Co-gnito: a Participatory Physicalization Game for Urban Mental Mapping

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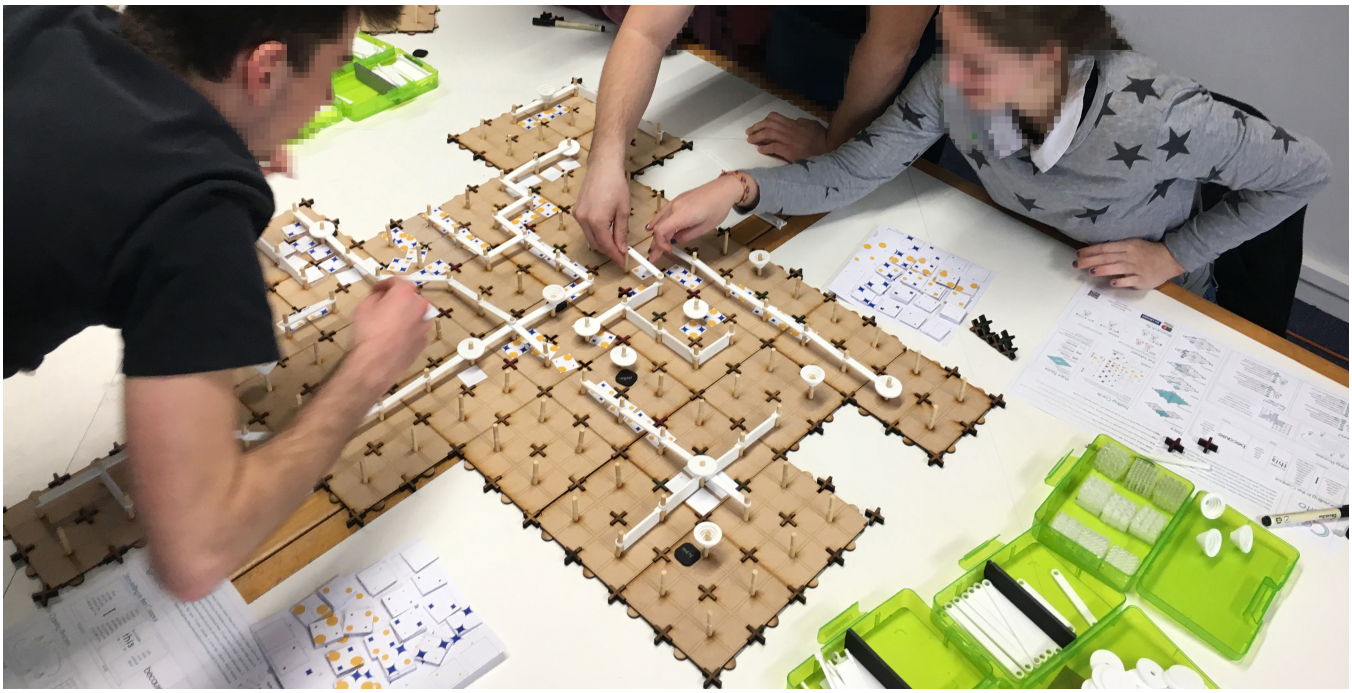

Figure 1: Three players in Co-gnito are collaborating to place physical tokens that together represent an urban mapping story. The aggregation of multiple stories builds a physicalization that holistically represents the urban mental map of the whole group. On the table are also visible: the board tiles, imageability tokens and feeling cards that are required to assemble the physicalization. Each player has in front of them their game instruction sheet as well as their earned points.

ABSTRACT

This study introduces Co-gnito, a participatory physicalization game that supports collaborative urban mental mapping through storytelling. Through Co-gnito we investigate gaming as a means to elicit subjective spatial experiences and to steer the synchronous construction of a physicalization that aligns and represents them. Co-gnito was evaluated during seven deployments by analyzing how 28 players mapped their spatial experiences of two university campuses. Our results indicate that storytelling as a gaming mechanic, guided and motivated the gradual addition of personal contributions towards a collective outcome, but its reward system did not nudge the mapping direction as expected. We also demonstrate how the shared construction process of a physicalization is influenced by how the data encoding scheme was negotiated, by the token physical affordances and by the game mechanics. We therefore believe that our core contributions, comprising of: 1) a

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working research prototype; 2) an augmentation of the physicalization pipeline towards collaborative settings; and 3) a set of reflective considerations, provide actionable knowledge on how to design participatory physicalizations in the future.

CCS CONCEPTS

• **Human-centered computing → Empirical studies in visualization**.

KEYWORDS

physicalization, serious games, storytelling, collaborative construction, urban design, mental mapping, participation, collaboration, making, visualization activity

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1 INTRODUCTION

The field of environmental psychology has shown how the subjective experience of physical environments like cities can be captured in urban mental maps. Urban mental maps are visually-oriented tools such as drawings or graphical collages that represent how people have internalized complex spatial settings. Urban mental mapping is a well-known method to elicit the subjective experiences from local inhabitants of their urban environment, which are then taken into account during the urban design process[4]. While most often urban mental maps are created individually, they can also be generated in group-based contexts. In the Map Room [41] for instance, collaborative map-annotation was used as a means to provoke discussion on spatially related issues, such as to identify dormant resident themes within a neighborhood. Collaborative urban mental maps are considered useful research probes in the domain of urban design because inhabitants with similar cultural standings tend to interpret their built environment similarly [4]. Nevertheless, collaborative mental mapping exercises are still relatively hard to organize, with urban designers themselves often acting as the translators of participants' mental maps into sketches. There is therefore a need for new methods that support creative, engaging and accessible collaborative urban mental mapping, yet still allow the resulting maps to be representative and comparable among different groups of inhabitants.

Physicalization, the physical representation of data for analytical purposes [18], forms an accessible medium through which sense-making of relatively complex types of data can be encouraged [15, 37]. Physicalization allows for more natural and inviting types of encoding and interacting with data [40], which potentially leads to more affective, reflective and social forms of user engagement [46]. While physicalization usually requires quantitative data, recent studies demonstrated how qualitative or tacit knowledge can also be represented tangibly, so as to enhance externalization and enable group-based sensemaking [24, 35]. Taking into account this promising potential, this research explores how data physicalization can be exploited in the participatory context of group-based urban mental mapping. Inspired by the use of games in participatory design, this study does not only focus on producing unique physicalizations that are representative of a complex collaborative process, but also investigates how physicalization can be enhanced with game mechanics to regulate and orchestrate its participatory construction.

Gaming helps bring structure, ensure equality of participation and sustain motivation in group activities [43] and participatory design sessions [5]. While their use in research has been questioned because of their potentially biasing nature [7], they are still popular in design-oriented and creative research for their generative potential. Reward and punishment gamification mechanics for instance are commonly used in educational applications to guide and motivate students during complex and otherwise demotivating learning processes [38]. While conceptually close, to the best of our knowledge, game mechanics have not been explored for their potential in data physicalization construction.

We introduce Co-gnito, an abbreviation from "Collective Cognitive Mapping", as a gamified physicalization methodology that aims to support collaborative urban mental mapping [1]. Co-gnito is based on a set of predefined physical tokens that externalize the spatial experience of multiple co-located people, and deploys rules, rewards and storytelling, all prominent aspects of gaming, to steer how these experiences are assembled into a single, unified physicalization. We deployed Co-gnito seven times in the context of mapping two different urban environments, which resulted in the storytelling of 104 distinct spatial experiences from 28 players.

Our findings indicate that while storytelling sustained motivation, our intricate scoring did not seem to nudge the mapping directions as expected. We also observed how the collaborative physicalization construction was influenced by the social dimensions of the group which negotiated the data encoding scheme; the physical affordances of the tokens that guided assembly; and especially for our case, the game mechanics that distributed the player actions. Our contributions, which include a working research prototype, an augmentation of the physicalization pipeline and a series of reflective considerations, provide knowledge on how to steer the creation of synchronous participatory physicalizations. The ability to collaboratively create a data physicalization seems particularly useful in application domains where multiple stakeholders come together around shared values and goals, including but not limited to citizen participation, constructivist teaching and cross-disciplinary sense-making.

2 RELATED WORK

This study builds upon existing participatory physicalizations and the use of games in urban design.

2.1 Participatory Physicalization

Tangible interfaces, such as participatory physicalizations, can facilitate collaboration by grounding conversations and supporting equitable usage among participants [36]. Tangible interfaces for public display visualizations in particular, are proved to be more engaging for participants, allowing them to to discover deeper insights when compared to digital-only interaction modalities [6].

[1] For the purpose of this paper we consider cognitive and mental mapping as equivalent.

Accordingly, participatory physicalization, i.e., the collective process in which multiple people add data 'parts' to create a larger, collective physicalization together, can potentially encourage a more engaging data-driven collaboration.

For instance, the Cairns project [12] crowd-sourced and represented local Fablab activities through a tangible interface that permitted a more casual collection of otherwise tedious survey data in public space. Data Strings [8] and Physical Bar charts [20], two large-scale physicalizations that were installed during events, were collectively generated by discrete contributions from individual visitors. By adding or removing tangible data morsels in the form of strings and colored tokens respectively, they allowed each contributor to reflect on their relation to the aggregated data of their (temporary) community. Data Badges [30] similarly facilitated the co-located self-assembly of personalized conference badges in an attempt to encourage informal discussions around the personal characteristics that were physicalized on those badges.

It is the construction process, and not necessarily the physical outcome, of a physicalization that can bring about self-reflection regarding the encoded data and its context [28, 30, 42]. Participatory data translation activities such as co-located data crocheting [27] or data cuisine sessions [19, 45] showed how the social interactions that tend to occur alongside the construction of a physicalization focus on negotiating and aligning interests and sensitivities around the data. The Mental Landscapes [35] project, in which simple cut-out shapes of landscape elements were given to groups to help them represent abstract concepts, demonstrated the group bonding nature of working with tangible material, even when 'concepts' are only loosely related to 'data' in its traditional sense. Chemicals in a Creek [32] presented an action design process to represent the pollution levels of a local creek with a floating physicalization. They demonstrated how the collective process gave participants a sense of ownership, and their closing "ceremony" focused the collective attention on the data over a *"defined but fleeting period of time"* [32].

2.2 Participatory Games in Urban Design

Urban designers have employed various methods to capture and understand citizen's stories and wishes, ranging from 3D-modeled simulations, hands-on participatory mapping toolkits [9], Augmented Reality technology mediated applications [41, 44] and serious games [33]. Among these, participatory games have shown to help illustrate complex urban issues, educate citizens on the inside workings of the urban design process, and make the participatory process "*lighter*" and more accessible [1]. Many types of games now exist that allow players to create, simulate and manipulate cityscapes [3], some of which are of actual places under consideration for restructure [33].

3 CO-GNITO

Co-gnito is a participatory game that aims to create a single urban mental map from the narrated experiences of multiple individuals. Its gaming rules are structured so that each experience is represented by physical tokens that are progressively added. Because all its tokens represent data, the physical outcome forms a data physicalization of which the whole is more meaningful than its individual parts. In an attempt to nudge the spatial and contextual distribution of the experiences, Co-gnito is played during four successive rounds during which points can be competitively gained by narrating experiences over specific physicalization regions.

3.1 Conceptual Design

Conceptually, Co-gnito draws from the work of Kevin Lynch, an established scholar in the field of urban design who originally introduced the concept of cognitive mapping [26]. Lynch, unlike the technocratic planners of the time, advocated for a social planning attitude that understood the experiences of city inhabitants through qualitative data [47]. He examined maps of city spaces, outlining what city features inhabitants were memorizing and what they were overlooking. He argued that inhabitants construct mental maps of a built environment that are shaped by how they experience the space, how the space makes them feel and how they turn the experience into memory. Accordingly, he classified five types of "urban imageability" elements that together are able to semantically represent urban mental maps by special types of inhabitants (e.g. newcomers), and even other non-visual senses (e.g. soundscapes) [26]. These types consist of: 1) *paths*, routes of movement such as streets, sidewalks and alleys; 2) *nodes*, strategic focus points for orientation such as squares and junctions; 3) *edges*, boundaries and breaks in continuity such as walls, train-tracks and river banks; 4) *landmarks*, external points of orientation which are often easily identifiable in the landscape; and 5) *districts*, areas characterized by common characteristics such as building design, forest or altitude.

We designed Co-gnito to similarly capture the urban mental mapping of space as first-person stories that build upon Lynch's five imageability elements (Figure 2c). Each imageability element is manifested as a distinct physical token to be placed on a game-board tile (Figure 2a), which in turn can be connected and aggregated with other tiles to embody a larger spatial area (Figure 2b). Beside the imageability elements, Co-gnito also captures participants' experience at certain space by dedicated *feeling cards* (Figure 2d) which graphically represent "coziness" and "inspiration" on four pair-wise combinations of an ordinal scale of 0 to 3. There might be several feelings that are attached to urban spaces, but we deliberately focused on two feelings that act as emotional bonds between person and place. First, the feeling of coziness in certain places refers to the particular appeal that of providing an experience of pleasant relaxation, it also denotes to the role of co-presence with other people on site and shaping social interaction among them [23]. Second, the feeling of inspiration in urban spaces denotes to how such spaces create memorable and relevant experiences by bring people alive, attracting and energizing them.

3.2 Physical Design

As a tangible construct to be utilized by multiple co-located players, the physical design of Co-gnito needed to be robust and affordable, yet also fun and engaging to manipulate. As a visualization construct that maps individual urban experiences, Co-gnito needed to represent a wide and unpredictable range of stories in a unified outcome that accurately aligns the underlying meanings in terms of data.

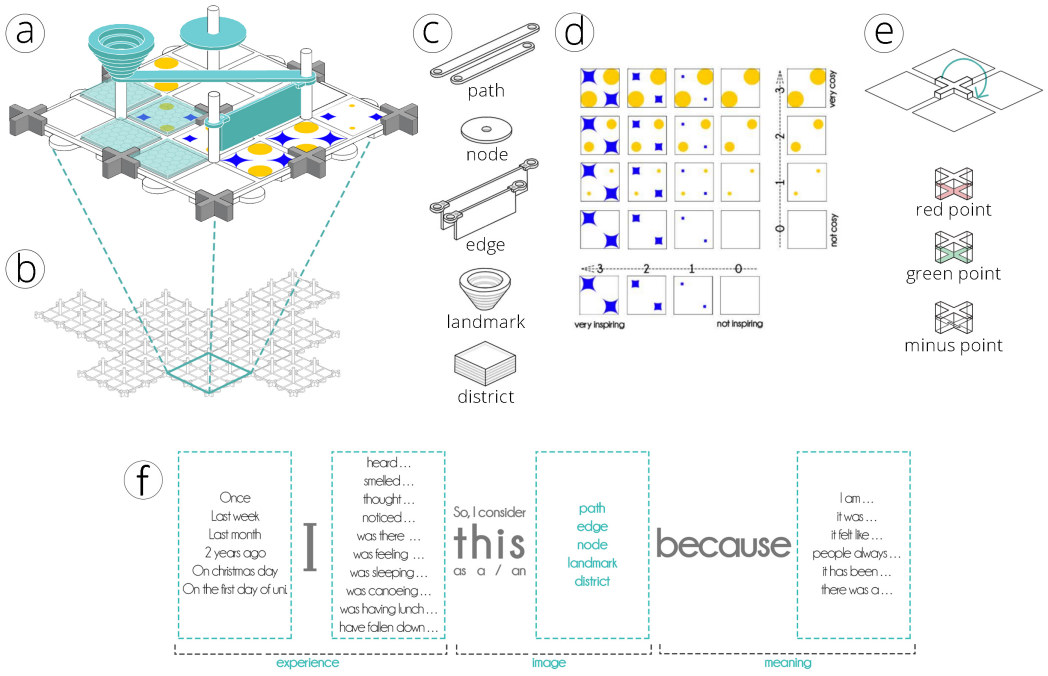

Figure 2: The physical design of Co-gnito. a) An example constellation existing of imageability tokens, feeling cards and point-crosses, placed on a single game-board tile. b) Multiple game-board tiles can be connected and aggregated to embody a larger spatial area. c) Each constellation can exist of five imageability elements that capture players urban mental mapping of certain spaces as defined in Keven Lynch's "Image of the City" [26]. d) Feeling cards encode the perceived coziness and inspiration of certain spaces in a visual ordinal scale of 0 to 3. e) Points are located at the cross-sections of game-board tile and can be negative or colored in a team color for scoring points. f) The call-to-action for initiating a player's story.

3.2.1 Data Encoding. We initially followed common data visualization practice by relating the importance of each data dimension to its expected cognitive effort. We thus decided that colors encoded feelings and experiences, while the relative locations and connections of the imageability elements conveyed their spatial relevance and interdependence, respectively. To increase legibility, the physical appearance of each imageability element embodied its realistic counterpart, so that for instance a path resembled a line, whereas an edge looked more like a three-dimensional physical boundary. All tokens intentionally lacked decorum to accentuate their abstract nature and avoid attracting attention to particular visual features.

3.2.2 Physical Characteristics. All physical elements were fabricated using common digital fabrication technologies. The attachable board tiles and points (represented as crosses among the tiles) were laser-cut from MDF panels, and all the imageability tokens, except the districts, were laser-cut from white acrylic sheets. Both paths and edges were available in two different sizes to allow for both orthogonal and diagonal placement (Figure 2a). Districts were cut and engraved squares from transparent acrylic sheets. Feeling cards were created from thin cardboard squares that featured gradually increasing graphical depictions. All tokens were designed to foreground particular affordances [29] that encourage or resist certain physical combinations in a predetermined way. For example, each board tile featured two-way notched sides, which suggested an open-ended, puzzle-like attachment system. It also featured four 'poles' to allow attaching the imageability tokens; sixteen smaller square areas to host the feeling cards and districts; as well as nine empty cross slots to hold the points that could be collected by players. Landmark and node tokens featured single holes that could be woven through individual poles, while paths and edges, which contained two holes, could be used 'hang' these elements among poles. Districts came in a set of eight equally-engraved squares that could be placed next to each other on the board to represent a single district.

3.3 Game Design

Co-gnito was designed to be played by two teams of two players each. Participants sat around a table, so that the physicalization can expand in the space between them, with members of the same team being positioned diagonally. An A3-sized sheet explained the game rules, had a call-to-action for the story, and explained the data encoding scheme of the imageability elements and feeling cards (see Figure 1).

3.3.1 Storytelling. Each player was invited to recount a spatial experience by means of first-person storytelling, which is a generative

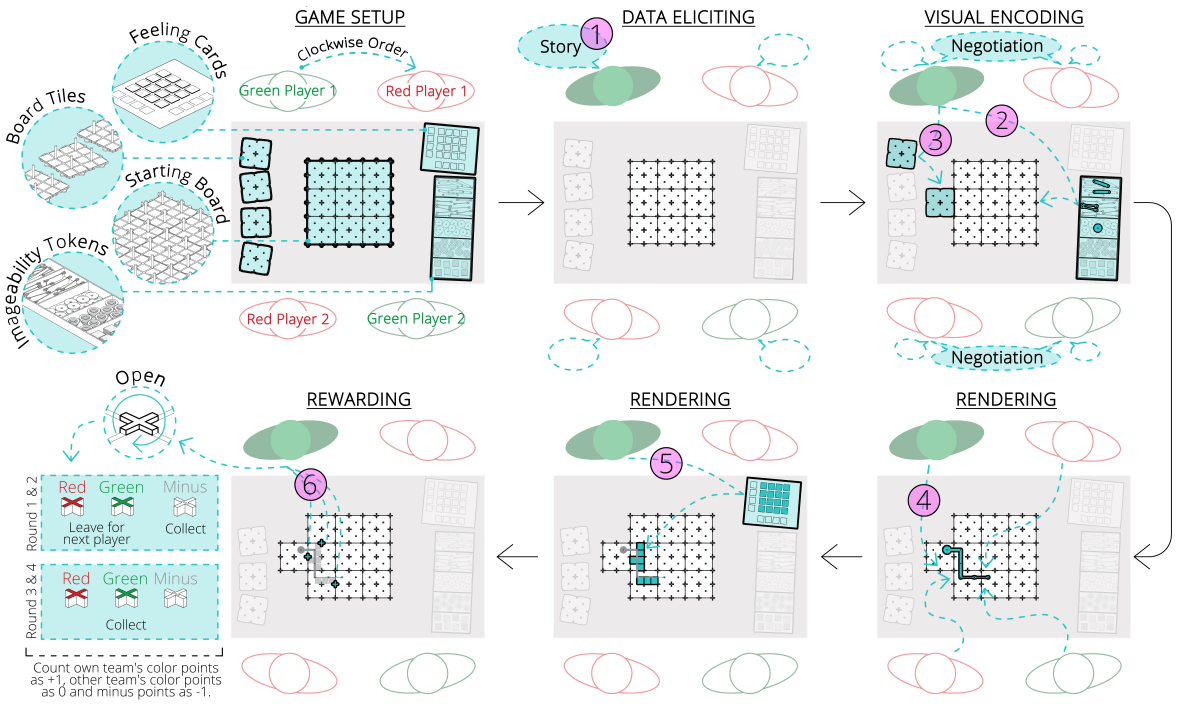

Figure 3: Diagram illustrating the gameplay: 1) Recount a story that captures a spatial experience. 2) Select appropriate token types as they appear in the story. 3) Choose a location on the board. Expand the board if required. 4) Re-arrange and place the tokens. 5) Place feeling cards based on the experiences described in the story. 6) Collect the points.

gaming method that can elicit and ground personal experiences while avoiding generalization [13, 21]. As depicted in Figure 3, the player had to first describe a personal experience (a story) about a location of interest, structured along a "when?, what?, why?" sequence (Figure 2f). They then mapped this story to imageability elements discussing with the other players why they chose a specific type of token. They then placed the tokens on the gameboard, considering the existing tokens and adding board tiles as needed. They encoded their feelings of coziness and inspiration for the spaces described in their story by placing the corresponding feeling cards unto those locations on the boards; and finally they revealed or collected three game points from the boards that lay adjacent to the newly introduced feeling cards. Overall, players were encouraged to contribute to each other's stories and to try to come to an agreement on aspects like scale and token placement.

3.3.2 Scoring. A single game round was completed when all four players each shared a story. Game points manifested as individual crosses that were located between the board tiles (Figure 2a). Crosses first had to be 'turned-over' during the first two rounds before they could be collected, yet could be gained immediately during the last two rounds. This scoring mechanism was designed so that the locations of the initial stories would overlap with existing ones so to increase the detail of the physicalization; and postpone the branching to peripheral locations to the later stages of the construction process.

4 STUDY DESIGN

Co-gnito was deployed in the context of two university campuses located in different countries, which were chosen to differ in typology, morphology and scale. The first, campus A, is a non-gated area (1.5 km²), hosting academic departments and student cafeterias in an open landscape. Campus B is a gated, live-in and urbanized area (2.5 km²), containing many alternative facility buildings. Co-gnito players were recruited via posters on each respective campus, online groups and forums inviting them to play a mental mapping game regarding their campus. In total, we organized three mapping sessions at campus A and four sessions at campus B with a participant cohort consisting of university students and researchers who all had a direct, sustained (between 0.5-14 years) and ongoing relationship with the university campus of focus. The study was approved by the ethical review committee of the host university. Each deployment consisted of a Construction and an Interpretation session.

4.1 Construction Session

In total, 28 students and researchers played Co-gnito (campus A: 8 female, 4 male, aged 21-27, mean 22.6; campus B: 7 female, 9 male,

aged 21-31, mean 24.6). Before each session, participants filled in a short survey about their demographic profile and relationship to the campus. Divided in teams of two, participants were introduced to the physical tokens and game rules by a facilitator with help of the instruction sheet. After gaining explicit permission, all sessions were video-recorded from a side and a top view. At the end, participants filled in a closing survey with open-ended and closed questions (on a 7-point scale) regarding their overall experience.

4.2 Interpretation Session

We recruited 13 additional people as domain experts (campus A: 4 female, 1 male; campus B: 7 female, 1 male). They had similar profiles as the Co-gnito players, but also possessed at least four years of architectural or urban design education. In case of campus A, the domain experts were also actively engaged in an urban design studio whose goal was to redesign campus A. After each construction session, teams of two domain experts were asked to interpret the physicalization outcome and formulate out loud how they made sense of it. We deliberately arranged it so that three of the domain experts had already participated in a Co-gnito construction session so as to assess if their previous experience affected the interpretation. While this may seem biasing, it is common practice that interventions such as the mental mapping sessions of Co-gnito are attended by urban designers. The interpretation sessions were also video recorded for further analysis.

4.3 Data Analysis

We analyzed the construction sessions from the perspective of supporting the participatory process of urban mental mapping and physicalization construction. We used the physicalization pipeline [17] to analyze the typical steps of data eliciting, visual encoding and rendering when a physicalization is constructed (see Figure 5) and also added the step of 'rewarding' which was specific for our case and game-based physicalization. We use this structure to present our results in Section 5.

The source data from the construction sessions included video recordings, surveys and final interviews. The audio and video streams of the side view were used to document the player stories and discussions, which were coded for instances of negotiation, collaboration and strategic thinking. The top view video was coded to document, per round: the duration, the number and location of board tiles additions, the type and location of added imageability tokens; the existence of previous tokens when placing new ones; as well as instances of token rearrangement. As shown in Figure 6-1, we color-coded the spatial evolution of each session in a two-point color scale to capture the branching effect of the scoring mechanism. The interpretation sessions were transcribed and coded, so as to identify emerging themes about how the domain experts interpreted the physicalization outcome.

5 RESULTS

Figure 4 illustrates the physicalization outcomes of all seven deployments, depicting about 104 distinct stories. Each construction session lasted approximately two hours, including the 15 minutes for the closing survey. The subsequent interpretation session took approximately an hour. As per game design, each construction session took four game rounds except of Sessions 1, 3 and 7 due to time limitations.

5.1 Constructing the Physicalization

Overall, participants were immersed in the game and its mental mapping process. After a single participant formulated a story, others – even those who were competing - started debating, planning, sharing and then constructing its physicalization. As shown in Figure 1, participants often altered their positions around the table to better access or view the process. Each physicalization outcome encoded between 12 and 16 stories featuring varying themes. In the closing survey, participants graded their overall experience positively, ranking it as enjoyable (mean: 5.8; median: 6; 1:annoying – 7:enjoyable), creative (mean: 5.6; median: 6; 1:boring – 7:creative) and quite attractive (mean: 5.4; median: 5; 1:unattractive – 7:attractive). Participants especially highlighted their excitement for playing in teams and sharing stories. "[The game] *made me think of everyday spaces and experiences from a different point of view.* [I enjoyed] *listening to other people's perception of the same spaces.*"(P25, game 6, campus B, in response to aspects they enjoyed most). As some survey answers suggest (11 from the 28 respondents), the game was fun but not necessarily easy to play.

5.1.1 Data Eliciting: From stories to data. In Co-gnito, a story is a short narrative that drives the experience, yet the storytelling also formed a data elicitation step, as each story was later mapped along the imageability tokens and feeling cards.

> "*The castle (a prominent location in campus A) was the place where I first saw a PhD thesis defense of a colleague. The room was so beautiful, and I was thinking someday it will be me. I find it very inspirational because of that reason.*" (P11, campus A, game 3)

> "*When I came for the interview for the first time, I tried to enter from A1 (entrance). Actually, all of the entrances of the [CAMPUS B] are like an edge which you can not enter [...] Security did not let me go in by car, so I parked here and walked till the faculty. [...] So, the level of coziness and inspiration increases (while walking) towards the faculty from the gate on this road.*" (P6, campus B, game 2).

The stories varied between mundane everyday interactions to unique one-off memories, such as those described in the quotes. Most stories included some type of trip or path across or through the respective campus, even though that was not a requirement of the game. Besides the campus and participant characteristics, the choice of stories seemed also to be influenced by two factors related to the physicalization process: the gradual construction process, as previously shared stories inspired subsequent ones, and the players' strategy for gaining points.

Inspiration. Participants were inspired by previous stories due to the co-located and synchronous construction process. Details like landscape features and lighting conditions, problematic crossroads, special moments or hidden, unknown gems on campus, etc. were typically followed up by stories that featured similar experiences.

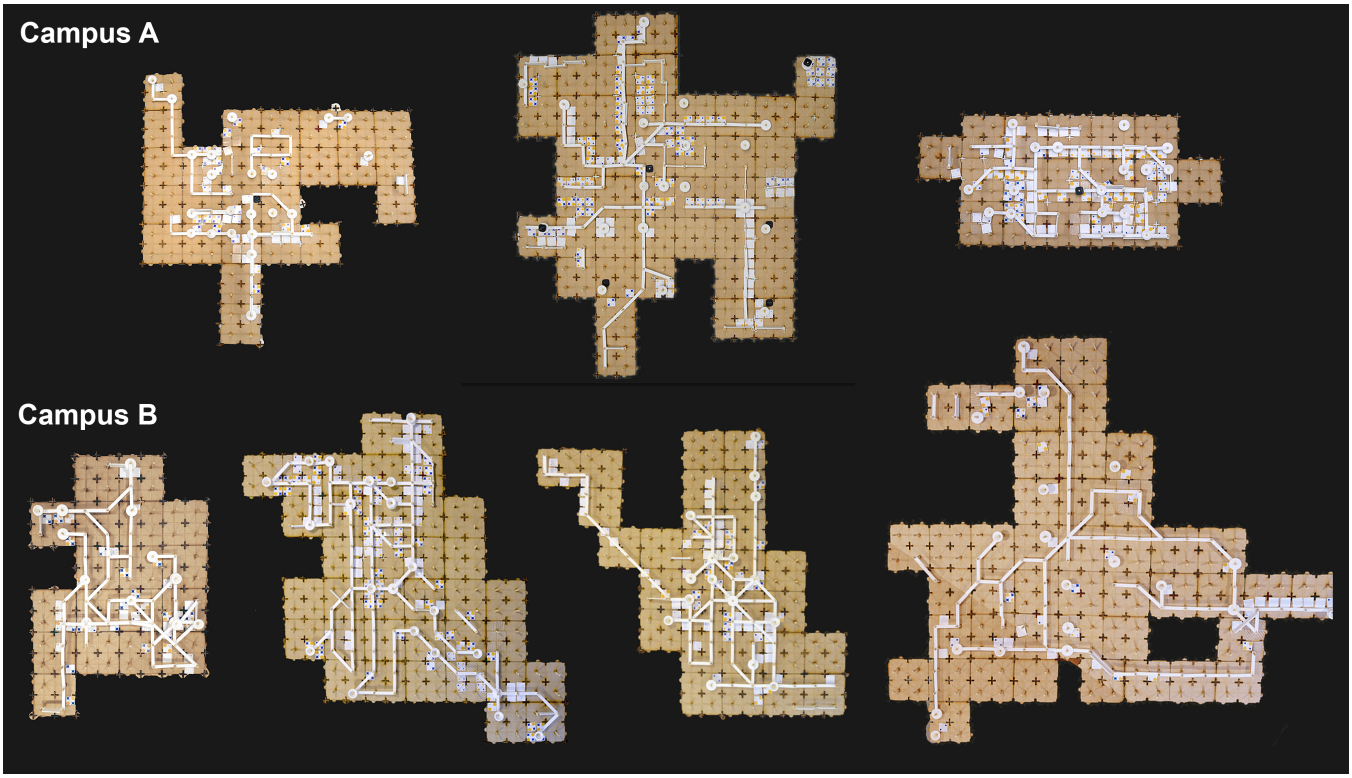

Figure 4: The top-down overview of the seven physicalization outcomes, ordered by campus. It can be noted that physicalization outcomes that convey an identical campus are challenging to compare, despite their consistent data encoding scheme. The apparent differences in size and detail of each physicalization yet form a situational remnant of the construction process that could be interpreted.

As would be expected in an unstructured group conversation, connecting stories seemed to help create a welcoming and productive environment.

Scoring Strategy. Some participants deliberately chose to narrate their stories over specific locations during the first two rounds and to only branch out towards locations that offered them immediate points in the later rounds. We also identified this strategizing in their group discussions: "*If we are going to play the game to win, we should get these*" (P18, Session 5, pointing to the open crosses of their team's color during a second round). Nevertheless, strategizing was not as prominent as only three game sessions showed the expected branching pattern (see Spatial Evolution of Sessions 2, 3, and 5 in Figure 6-1).

5.1.2 Visual Encoding: From data to tokens. The elicited data in a story became encoded in tokens when the participant chose the imageability tokens and feeling cards that best represented the mentioned places, and their emotions.

Predefined encoding. The predefined visual encoding allowed core characteristics between campuses to be identified. For instance, because most stories featured narrations of routines or commuting patterns, they were encoded with path and edge imageability elements. Because yet the physicalization outcomes from campus A contained considerably more edges than of campus B, they accurately reflect their core differences in terms of spatial and infrastructural layout and predominant modes of transport. For instance, campus A elicited a total of 10 stories (25%) included cycling, versus only 1 (1.3%) in campus B, in which most participants narrated driving or walking.

The choice of how to encode the stories into data was also dependent on the encoding capacity of the tokens. As such, many stories foregrounded experiences that were far richer than what our tokens could encode. For instance, feelings of "insecurity" in a dark alley or the "stress" associated with a building where exams were held had to be encoded as "not cozy" or "not inspiring" which does not capture the same nuance. Similarly, depending on the participants' background, even physical activity was encoded as inspirational "*It is somewhat inspirational to bike uphill!*" (P10, campus A, game 3) or even uncomfortable "*It's very uncomfortable because it is such a steep hill*" (P1, campus B, game 7 - taking a blank coziness feeling card). Yet in our design, comfort and inspiration were originally only thought of only in terms of creative practice and calmness of a space, not physical effort. While these nuances were not captured on the board and feeling cards, they were nevertheless understood among the players.

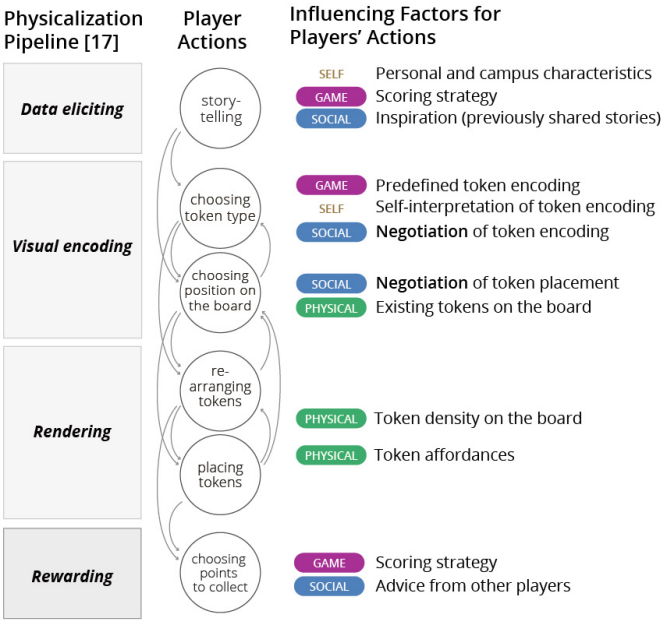

Figure 5: The data physicalization pipeline [17] was extended with a 'rewarding' step to capture how its participatory construction could be nudged via gaming. Each step is annotated with player actions and their influencing factors throughout each game tu rn. These factors are color-coded according to their social, game, and physical-related dimensions.

Self-interpretation. Where tokens were placed was influenced by the internalized scales of the urban mental maps. Participants understood the scale of their campus differently depending on the relative time and attention that they spent discussing a specific location, or on how familiar a location was for them. For example, a walled pavement became depicted as an elongated edge by those who only rarely experienced it, and was more accurately mapped in geometric and relative scale with its entrances and crossings by those who often used it (see Figure 8).

Negotiation. The unavoidable clash among these mental maps manifested as negotiations about accurate token locations and their relative scale (Figure 7). Participants engaged in a conversation during which they compared existing token locations, and even eventually deconstructed and rebuilt already existing board constellations. During one such lengthy example in Session 7, the participants negotiated and re-arranged a constellation of tokens four times while trying to align a newly added landmark to the existing tokens on the game-board (see the moment of intense negotiation in S.7, Figure 6-3). Notably, while most negotiations regarding occurred progressively over the whole construction process, Session 6 spent the first five minutes on discussing the base scale and orientation.

> P3: *Where do you think the library is?*
> P1: *I think it is here.* (pointing)
> P2: *When you turn from the intersection here, it's the mechanical engineering. So…*
> P1,3 and 4 all together: *No way.* [...]
> P1: *Where is the central engineering building then according to your logic?* [...]
> P2: *Just show me the stadium then I can understand.*

(excerpt from Session 6 in campus B)

These negotiations also made the meanings behind the physicalization tokens situated, in that they differed for each deployment. For instance, a landmark token tended to represent different types of things and places in each game. Its meaning was explicitly negotiated as participants externalized their diverging opinions: "*For me this is a 'landmark' because we (our department) collect our books from there.*" (P7, campus A, game 2). In this case, the participants disagreed on using a 'landmark' token and suggested a 'node' token instead, eventually concluding that a landmark was preferable due to the above statement. In other deployments nevertheless, this reference was depicted as a node or not at all. .

5.1.3 Rendering: From multiple tokens to a unified physicalization. In Co-gnito, the rendering step includes all the actions that the players executed to attach and assemble their chosen tokens unto a specific location on the board.

The rendering process was relatively slow during the first game turns, as participants were getting accustomed to the game. Nevertheless, most subsequent turns took less time (mean 6m28s) As shown in Figure 6-3, subsequent turn durations gradually decreased while the peaks in the same graphs for the most part represent the extended time needed for negotiation rather than for rendering. As the game progressed, already constructed tokens were incorporated in new stories, which demonstrates the ongoing shared mental mapping process.

Physical affordances. Given the self-assembly nature of Co-gnito, the rendering of the physicalization was also impacted by the physical design of the tokens and the boards. As the locations of different stories overlapped, the density of aggregated tokens on the according boards increased (see heat map of Figure 6-2). That often meant that to make space to add new tokens, previous ones needed to be removed, rearranged and then placed back. From all the available tokens, the landmark token was most frequently rearranged, since its physical affordance only allowed one particular sequence of placement, in that no other token could be placed on top of it.

Board density. Besides rearranging, tokens were also placed in ad-hoc ways depending on what the board allowed. Figure 9 (middle, right) demonstrates several concrete examples of how the density of token constellations influenced more improvisational placements of subsequent tokens, as participants attempted to respect the expected assembly order as close as possible. Specifically, we observed paths that were left laying on nodes due to lack of space on the corresponding board pole, as well as edges that were placed irregularly so as to avoid rearranging existing tokens (Figure 9-middle).

Because the tokens could be easily shared and concurrently placed, the rendering often occurred in a collaborative fashion. This was especially the case when needing to divide and share more complex token placements. We observed how participants helped each other by assembling additional board tiles, by adding tokens to board tiles that were further away, or by simply giving verbal advice or instructions.

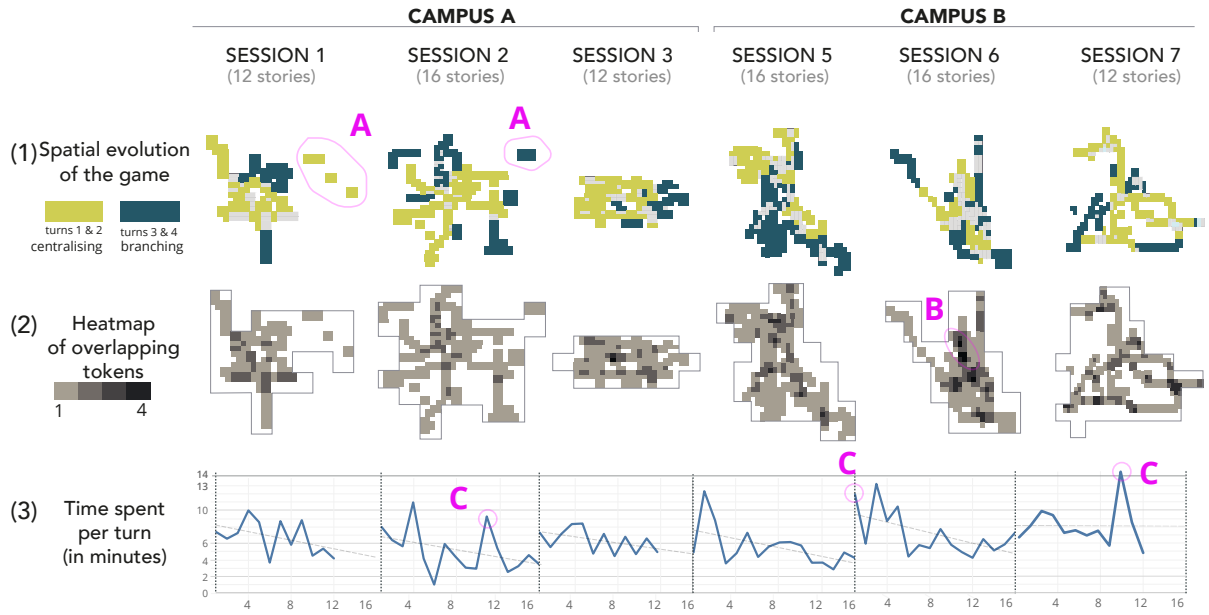

Figure 6: Analysis of each construction session progression, except of Session 4 which suffered a video malfunction. Notable insights are highlighted by a capital letter. A: The highlighted islets are the only two isolated story placements. B: A very densely constructed region, shown in more detail in Figure 7-left. C: Moments of intense negotiations among the players described in Section 5.1.2.

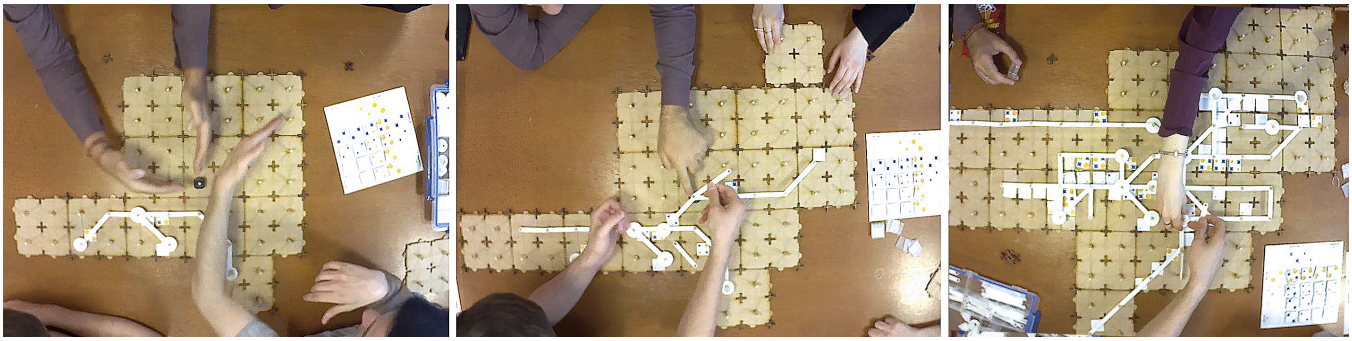

Figure 7: Snapshots from Session 6. Left: Players negotiating the orientation of the main road in comparison to the gate. Middle: Collaborative rendering, a player is placing a path while the other is attaching a new tile towards that direction. Right: Reorganizing a landmark token so as to attach a new path.

5.1.4 Rewarding: Collecting points. Participants seemed to engage well with the gaming aspects of Co-gnito as they never overlooked the reward phase, and they closely guarded their gained points in front of them. In fact, the unveiling of the point crosses became a collective experience of enthusiasm or disappointment, and was the most important theme of the collective discussions that took place after the game finished. In the closing survey, scoring was a contested aspect as 14 participants (N=28) mentioned it as one of three aspects they liked the most, while 5 participants mentioned the scoring as a clearly negative aspect, critiquing that it was unnecessary or biased the results "*Our mapping was affected a little by the desire to get more points and touch points that already exist*" (P25, Session 7). However, regardless of the participant's stance, it did not seem to significantly drive the overall gameplay. Strategic choices were mostly initiated by spontaneous advice from their teammates instead of following well-considered or longer gaming strategy.

5.2 Interpreting the Physicalization

Interpreting possible data patterns in the physicalizations proved to be a complex task for domain experts. We believe that to be the case because the experts needed to learn the encodings on-the-fly

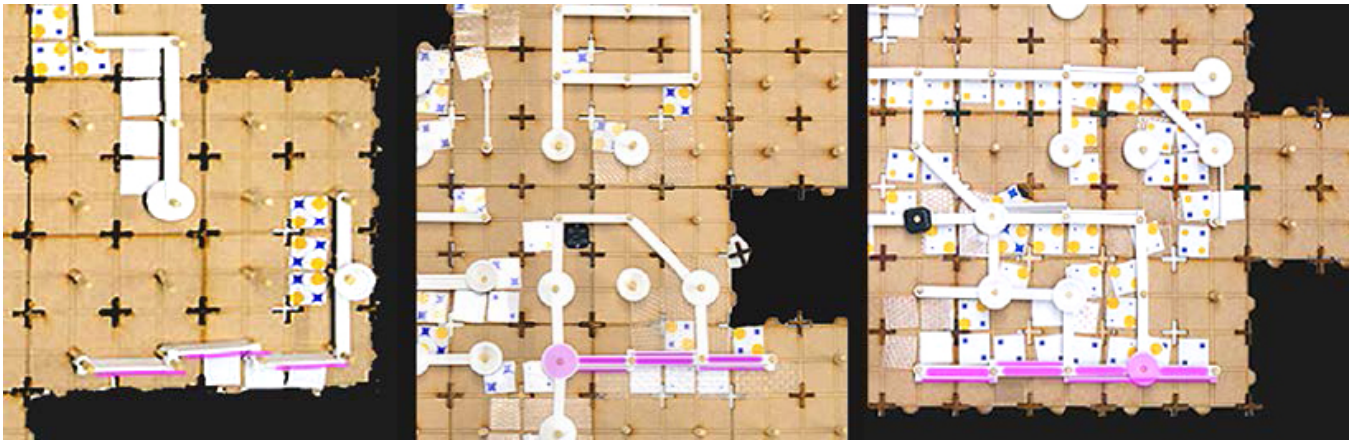

Figure 8: The same location - a long walled pavement that is commonly used to enter the campus - was depicted differently due to participant negotiations during the construction process. It was depicted at different scales (using 1-3 tiles) as well as with different imageability tokens. While in S1 (left) the pavement is represented as an elongated edge due to its wall, it is shown as a path and district in S2 (middle) to represent the forest around the area. It includes an additional landmark token in S3 (right) to convey an entrance.

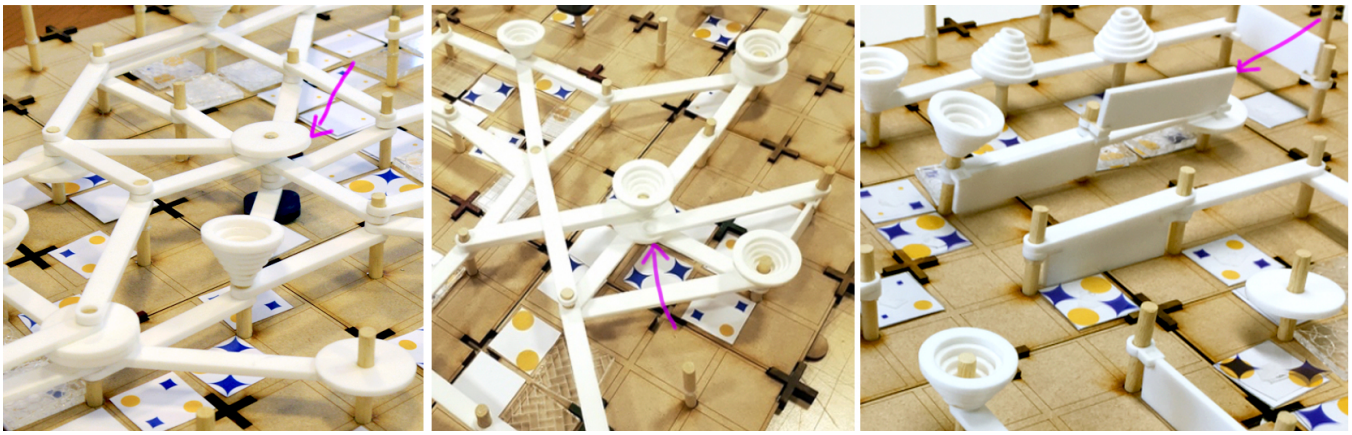

Figure 9: Examples of particularly dense token constellations and exceptionally placed tokens. Left: A dense token constellation of a node with seven paths (snapshot from Session 6). Middle: Too many tokens are overlapping so that paths are left "hanging" (snapshot from Session 4). Right: An incorrectly placed edge, making it resemble a hedge while it actually represents a river (snapshot from Session 1).

while having limited guidance on what specific landmarks or nodes represent. Instead of fully deconstructing and understanding the meanings hidden in the physicalization, experts often started to reflect upon their personal values and perceptions of what the physicalization attempted to convey. They generally put themselves in the frame of the participants to motivate their perspectives "[...] *they see many landmarks*" (E5.2, regarding Session 5) and at times incorporated their own opinions to make synthesizing interpretations, e.g.: "*I think this [pointing] is a very undervalued area of the campus*" (E3.1, regarding Session 3). Overall, the experts were cautious with their interpretations and for those who had not experienced playing Co-gnito for themselves, the physicalization seemed less insightful. In contrast, the experts that had been also players were more actively describing and pointing at locations comparing it to their own experiences, as well as explaining to their colleagues example stories narrated.

6 DISCUSSION

6.1 Co-gnito as an Urban Mental Mapping Tool

Overall, our mapping results are in line with literature in urban design. No two urban mental maps were identical, as each physicalization outcome shown in Figure 4 represents a unique, collectively produced personal and selective representation of the participants' perception. While a single physicalization may not be insightful to domain experts that did not witness it transpire, by detecting patterns, differences and similarities within the series of individual

physicalizations, explicit characteristics with collective meaning can be located. For instance, we could clearly observe different mobility and node distribution patterns among campuses. Examining the compilation of such characteristics, we can distill the respective 'place identity' [39].

Our survey results indicate a consensus among the participants about the game's ability to enhance environmental and spatial awareness, while many of the participants were also agreeing on its ability to enhance social awareness. Moreover, most of the social engagement that occurred was not a result of competitive strategizing, but rather the interaction and sense of sharing among the players. This demonstrates how the storytelling was one of the key features of Co-gnito further differentiating it from other mental mapping techniques. Although the game allowed us to quantify the presence or absence of cozy and inspirational locations, the storytelling also elicited a wide range of more qualitative data about the campuses beyond those two emotions. For instance, through storytelling we could identify how different groups remembered the history of a specific urban space, what they associated the space with and which features shaped their good and bad experiences.

These feelings and meanings of place could potentially be further analyzed and compared among different deployments to define the 'collective meanings', 'collective memory', and 'collective values' for these campuses. Defining such concepts opens a direction for urban designers to understand the phenomenological and experiential values that need to be respected when designing interventions to conserve a place, promote a sense of place among residents or support a sense of community. It also provided a shared goal from which to motivate the sharing of information and reflecting upon its value towards potential future urban design interventions. As suggested in participatory planning literature [10, 11, 47], its benefit thus was not only to support the engagement of individuals but also to use the process as an opportunity for bettering the civic awareness of the urban environment.

Because Co-gnito created a situational context, an event of sorts, where participants felt confident to share and record personally subjective information, we were able to collect first-person urban experiences without the need for impersonal and quantifiable methods such as surveys. Accordingly, we understand the process of playing Co-gnito as potentially even stronger than physicalization outcome itself.

6.2 Co-gnito as a Participatory Physicalization

6.2.1 *The Use of Game Mechanics.*

The use of turn-based rules can facilitate the equal contribution of personal contributions in the physicalization outcome. According to the participants, 'hearing stories from the other players' was one of the most positive aspects of Co-gnito. We find it was the game rules that equalized the opportunity to narrate a story and place tokens. These simple measures thus ensured that the participatory physicalization was equally representative of the mental maps of all participants. Other participatory physicalizations, such as Cairns [12], Physical Bar Charts [20] and Data Strings [8] did not have an immediate need for balancing participation as their construction was primarily asynchronous. We argue therefore that participation dynamics forms a unique aspect of effective synchronous and co-located physicalization construction. For instance, Chemicals in a Creek [32], took a longitudinal approach and ensured equitable participation through their continuous interactions with locals, so that their eventual synchronous physicalization event was representative of that community. While Co-gnito cannot claim the same depth of stakeholder engagement as a longitudinal study, we believe that through its game structure, storytelling and underlying participatory principles, it can form part of a larger participatory action.

Gaming aspects like scoring and storytelling sustained the motivation of collaboratively building up an intricate and laborious physicalization. Adding a rewarding step in Co-gnito's physicalization process foregrounded the relative value of each intermediate contribution towards reaching a common end goal. Moreover, the unveiling of points after each round emerged as a socially collective moment during which participants expressed enthusiasm to score. It was this enthusiasm that helped drive the laborious process of iteratively constructing a physical outcome that was made up of about 106 individual tokens. Nevertheless, even though teams cheered when receiving points, most did not strategize to collect them. We speculate that this was caused by the relatively complex scoring mechanism and the limited time to learn it, or perhaps because of a social disinterest to compete with fellow players. Future work can build on these findings and examine how other rewarding mechanisms, more accessible or without competitive connotation, could be more effective in nudging the participatory construction process.

Accordingly, for synchronous and co-located physicalization, turn-based methods such as gaming can orchestrate equitable participation. This would allow the inevitable group negotiation to focus on the data encoding and rendering rather than the social space required to provide individual contributions. Moreover, when gaming is used as an orchestration method in the physicalization process, the effect of competitive scoring mechanisms should be considered on the collegiality and collaborative experience of the participants.

6.2.2 *The Social Dimensions of Constructing.*

The collaborative rendering process made its outcome reflective of the situated setting in which it was produced. Each of the final physicalizations included dense and sparse areas, depending on where the participants' stories and discussions focused on. Across the deployments, however, these dense and sparse areas emerged differently as they depended on where each group had placed their collaborative attention. Previous research has examined the use of free-form materials without predefined encoding for representing complex internalized concepts (e.g. such as interdisciplinarity) in co-located groups [24]. They demonstrate how the physical outcomes acted less like physicalizations and more as "*tangible evidence*" of a group's conversations. Data Badges [30] also reports on similar behavioral patterns in which the social setting impacted the physicalization outcomes insofar that the participants completely overruled the predefined meaning. While these insights are much inline to our own observations, Co-gnito is unique because of how each deployment differed significantly, even though its procedure

was to a large extent predefined. We therefore speculate that the social dynamics of working together over tangible 'things' and the situated discussions that those may provoke, may be a stronger impacting factor for physicalization construction than wanting to reach its actual outcome with the given predefined encodings.

The ambiguity of the predefined data encoding scheme encouraged collaborative negotiation of meaning. Co-gnito used a partially-defined encoding scheme, as some encodings were predefined (i.e. the imageability tokens, feeling cards) while others were deliberately left undefined (i.e. the scale and token placement). Even when such ambiguous encodings required negotiations among participants, their explicit grounding in theory allowed to commence from a common basis. For instance, although most participants had no previous knowledge of the imageability tokens or Lynch's theory, its simplicity and accessibility allowed them to map subjective data in a consistent way. Even some of the predetermined encodings were collaboratively appropriated. For instance, although the "inspiration" feeling card was meant to depict creativity, it was also used as a proxy for effort, excitement and general pleasantness.

The potential for ambiguity to promote negotiation and engagement has been identified in other settings where participants projected their own understanding onto presented physicalizations [27, 28]. In addition, the appropriation of meaning to a physical token during physicalization construction has been documented in individual settings [15, 42] as people chose differing token encodings when building physicalizations of identical datasets [15]. When creating physicalizations of personal data, participants do not only assign personal meaning, but also reflect on the data and process on the way [42]. Co-gnito expands this view by noting how parts of a data encoding scheme are also negotiated or appropriated during the construction process in a *collaborative* way.

Much like the Mental Landscapes [25], Co-gnito represents qualitative experiences with tangible objects. However, with the use of pre-defined encoding it partially it aims to quantify these experiences so that different participant groups or even third parties can interpret them. These numerical values might not be fully accurate, nor are their encodings meant to be analytically analyzed, yet they "*bring space for collective reflection*" [32] not only among participants but also among participants and urban designers.

Therefore, we argue that collective negotiation may well be an integral part of co-located, synchronous participatory physicalizations. Designers can thus leverage or then limit such negotiation by using more open or stricter data encodings schemes in their physicalizations.

6.2.3 *The Impact of the Physical Affordances.*

The metaphorical embodiment of the tokens helped players to indirectly assign meaning. Unlike standardized building blocks like Lego, the Co-gnito imageability tokens mimicked real spatial aspects of the data dimensions they encode. Their physical shapes were designed to literally depict reality, as to decrease their metaphorical distance to the data [48] and increase their memorability [25]. This metaphorical depiction was not straightforward, as for instance the edge token - due to its long, flat-like shape and placement - was sometimes interpreted as a wall when placed normally and sometimes as a hedge when placed upside down (Figure 9), thus encouraging some creative reinterpretation to happen.

The token modularity allowed for sharing the rendering process among multiple participants. The tokens were specifically designed to be physically linked and combined in a particular order, as to reflect how a story transgressed over space and over already told stories. Yet the modularity of the boards and tokens also allowed the coordination and distribution of the rendering process among all the participants, even when it was not their own turn. The modularity yet also complicated the design of the tokens, as for instance each edge and path needed to be fabricated in various complementary sizes to account for their diagonal and orthogonal placement (see Figure 2a).

Product design research already suggests how assembly instructions could be avoided by incorporating appropriate physical affordances of objects to guide their assembly . These, for instance, use color-coding to indicate connecting pieces [31] thus indirectly nudging how separate pieces should be connected. Since, to the best of our knowledge, physicalization research has focused on self-reliant tangible tokens, Co-gnito forms an exemplar of how the modular interdependency among tokens can nudge physicalization construction towards specific assembly sequences or directions.

Consequently, the physical token design might well support collaboration during synchronous participatory physicalization. Designers should consider using token modularity or even intuitive shapes that hint towards their self-assembly to orchestrate the physicalization, perhaps thus even reducing the need for a facilitator to guide the process.

6.3 Future Work

We claim that Co-gnito is an inclusive tool for community decision-making that can engage multiple stakeholders in the urban design process. It demonstrated the ability to create a trusted context in which personal stories and critical discussions could emerge among diverse groups of individuals about the urban environment. Future research could therefore focus on how it could become integrated into a longer participatory process. For instance, future work could focus on Co-gnito's potential for different demographic groups like children or new migrants. Reflecting on our findings, this potential might not only be for collecting urban mental maps, but also for helping these groups develop their spatial cognition, their collegiality and collaborative spirit, or even their broader sense of community culture. The physicalization outcome can then be used as an identifier for that community drawing from previous collaborative data projects where the members even eventually hold a feeling of ownership of the design [2].

In urban design as well as in physicalization, physical models are used to help simulate and provide context of specific designs [14]. Considering Co-gnito as an 'input' physicalization [16] that collects new and in particular qualitative and personal data into a model, we could start to examine how to augment its interaction modality. Projecting quantified open data for instance could allow urban planners to compare the 'lived' versus the quantified experiences. Including further annotations or other markings from participants themselves directly on the tokens would also permit more nuance

in the type of experiences collected, and perhaps even make their interpretation easier.

Regarding the physical design, future research could investigate more sophisticated ways of guiding the data encoding process or developing new types of modular tokens that only can be physically assembled in meaningful ways. For example, digitally augmented tokens, as in the case of the Zoids [22], can be redesigned both physically and programmatically with more sophisticated physical affordances to guide smoother or dynamic, and potentially even algorithmically-driven construction.

Similar to the findings of Data-things [27], we recognize the social potential of sharing the 'making' process of a physicalization as a communal activity. The participants clearly "looked through each other's eyes" to create shared meaning, which became further augmented by the explicit need to merge and align their individual goals within the same physicalization. It is obvious that participants reached a situational understanding of the physicalization outcome that is close to impossible to be attained by people who were not present during its actual construction. This so-called "reflective power" which is generally recognized during communal making [34, 42] seems to be particularly applicable to collaborative and synchronous physicalization construction. The ability to facilitate more accessible forms of data elicitation and its collective discussion – next to its already established power to facilitate data analysis - thus points to promising application domains for educational, participatory or interdisciplinary sensemaking purposes.

6.4 Limitations and Shortcomings

Although deployed multiple times in two different contexts, Co-gnito only demonstrates one particular and custom implementation of how the gamified collaborative construction of a physicalization can be facilitated. Several other game design principles could have been integrated, potentially leading to other engagement patterns from participants. However, because Co-gnito deliberately mixed different forms of restrictive as well as open-ended game rules and physical affordances, we believe the variety of our findings enabled us to generalize some qualitative considerations that can inform future research.

We also realize that when drawing conclusions regarding a physicalization outcome, the application of urban mental mapping inherently comes with several domain specific constraints that are not necessarily representative to the more numerical and space-agnostic datasets. While we find the physicalization of qualitative and highly subjective data a strength of Co-gnito, more research is needed to generalize our findings to more quantifiable and analytical contexts. For instance, as participants had to immediately imagine and directly encode stories, their generalizations among the different deployments was challenging. Comparing the processes and outcomes of deployments with objectively identical datasets might reveal more causal influences to how participants deal with different construction strategies.

7 CONCLUSION

We developed and deployed Co-gnito, a participatory physicalization game for urban mental mapping through which personal user experiences were synthesized into a single physicalization. We showed how gaming process with partially predefined tokens can produce unique physicalizations that are representative of a complex collaborative process and yet are still relatively comparable. We discovered that the physicalization construction process is mainly influenced by three intertwined processes, i.e. the social aspects of negotiating the underlying data encoding scheme; the affordances of the physical tokens that encourage or resist specific physical combinations in predetermined ways; and the game mechanics that can sustain playful forms of engagement towards a common goal. Our study contributes to physicalization research with a working research prototype as well as by providing empirically-grounded considerations for designing co-located and synchronous participatory physicalizations. These findings can be particularly useful in emerging physicalization application domains that require collective action, such as citizen participation, constructivist teaching and cross disciplinary sense-making.

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