Operationalizing Kairos: Digital-Twin Supported Participatory Action Research for Community-Driven Design

Daniel Cronan[1], Iman Fayyad[2]

[1]Washington State University, Washington/USA · dan.cronan@wsu.edu
[2]Harvard University, Massachusetts/USA · ifayyad@gsd.harvard.edu

Abstract: Landscape architecture's digital transformation is increasingly tied to collaborative, data-rich processes that blend community insights with computational modeling. We propose the integration of Kairos Moments, pivotal opportunities for timely reflection and action, into a digital twin-supported participatory design framework. In a one-year community design project in a mid-sized city in upstate New York, spatial data on heat, flood risk, walkability, and demographics were embedded in a web-based digital twin to facilitate stakeholder deliberation and iterative scenario development. The framework uses heuristic cues (based on Tversky & Kahneman's cognitive biases) to classify engagement episodes as representativeness, availability, or anchoring adjustments, which in turn flag Kairos Moments when collective decisions are most opportune. These moments serve as a bridge between real-world events and the digital twin environment, synchronizing community momentum with design interventions. Results indicate that the interactive digital twin improved transparency and allowed participants to visualize trade-offs, while the Kairos-based timing analytics enhanced stakeholder trust and foresight by aligning design actions with critical community readiness. We conclude with practical recommendations for embedding Kairos-informed, ethically grounded digital methods in participatory design practice and institutional policy.

Keywords: Digital twin, participatory action research, community support, Kairos moments

1 Introduction

Recent participatory and scenario-based approaches highlight a disciplinary shift from representational technologies toward collaborative digital infrastructures that mediate data, design, and deliberation (HOVERSTEN & SWAFFIELD 2019, IWANIEC et al. 2020). Yet despite advanced visualization and computation, digital participation often remains extractive when institutional timelines, funding cycles, or research goals eclipse community priorities. This paper responds to that challenge by introducing the concept of Kairos Moments, defined as critical windows of opportunity for reflection and action in participatory design. Such moments mark the opportune timing when interventions or decisions can have heightened impact, effectively serving as "wormholes" that tightly connect real-world community events with corresponding actions in the digital twin environment. These moments become an analytical and operational component within digital participatory workflows, ensuring that engagement happens at the most impactful times for the community. Without recognizing these Kairos opportunities, even well-intended projects risk missing key chances for building trust or achieving change, as misaligned timing can lead to lost momentum.

Drawing upon a Participatory Action Research (PAR) project addressing racial wealth disparities through urban design, we argue that Kairos can structure *when* and *how* interventions occur within digital workflows. The digital twin becomes both the site and the medium of co-creation: a shared, dynamic model where community knowledge, environmental data, and

Journal of Digital Landscape Architecture, 11-2026, pp. 950-964. © Wichmann Verlag, VDE VERLAG GMBH · Berlin · Offenbach. ISBN 978-3-87907-770-0, ISSN 2367-4253, e-ISSN 2511-624X, doi:10.14627/537770090.

design alternatives converge to support collective decision-making. We define this synthesis as Kairos-informed participatory design, a process that integrates ethics of timing, trust, and stewardship into digital landscape practice. By explicitly considering *when* to engage (and not just *how* or *what* to design), the approach foregrounds an often-overlooked dimension of equitable participation, the timing of decisions, as a key determinant of ethical and sustainable outcomes.

2 Background and Conceptual Framework

2.1 Participatory Action Research (PAR) and Design Justice

PAR has long bridged research and social transformation by positioning community members as co-creators of knowledge (KINDON et al. 2007, WALKER & LOOTS 2018). Within the built-environment disciplines, PAR's iterative inquiry-action cycle (visioning, planning, implementing, evaluating) supports design processes grounded in reciprocity and long-term stewardship. The theoretical foundations of PAR originate from Paulo Freire's critical pedagogy, which posits that those affected by oppression must be co-creators of knowledge in order to achieve liberation (FREIRE 1972). In practice, PAR shifts the focus from knowledge *extraction* to collaborative knowledge production, directly involving community partners in defining problems and solutions. Complementing PAR, Design Justice (COSTANZA-CHOCK 2020) challenges "who designs, for whom, and with what power." Embedding Design Justice principles in digital workflows helps redistribute authorship from the expert to the community and transforms digital tools from passive visualization devices into active instruments of social negotiation. Together, PAR and Design Justice provide an ethical scaffolding for our digital twin methodology, ensuring that technology-enabled design is guided by principles of equity, inclusion, and mutual learning.

2.2 Kairos Moments as Temporal Ethics

In classical rhetoric, Kairos denotes the right or opportune moment for action (RÄMÖ 2004). Applied to community design, it reframes participation as a temporal as well as procedural challenge. Ferguson et al. (2017) and Manzini (2015) note that trust and care require synchronization between institutional readiness and community momentum. We therefore define Kairos Moments as decision nodes within participatory workflows where timing and responsiveness determine ethical quality. In other words, a participatory process is not only judged by what decisions are made, but when they are made in relation to community readiness. By operationalizing Kairos through a digital twin, we convert an abstract ethical notion of timing into measurable, interactive events: for example, when data thresholds are crossed, when feedback loops close, or when stakeholder consensus suddenly emerges. Each such event provides a digital trace of how and when collaboration occurs, allowing the project team to monitor whether engagement is keeping pace with community needs. Critically, failing to act during a Kairos Moment, due to delayed action or misaligned priorities, risks a missed opportunity that can erode trust or stall progress. Identifying these moments in real time thus becomes a strategy for prompt reflection and action, aligning design decisions with the lived temporal rhythms of the community.

2.3 Digital Twins and Participatory Design

The scenario-based digital twin, a dynamic, data-linked virtual model continuously updated with real-world feedback, extends traditional GIS and visualization tools into decision-support systems for socio-ecological design (MAHMOUD et al. 2009, WILLIAMS et al. 2023). In this project, the twin functions as both analytic and pedagogical infrastructure, enabling community members to visualize how physical design interventions could influence well-being indicators such as shade coverage, ambient temperature, flood risk, and accessibility. Integrating the twin with a PAR approach transforms it into a living participatory model where each iteration reflects both data and dialogue. Rather than using the digital model merely to display outcomes, participants directly interact with it, adjusting parameters, testing scenarios, and seeing immediate feedback, thereby co-creating knowledge. This interactivity means the digital twin is not a static representation but a facilitative space where stakeholder input and quantitative analysis inform each other. By logging interactions and discussions within the twin, the system can highlight when engagement peaks or when new information significantly shifts the discourse. These capabilities set the stage for embedding Kairos Moments: the twin helps reveal when critical shifts occur and provides a medium to capitalize on them, effectively synchronizing the "virtual" design process with real-world community dynamics.

3 Methodology

3.1 Study Context

The case study was a one-year participatory design project (2022-2023) in a mid-sized city in upstate New York, examining how environmental design interventions can promote economic and social equity in historically marginalized neighborhoods. Using PAR protocols, the research team collaborated with local community organizations and municipal agencies to co-define project objectives, design criteria, and evaluation metrics. This project specifically addressed aspects of the racial wealth gap through urban design strategies (such as improvements to public spaces and infrastructure in underserved areas). The effort faced several practical challenges that underscore the importance of timing and trust: for instance, initial delays in funding disbursement and municipal approvals created lags in the schedule, and community members expressed skepticism rooted in "research fatigue" from past planning initiatives. These conditions made it clear that building trust and aligning the project timeline with community readiness were paramount. In response, the team explicitly incorporated mechanisms (described below) to identify and act upon critical moments when stakeholder engagement was high and consensus was emerging. All community participation followed ethical guidelines and was facilitated through a series of public workshops and design charrettes conducted over the project year.

3.2 Digital-Twin Workflow

The workflow integrates four stages, each leveraging the digital twin platform to support participatory planning:

1. **Data Integration:** Multi-scalar spatial datasets (e. g. socio-ecological indices, surface temperature maps, tree-canopy density, walkability scores, floodplain extents, and demographic statistics) were compiled and ingested into a GIS-based digital twin environ-

ment. We utilized a suite of tools (ArcGIS Pro, ArcGIS Online, CityEngine, and BIM/ Revit for 3D modeling) to create a realistic, interactive model of the study area. Data layers were visualized through web-based interactive dashboards, enabling participants to toggle layers and explore current conditions as a foundation for participatory analysis.

2. **Participatory Modeling:** Stakeholders and researchers engaged with the twin during a series of workshops (5) with an average of 5 participants via a browser-based interface. In real time, participants could adjust planning parameters or design features, such as adjusting land-use allocations, adding green infrastructure, or altering public space accessibility, and then immediately visualize the projected impacts. For example, community members experimented with scenarios like increasing street-tree coverage on certain blocks to see modeled reductions in heat islands. This hands-on modeling encouraged collaborative exploration of alternatives and helped surface preferences by showing tangible outcomes of each idea. The digital twin thus acted as a common ground for discussion, where quantitative simulations informed qualitative deliberations.
3. **Kairos Identification:** We embedded a heuristic decision-support logic into the workflow to identify Kairos Moments. Drawing on Tversky & Kahneman's (1974) cognitive heuristics, we manually coded engagement episodes (from workshop transcripts and digital interaction logs) for three types of cues:
   - **Representativeness** – instances where proposals or comments reflected familiar community norms or prototypes (e. g. a resident suggesting a solution that mirrors a successful past initiative in the neighborhood).
   - **Availability** – the frequency and intensity of recurring priorities in discussion (e. g. a particular concern like "shade for playgrounds" being raised repeatedly by multiple participants, indicating it is top-of-mind and collectively salient).
   - **Adjustment from Anchor** – evidence of a significant change in stakeholder stance after new data or visualization appeared (e. g. a participant revising their position on a housing density issue once shown flood risk maps, demonstrating a shift from an initial anchored viewpoint).
4. Each workshop transcript was reviewed using a structured qualitative coding convention. For reproducibility, each Heuristic indicator such as Representativeness, Availability of Instances, and Adjustment from the Anchor, was analyzed through explicit coding definitions, keyword families, and observable behavioral marks. The research team conducted an initial rubric to evaluate, calibrate, and revise inputs to the digital twin being it was the decision tool for the project. We selected a manual and thematic qualitative coding approach due to the moderate dataset size and the contextual nuance required in the deliberative dialogue. This approach was supplemented with structured quantitative measures. A 'crosswalk' was generated where we analyzed topic frequency counts with applicable digital twin data inputs to corroborate 'Availability of Instances' cues and digital twin variables or parametrization criteria associated with 'Adjustment from the Achor' effects.

   A Kairos Moment was recorded only when multiple independent indicators converged during that period of time or meeting series. In short, thematic repetition was an indicator of a Kairos Moment in terms of intensity. By combining explicit coding definitions, parameterization through the crosswalk, and identification of Representativeness, Availability of Instances, and Adjustment from the Achor, the workflow provides a replicable framework for future researchers to operationalize in similar studies.

Activation and Response: Once a Kairos Moment was identified (either during the session or in post-analysis), the facilitators would intentionally *activate* it by guiding the group to reflect or decide on that issue while momentum was high. In practice, this meant adjusting the engagement strategy or design process in real time or in subsequent meetings. For example, if the heuristics indicated a surge of support for a certain idea (as with the shade intervention), the team would allocate extra time in the agenda to develop that idea further or fast-track a detailed design exercise around it. In some cases, activation involved aligning external actions with the moment: after a consensus on a market pavilion design emerged, the team coordinated with a municipal grant opportunity that was open at that time, to seize the funding *window* for implementation. The goal of this stage was to ensure that identified Kairos Moments were not merely observed, but translated into concrete adjustments, be it a design decision, a policy proposal, or scheduling the next engagement at an optimal time. In essence, the digital twin's Kairos monitoring became a prompt for timely action, helping the project remain responsive to the community's rhythms.

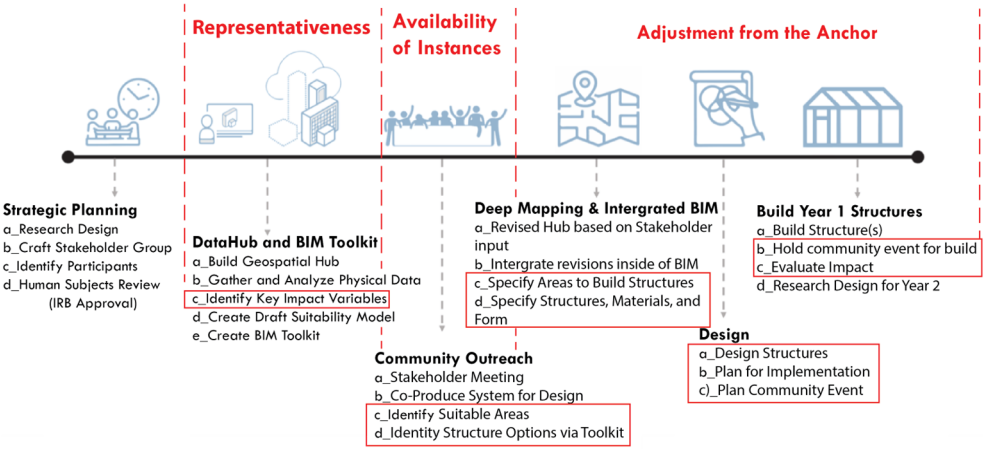

Fig. 1: This diagram illustrates our workflow within the case study, including data integration, participatory modeling, and the identification of key Kairos Moments via heuristic cues

3.3 Engagement Methods

A mixed-methods participatory approach was used to carry out the project, combining multiple forms of engagement and data collection:

- **Community-Led Workshops** (n = 5): These facilitated sessions (each 2-3 hours long) brought together residents, local leaders, municipal staff, and researchers to co-create goals, assess digital twin scenarios, and review design proposals. An average of 5 participants participated in workshops. Activities included group discussions, mapping exercises using the digital twin interface, and priority-voting on design options.
- **Semi-Structured Interviews:** Outside of the workshops, we conducted one-on-one or small-group interviews with key stakeholders (residents of the focus neighborhoods, city planners, and local NGO representatives). These interviews provided deeper insight into personal experiences, historical context, and stakeholder values, which informed how we interpreted workshop outcomes and refined the digital twin's data.

- **Design Charrettes:** Toward the latter part of the project, we hosted intensive design charrette sessions to translate digital scenarios into tangible spatial interventions. For example, one charrette focused on developing a modular shade pavilion concept for a neighborhood marketplace, taking the idea (which emerged in workshops as a priority) and sketching out its form, materials, and placement on the digital twin model. These charrettes allowed participants to move from abstract scenario exploration to concrete design prototyping.

Digital Trace Analytics: Throughout the engagement, the digital platform logged user interactions (e. g. which layers were toggled, which scenario comparison views were opened) and we timestamped discussion themes from video recordings. These interaction logs and transcripts formed a digital trace of the participatory process, which we later analyzed to understand the timing and frequency of stakeholder inputs. This data was crucial for the Kairos identification described above, effectively linking *what* participants did and said with when they did so.

3.4 Evaluation Criteria

We evaluated the process and outcomes using three main dimensions, reflecting both the efficacy of the digital tools and the quality of the participation:

- **Digital Effectiveness:** Assessed the usability and comprehension of the digital twin interface. We collected feedback through post-workshop questionnaires and observations, looking at whether participants could easily navigate the tools, understand the visualizations, and gain insights from the simulations.
- **Collaborative Efficacy:** Examined the diversity and equality of participation. Using dialogue transcripts and facilitator notes, we coded interactions to see if a broad range of voices were contributing (versus one or two people dominating) and whether traditionally marginalized community members felt empowered to speak. This criterion was influenced by Design Justice principles. Success meant that community knowledge genuinely drove the dialogue. We also noted instances of co-learning or consensus-building as signs of effective collaboration.
- **Temporal Responsiveness:** Measured how the identification of Kairos Moments influenced the project's decisions and timing. We tracked the frequency of Kairos Moments (e. g. how many were identified per workshop, with a total of 23 across all sessions) and evaluated their impact on subsequent design decisions or actions. For instance, if a Kairos Moment was identified around the need for shade structures, did that directly lead to incorporating a shade pavilion in the final design proposal or adjusting the project timeline to pursue a funding opportunity? A high temporal responsiveness score would indicate that the process successfully synchronized engagement timing with decision-making; essentially, that the team "caught" the critical moments and acted on them.

By triangulating these criteria, we aimed to get a holistic sense of how well the digital twin-supported process worked, not just in producing a plan but in doing so ethically and effectively from the participants' perspective.

4 Results

4.1 Digital Twin as a Collaborative Medium

The interactive digital twin proved to be an effective collaborative medium, enhancing transparency and shared understanding in the design process. It translated complex environmental data into legible visual narratives that all participants could grasp, irrespective of technical background. Users reported greater trust in the data when they could manipulate parameters themselves and instantly see spatial outcomes reflected on the map or 3D model. This aligns with findings by Iwaniec et al. (2020) on the co-production of sustainable scenarios, where stakeholder engagement with scenario tools builds confidence in outcomes. The twin's dashboard interface allowed side-by-side comparisons (e. g. before vs. after or Scenario A vs. Scenario B), which helped clarify trade-offs between different design options. For example, participants explored scenarios to increase tree canopy in various locations and could visually compare how each scenario affected summertime air temperature, shaded public space, and implementation feasibility. These comparative visualizations led to more informed deliberations: the group could point to the screen and say, "If we add trees here, we gain shade but might reduce open play space, how do we balance that?" In essence, the technology shifted the dynamic from abstract debate to evidence-informed negotiation, where participants collectively interpreted model outputs. Several participants noted that seeing their ideas reflected immediately in the digital model made them feel heard and validated. This interactive process also fostered inter-stakeholder trust: community members and officials alike gained confidence that decisions were based on transparent data, and community members felt a sense of ownership over the emerging designs. One practical outcome of this approach was that it surfaced creative solutions with broad support, most notably, the concept of a modular shade pavilion for the neighborhood market, which emerged from the twin-enabled discussions and quickly became a centerpiece of the design proposal.

4.2 Detection and Activation of Kairos Moments

Across the five workshops, we recorded 23 distinct Kairos Moments, which are instances where the combination of stakeholder input and digital feedback triggered a notable shift in collective priorities or the direction of design discussions. Analyzing these moments revealed three recurring typologies of Kairos in this context:

Data-Driven Kairos: Moments sparked directly by the visualization of new data or model outputs. For example, when the twin displayed a heat-island intensity map of the city, participants immediately recognized the stark temperature differences in their neighborhood. This prompted an instant surge of advocacy for tree canopy interventions (planting street trees, adding shade structures), a pivot in the discussion that might not have occurred without seeing the data. In this case, the data visualization acted as a catalyst in which participants' availability heuristic kicked in as the freshly seen extreme heat problem dominated their attention, and a representative solution (more trees, a familiar community response to heat) was readily proposed. The digital twin log showed a spike in interactions (many users turning on the "temperature" layer and sketching tree locations) exactly at this juncture, confirming it as a Kairos Moment driven by data revelation.

Socio-Political Kairos: Moments emerging from social dynamics, value discussions, or power-related considerations within the group. For instance, during one workshop the conversation shifted to long-term maintenance of proposed interventions. A community elder raised a concern: "Who will own and care for these new public spaces?" This led to a deep discussion about ownership, stewardship, and equity, especially when the twin was used to highlight that certain vacant lots (potential project sites) were city-owned versus community-owned. That realization, which combined factual information (ownership status) with community values, created a window where participants reevaluated design priorities to ensure local stewardship was feasible. The representativeness cue was evident here as well: participants invoked local precedents (e. g. a nearby community garden run by residents) as models for how any new space should be managed. This socio-political Kairos Moment resulted in adding a requirement that any design proposal include a community stewardship plan, aligning the project more closely with local values.

Institutional Kairos: Moments tied to external institutional timing and constraints, where aligning the project's actions with these larger rhythms was crucial. For example, in one instance the team discovered that a municipal grant for green infrastructure was accepting applications shortly after the final workshop. Meanwhile, in that workshop, the community achieved consensus on a green streets proposal (bioswales and tree planting along a particular corridor). This coincidence of community readiness (having a concrete, supported plan) and an institutional opportunity (funding availability) was a classic Institutional Kairos Moment. We recognized it as such and shifted immediately into drafting a grant application with community input, so as not to miss the funding window. Conversely, we also documented a case of missed Institutional Kairos: a proposed affordable housing design from the project aligned with a city initiative, but bureaucratic delays in our collaboration caused the timeline to slip past the city's budget cycle, losing a year before the next opportunity. These experiences underscore that Institutional Kairos is often the most challenging to harness. It depends on factors beyond the immediate control of the community or facilitators, yet it can make or break a project's ultimate implementation. In our analysis, Institutional Kairos moments were fewer in number than the other types, but when they occurred they had outsized impact on whether project ideas advanced toward real-world action.

Notably, nearly all identified Kairos Moments coincided with peaks in user interaction within the digital twin, which validates our heuristic classification approach. In the moments described above, the digital trace data showed increased activity (layer toggling, scenario adjustments) precisely when participants were most animated in discussion. This correlation suggests that our method of detecting representativeness/availability/anchor-adjustment cues was capturing real inflection points in engagement. Figure 1 (Section 3.2) charted these moments along the project timeline; we observed, for example, a cluster of data-driven Kairos spikes in the early workshops (when baseline data was first introduced), and more socio-political and institutional spikes in later stages (as designs solidified and external partnerships came into play). The end result was a more synchronized process. Decisions about design changes or next steps were taken at times that felt natural and right to the participants, rather than according to a rigid pre-set schedule.

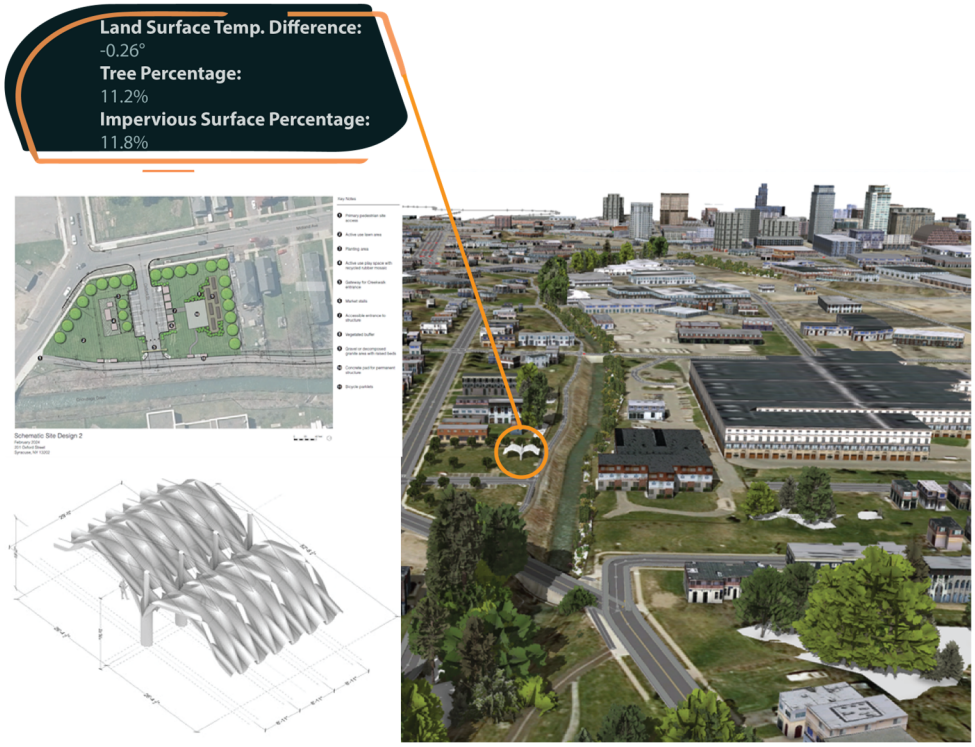

Fig. 2: Shade Structure Detail and Digital Twin

4.3 Ethical and Temporal Outcomes

Implementing the Kairos framework yielded several notable outcomes related to the ethics of timing and overall participant experience. First, it significantly improved the responsiveness of the project by synchronizing institutional action with community momentum. In instances where we successfully activated a Kairos Moment, stakeholders saw nearly immediate follow-through. For example, after the consensus on the shade pavilion idea (a socio-political Kairos moment), the research team helped channel resources to develop that concept further and initiated talks with the city about a quick implementation pilot. This kind of prompt response reinforced to participants that their input carried real weight. One community member commented in a post-workshop interview that "in past meetings, we'd give ideas and never know what happened. Here, we could see our idea taking shape on the screen and then see it move forward in the real world." Such feedback indicates a higher level of trust and satisfaction with the process. Indeed, participants overall articulated greater satisfaction with the transparency and reactivity of the engagement. They reported feeling that the process was not just a formality, but a living collaboration where their input had tangible effects on the final outcomes.

The flip side was also instructive: delays due to bureaucratic constraints were documented as "missed Kairos," underscoring the ethical cost of inaction or misaligned timing. For example, as mentioned, one promising design proposal lost some momentum when it couldn't be pur-

sued immediately because of external red tape. We openly discussed this with the community in a debrief, framing it as a missed Kairos Moment. While disappointing, that discussion itself was valuable. It validated the community's frustration and highlighted exactly where institutional processes need to change to better support grassroots initiatives. In terms of measured impact, our Temporal Responsiveness criterion captured these dynamics: we found that a majority of the design decisions that made it into the final plan were traceable to identified Kairos Moments (i. e. they occurred either during or shortly after those moments). This suggests that by paying attention to timing, the team was able to focus on and elevate the ideas that had the strongest authentic backing.

An ethical insight from this approach is the importance of pacing and patience. While the digital twin technology enabled rapid exploration of ideas, the Kairos perspective reminded us that there are optimal times to pause and reflect. In practice, some workshops ended a bit early on content because we sensed the group had hit a significant realization (i. e., a Kairos point) and it was better to let that marinate and reconvene later than to push on. Participants later noted that this pacing, doing the "right thing at the right time," made the engagement feel more respectful and less rushed than typical planning meetings. In summary, the integration of Kairos Moments into the participatory digital twin workflow enhanced both the effectiveness and the ethical grounding of the project. By the end, the community not only had a set of co-created design proposals (such as the shade pavilion and green infrastructure projects) but also a greater confidence that the process honored their timing and readiness. Several stakeholders expressed that they felt a stronger sense of stewardship over the outcomes, having seen how their collective moments of decision were recognized and acted upon in a timely manner.

5 Discussion

5.1 From Representation to Relationship

Traditional digital tools in landscape architecture often prioritize precision and photorealistic representation of proposals. In contrast, the Kairos-twin framework reorients these technologies toward what might be called relational ethics: the timing and context of engagement become as critical as the accuracy of data or visuals. By making moments of decision visible and salient, the system transforms what is usually an abstract or hidden aspect of collaboration (the ebb and flow of participant readiness) into a traceable, discussable, and ultimately actionable process. In our case, participants could literally see when a decision node had been reached. For instance, we observed that "everyone was silent when that map came up, which means we were all thinking hard about it." Such meta-cognitive awareness, facilitated by the digital trace, began to shift the group's perspective from simply generating content (ideas, maps, and designs) to also minding the health of the process (relationships, trust, and timing). This supports a broader conceptual shift: digital participation tools should not only represent biophysical conditions but also foster relationships between stakeholders, and between people and data through careful attention to when and how information is introduced. In essence, the Kairos approach pushes digital landscape practice beyond just delivering scenarios toward cultivating a mutual readiness to act. The visible logging of decisions and moments also made the process auditable in hindsight; community members and external observers could review the timeline of engagement and see why certain decisions were made when they were. This kind of accountability is rarely available in standard design charrettes. Thus, emphasiz-

eng timing (Kairos) alongside content turns the participatory design into a relationship-centered practice, where trust and ethical alignment are built into the very sequence of interactions, not treated as an afterthought.

5.2 Integrating Heuristics with Participatory Design

Adapting Tversky and Kahneman's (1974) cognitive heuristics for community engagement proved to be a novel but effective means of quantifying and mapping decision behavior in a qualitative design process. In our framework, representativeness, availability, and adjustment from anchor served not only as cognitive descriptors of individual behavior, but as participatory design analytics essentially, measures of inclusivity, salience, and adaptability in group decision-making. Embedding these metrics within the digital twin interface encouraged a form of reflexive practice among participants and facilitators alike. For example, when the group saw (through facilitated feedback) that many of their ideas were clustering around familiar solutions (high representativeness), it prompted a discussion about whether they were overlooking innovative options. In other words, it made bias visible in a non-confrontational way. Likewise, noticing that a particular concern (e. g., flood risk) kept coming up (high availability) helped justify dedicating more time and consideration to that issue in the design. This use of heuristics provided a common vocabulary for the team to analyze the collaboration itself.

Importantly, integrating heuristics did not mean reducing the richness of participation to numbers. Rather, it added a light layer of structure that supported the human interpretation of complex discussions. It also opens up possibilities for replication in other settings. The heuristic categories are general enough that other participatory design projects could adopt similar coding to monitor their processes. The successful example we provided (coding a repeated comment about shade as an availability cue) illustrates how straightforward yet powerful this can be. Of course, one must be cautious: heuristics are simplifications of cognition and can't capture everything. But in our experience, they captured enough of the pattern of interactions to be a useful guide. Moving forward, it would be interesting to experiment with partially automating this (e. g., using text mining to flag repeated phrases for availability), but we suspect a human-in-the-loop approach will remain crucial for nuanced interpretation. In summary, the marriage of cognitive science and participatory design in this framework helped bridge qualitative and quantitative realms, encouraging participants to reflect on how they decide, not just what they decide. This reflexivity, in turn, can lead to more deliberate and democratic decision-making processes.

5.3 Implications for Landscape Education and Research

For academic programs and researchers pursuing advanced digital pedagogy, the workflow presented here offers a template for teaching what we might call ethical computation in design. In typical landscape architecture or landscape planning studios, students learn to use digital tools for analysis and visualization; we suggest extending this to also train students in reading the room and responding to the social timing of decisions. A studio using a Kairos-informed digital twin might, for example, have students play roles as facilitators who must decide when to switch tasks based on participant feedback analytics. This could cultivate a new skill set around dynamic facilitation and process ethics, alongside technical GIS/BIM skills. Additionally, this framework contributes to research on participatory modeling by providing a method to evaluate when engagement is effective. Future research could build

on our evaluation criteria, especially Temporal Responsiveness, to compare projects that use Kairos principles vs. those that don't. Such comparative studies could offer evidence on whether explicitly timing-aware processes yield better long-term outcomes (e. g. more sustained community involvement, or design implementations that stick). Another educational implication lies in interdisciplinary collaboration: our project drew on concepts from psychology (heuristics), rhetoric (Kairos), and data science (digital twins). This underscores the value of breaking silos; landscape architecture curricula might incorporate basic training in these other fields to equip future practitioners for such integrative work. Finally, there is an opportunity for open-source development: given that many components of our digital twin and analysis approach can be coded, universities could develop shared platforms or toolkits that embed Kairos monitoring into commonly used participatory planning software, making this approach more accessible and standardized for widespread adoption.

5.4 Policy and Institutional Reform

Our findings echo a broader argument in the literature and practice: achieving sustainable and equitable digital engagement demands institutional change, not just better tools. In particular, the concept of Institutional Kairos emerged as a critical, and often problematic, factor in our project. The timing of funding calls, grant cycles, and bureaucratic procedures at universities or city agencies often did not align with the community's timeline for momentum and trust-building. As Springer & Skolarus (2019) observe, short-term project funding rarely accommodates the temporal realities of building trust. This misalignment led directly to some of the "missed Kairos" moments we noted. To address this, institutions need to consciously create conditions that allow participatory projects to seize opportune moments rather than be stymied by red tape. In practice, this could mean establishing more flexible funding mechanisms that can be quickly tapped when community consensus is reached, or adopting rolling timelines for project deliverables that can adjust to community pacing. Ferguson et al. (2017) similarly highlight that synchronization between institutional readiness and community momentum is vital. Our work puts a fine point on that by showing what is lost when the two fall out of sync.

We propose several policy-level reforms inspired by our case experience: (a) Universities and public agencies should adopt multi-year participatory frameworks with built-in flexibility, rather than one-year grant cycles that force artificial deadlines. Longer engagement horizons, with periodic checkpoints rather than a hard stop, would better accommodate the ebb and flow of community work and enable capturing Kairos Moments whenever they arise. (b) Funding bodies might consider small discretionary pools of money that community-academic partnerships can draw on swiftly when an opportunity (Institutional Kairos) appears. For example, a sudden chance to acquire a property or implement a pilot project that has community support. (c) Research institutions should allocate a portion of indirect costs or overhead returns to support community partners (e. g. honoraria, childcare for meetings, technical assistance) over extended periods, acknowledging that trust and relationships require continual investment. And (d) establishing Community Advisory Boards to oversee ethical issues in digital data use and to co-manage project timelines can institutionalize a more relational model of partnership (BOYER 1996, DRISCOLL 2008). Such boards could literally have a say in adjusting project schedules if community members feel things are moving too fast or too slow.

Implementing these kinds of changes would operationalize the shift from transactional, one-off projects to relational, long-term engagement models (BOYER 1996). They directly address the barriers we encountered under the umbrella of Institutional Kairos. Ultimately, institutions that embrace these reforms are more likely to see successful outcomes from participatory initiatives, because they empower projects to act in time with the communities they serve. An encouraging sign is that some grant programs and city governments are already reflecting on these needs. Our work adds empirical backing and a framework (Kairos-informed design) that could guide policy in practical terms. In summary, for digital participatory tools like ours to reach their full potential, they must be coupled with institutional practices that honor the ethic of timing as much as the outcomes of design.

6 Conclusion

This research has demonstrated how Kairos Moments can be operationalized within a digital landscape architecture framework, merging temporal ethics with participatory action and design innovation. Our case study shows that digital twins can do more than visualize environmental conditions. They can also visualize and record the co-production relationships in time, instilling greater community stewardship and trust in the design process. By capturing when collaboration occurs and how data influences decisions, the Kairos-twin workflow transforms participatory design from a reactive, check-the-box consultation exercise into a proactive co-creation process where community insight drives not only what gets decided but when it gets decided.

Key outcomes of our study include:

1. A replicable workflow linking PAR, Design Justice principles, and digital-twin technologies to support equitable community engagement.
2. A heuristic model for identifying and responding to Kairos Moments, providing designers and facilitators with a practical tool to gauge and enhance the timing of participatory interventions.
3. Empirical evidence that raising awareness of timing (through Kairos analytics) can enhance trust and decision quality, as stakeholders feel heard at the right moments and see timely action on their input.

For future research, there are rich opportunities to scale and generalize this approach. Future work will apply the Kairos-informed digital twin framework across diverse socio-ecological contexts. For example, in regional climate resilience planning, in co-designing green infrastructure for flood-prone communities, and in partnerships with Tribal Nations on land stewardship initiatives. Each context will no doubt reveal new types of Kairos Moments and additional heuristics that matter. By iteratively testing and refining the method, we aim to develop a more robust theory of participatory timing that could complement existing landscape planning models.

In closing, embedding Kairos within digital landscape practices ensures that technology truly serves community values. It helps practitioners remember that timeliness of design engagement is as crucial as the design content. As the field of landscape architecture continues to embrace big data, simulations, and digital twins, frameworks like this can keep those innovations grounded in human relationships and ethical principles. We envision a digitally enabled, ethically grounded, and temporally aware practice of landscape architecture, one where

community co-design is not only inclusive and data-informed, but also timed to meet the needs of the community.

Acknowledgements

The authors thank the community partners and municipal staff who contributed their time and knowledge to this project. Portions of this research were supported by a national philanthropic grant (project details omitted for review). The collaborative spirit of all participants made this work possible, and their insights continue to guide our ongoing efforts. The authors acknowledge the use of ChatGPT (OpenAI, Version GPT-5.2) as a language support tool during manuscript preparation for grammar, clarity of intent, and language editing. All intellectual contributions, interpretations, and conclusions remain the responsibility of the authors.

References

BOYER, E. L. (1996), The Scholarship of Engagement. Bulletin of the American Academy of Arts and Sciences, 49 (7), 18-33.

COSTANZA-CHOCK, S. (2020), Design Justice: Community-Led Practices to Build the Worlds We Need. MIT Press.

DRISCOLL, A. (2008), CARNEGIE'S Community-Engagement Classification: Intentions and Insights. Change: The Magazine of Higher Learning, 40 (1), 38-41.

FERGUSON, L., CHAN, S., SANTELMANN, M. & TILT, B. (2017), Exploring participant motivations and expectations in a researcher-stakeholder engagement process: Willamette Water 2100. Landscape and Urban Planning, 157, 447-456.

FREIRE, P. (1972), Pedagogy of the Oppressed. Penguin Books.

HOVERSTEN, M. E. & SWAFFIELD, S. R. (2019), Discursive moments: Reframing deliberation and decision-making in alternative futures landscape planning. Landscape and Urban Planning, 182, 22-33.

IWANIEC, D. M., COOK, E. M., DAVIDSON, M. J., BERBÉS-BLÁZQUEZ, M., GEORGESCU, M., KRAYENHOFF, E. S., MIDDEL, A., SAMPSON, D. A. & GRIMM, N. B. (2020), The co-production of sustainable future scenarios. Landscape and Urban Planning, 197, 103744.

KINDON, S., PAIN, R. & KESBY, M. (Eds.). (2007), Participatory Action Research Approaches and Methods. Routledge.

MOHAMMED MAHMOUD, M., LIU, Y., HARTMANN, H., STEWART, S., WAGENER, T., SEMMENS, D., STEWART, R., GUPTA, H., DOMINGUEZ, D., DOMINGUEZ, F., HULSE, D., LETCHER, R., RASHLEIGH, B., SMITH, C., STREET, R., TICEHURST, J., TWERY, M., VAN DELDEN, H., WALDICK, R., WHITE, D. & WINTER, L. (2009), A formal framework for scenario development in support of environmental decision-making. Environmental Modelling & Software, 24 (7), 798-808.

MANZINI, E. (2015), Design, When Everybody Designs: An Introduction to Design for Social Innovation. MIT Press.

RÄMÖ, H. (2004), Spatio-temporal notions and organized environmental issues: An axiology of action. Organization, 11 (6), 849-872.

SPRINGER, M. V. & SKOLARUS, L. E. (2019), Community-Based Participatory Research: Partnering with Communities. Stroke, 50 (3), e48-e50.

TVERSKY, A. & KAHNEMAN, D. (1974), Judgment under uncertainty: Heuristics and biases. Science, 185 (4157), 1124-1131.

WALKER, M. & LOOTS, S. (2018), Transformative change in higher education through participatory action research: a capabilities analysis. Educational Action Research, 26 (1), 166-181.

WILLIAMS, P., KLISKEY, A. A., CRONAN, D., TRAMMELL, E. J., DE HARO-MARTÍ, M. E. & WILSON, J. (2023), Constructing futures, enhancing solutions: Stakeholder-driven scenario development and system modeling for climate-change challenges. Frontiers in Environmental Science, 11, 1055547.