs can be fairly brutal fairly quickly. From a technical perspective, I'd love to give up the larger business context behind things...but sadly, capitalism doesn't allow me. So I have to make sacrifices I have to make these sorts of trades. The frameworks in which I make those trades are not very well thought out, often. Sometimes it's just sort of licking the stamp and seeing if it sticks or whatever spaghetti approach."* This is not a unique concern to ethics in a SComp context, it is true across domains in ethics. Friedman and Kahn's [59] framework for ethical relationship pairs (pg. 1244–1245) could be easily adapted to highlight the (hypothetical) ethical value considerations unique to SComp:

- An SComp artifact is good for usability and independently good for human values with ethical import. This relationship is exemplified by Artifacts that, for example, prioritize honesty and attention equally. Imagine arriving at a smart door that which opens only for faces it recognizes for the first time and being presented clear and concise terms and conditions that are readable within seconds.
- An SComp artifact is good for usability, but at the expense of human values with ethical import. This relationship is exemplified by Artifacts that, for example, prioritize efficiency over privacy. Imagine that same smart door, but now, it saves bio-metric data without the consent or awareness of visitors.
- An SComp artifact is good for human values with ethical import, but at the expense of usability. This relationship is exemplified by Artifacts that, for example, prioritize privacy over access. Imagine that same smart door, which you have visited many times and you have indicated you would always like that it ask for your consent for continued storage of your data, only now it won't open until you agree again, but there is an emergency and you need to get through that door, now.
- An SComp artifact good for usability is necessary to support human values with ethical import. This relationship is exemplified by Artifacts that, for example, are so easy to use that they are used as intended, without devising workarounds that in turn undermine security, privacy, accuracy, etc. Imagine you are back at that smart door in an emergency, but now it knows that it is an emergency, so it lets you in immediately and alerts appropriate authorities/neighbors/trusted contacts so that there is either backup for the emergency or a way of ensuring you have not entered without going through the necessary steps.

There are many other methods and frames for addressing ethics in computing and design [60]. It was clear that participants and their teams were re-tooling design methods that involved research, creation, and testing in their conception and creation of SComp artifacts—however specific ethics-evaluation frameworks were not noted specifically[6]. In the background section we named a few salient frames for addressing ethics specifically. However, given this lack of identified systematized use in practice, we wanted to address a need for a comprehensive compendium of methods design engineers can keep in their toolboxes for centralizing ethics in their practice. Notable starting points are Value-Sensitive Design; In Action Ethics [45]; Participatory Design; Responsible (Research and) Innovation (RI and RRI, respectively); Constructive-, Real-Time-, and Participatory Technology Assessment; Ethical, Legal, and Social Impacts/Aspects Research (ELSI/ELSA); and Socio-Technical Integration Research (STIR). To make a categorical evaluation of all of these techniques and their efficacy in an SComp context is beyond the scope of this work, but doing so would be a significant contribution to the field. As Gill [52] notes, actively examining ethical considerations will help illuminate necessary new design engineering methods.

As further research is conducted to create new methods for centralizing ethics, we would like to draw special attention to research that suggests that awareness of ethics (and considering them as significant to the experience of the end-user) tapers off through a design project. In a study of design students studying cybersecurity, what was clear is that with time, while students increasingly indicated that they would make more conservative security choices personally, their designs did not reflect more conservative or "safe" cybersecurity options for their end-users [16]. Such details are significant to the creation of functional methods for considering ethics in an SComp context. Suggesting methods must not only be suited to the needs of the beginning or end for a design engineering process, but also need to be able to hold a design engineer's attention throughout the entirety of the process and throughout multiple iterations. Additionally, our survey finding made clear that there is a distinction in diversity in terms of design engineering team composition and users, and suggest that considering both should be central to any new methods.

7 CONCLUSION

In this paper we present a Framework for Ethical Spatial Computing Design Engineering to systematically consider ethics by highlighting the centricity of synthesis and underlining the opportunity for iteration. We first examine the qualitative research analysis of semi-structured interviews conducted with experts in SComp field to understand the current design process for the creation of SComp Artifacts and learn how ethics can be integrated into the development of them. The interviews indicated that:

1. Professionals working in the design engineering of SComp Artifacts find them to be more vulnerable to ethical mishaps than other types of design engineering artifacts;
2. While SComp design engineering teams follow design processes to produce and test SComp Artifacts, no processes unique to SComp were discussed (interviewees cited company culture, team culture, and the design engineers themselves as influencers of this fact);
3. Testing is necessary to mitigate negative effects of SComp Artifacts (though no clear method for evaluating outcomes was outlined by interviewees).
4. Ethics should be integrated early and often in the design engineering process of SComp Artifacts for the assurance of (more) ethical outcomes.

Grounded in the interview insights, to support the creation of new SComp design and development pathways, we propose a new framework which maps the three-phases journey consisted of (1) Enablers, (2) Synthesizers, and (3) SComp Artifacts. We trust that our work sheds light on considerations necessary to the creation of ethical Spatial Computing Artifacts.

Finally, we present the central question—paraphrased from a pre-test interview—that we hope future research in design, engineering, and HCI research systematically addresses: *"What needs to be different so that the default method for design engineering SComp Artifacts would make it difficult to do harm?"* This question highlights the importance of (1) centralizing and internalizing the import of ethics and (2) understanding the role and impact of methodological processes on design outcome. Asking and answering this question is essential to ensure the maintained vigilance of design engineers and their organizations about potential adverse consequences of creating SComp Artifacts.

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