Cognitive Inhabitation Analysis: Demonstrating Cognitive-Agent Simulation in BIM-Based Architectural Space

인지형 에이전트를 활용한 BIM기반 건축공간의 거주 시뮬레이션 분석 연구

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Abstract

Space gains its use from the relation between form and occupant, yet design-stage prediction has rested on form alone. This study demonstrates Cognitive Inhabitation Analysis: agents with memory, reflection and planning inhabit an unbuilt BIM school plan and the space is read from their conduct. In three days and three seeds, 36 agents left trajectories and 1,542 free-time conversations, read as five patterns: anchoring, encounter, appropriation, diffusion and adaptation. The output answered to space, occupant and time. Where form predicts, it converged with space syntax (occupancy $r = 0.62$, co-presence $r = 0.67$); where form is silent, it read further: cross-grade encounter was set by layout, not disposition, identical clusters diverged in use by grade, and bonds accumulated across days. The method thus brings inhabitation into the design stage and shows, before construction, what layout governs and what the occupant does.

Keywords : Cognitive Agent, Cognitive Inhabitation Analysis, BIM, Inhabitation Simulation

1. Introduction

1.1 Background and Purpose

Architectural space is, before it is a static volume enclosed by walls, an active condition that prompts conduct in the people within it. Space induces conduct, and so gains its use, in the relation between form and occupant. Architectural planning is the work of predicting in advance the conduct that will take place in a space not yet built, and its grounds have long lain in form. Space syntax computes, from the topological relations of a plan alone, the likelihood that people will gather and pass through, and so offered a way of reading the potential for encounter from a drawing at the planning stage (Hillier & Hanson, 1984). Yet form-based analysis, space syntax among it, which predicts conduct from form alone, lacks the other two axes that constitute space, the occupant and time, and so cannot answer when, and whose, conduct that potential becomes.

Attempts to fill this gap led to a conceptual framework that would set the occupant up as an agent of conduct (Cha & Kim, 2015) and to cognitive occupancy modelling on BIM (Gath-Morad et al., 2022); the former, having no means of reproducing judgement, remained a concept, and the agents of the latter only followed rules and accumulated no memory. Generative agents built on large language models (LLMs), carrying a cycle of memory, reflection and planning, then produced everyday behaviour resembling that of people (Park et al., 2023), but their stage was a virtual environment rather than an actual drawing; neither the study that moved them indoors (Wu et al., 2025) nor the case that put them to walking at urban scale (Noyman et al., 2026) observed the structure of inhabitation at the scale of a building. In Korea, a proposed architecture for a design system (Kang et al., 2025) and an indicator framework that places AI as the agent of design (Park, J.-S., 2026) likewise did not take the occupant's behaviour as the object of observation. A cognitive occupant and an actual design proposal, that is, have not yet been realised in one place.

This study demonstrates, on a single design proposal, a method that houses cognitive generative agents in the space of an actual proposal and reads that space from their autonomous conduct (hereafter Cognitive Inhabitation Analysis). Whether the output is valid as analytical material is verified on two counts. First, whether the output converges with the predictions of space syntax. Second, what it nonetheless reads through the occupant and time, which form-based analysis does not have. The first is a necessary condition of the method; the second is its distinctive contribution.

1.2 Scope and Method

Observation was limited to free-time conduct within a single school design proposal, because there groups of differing disposition share one building and the daily timetable contains autonomous periods in which no destination is assigned. The method is to house 36 cognitive agents — equipped with memory, reflection and planning, and deciding destination and dialogue through an LLM — in a space derived from an IFC (BIM) model, to simulate three days, and to repeat this with independent seeds departing from the same initial state, confirming that the patterns are not the accident of a single trial. The analytical material is the movement trajectories and the free-time conversation logs the agents left behind (1,542 sessions over all seeds), and every measure is derived from these two alone. The scope of verification is limited to relational validity — whether the output responds systematically to the variables of space, occupant and time; correspondence validity, agreement with the behaviour of actual students, lies outside it for want of a measured control.

2. Setting of the Study

2.1 Space

The subject is a two-storey school design proposal in which three grade groups, from the lower primary years to the middle-school years, live in one building. A central commons stands at the centre, with the clusters of the three grades branching around it, and each cluster gathers four classrooms and a group room about its lounge. The central commons, the cafeteria, the entrance and the like, lying outside the clusters, are called the shared zone. The three clusters are planned to be symmetrical to one another in form and in connection, which makes them well suited to observing whether conduct diverges in spaces of identical form. The spatial environment was produced by reading the geometry of rooms, walls, doors and stairs directly from the IFC (BIM) model and converting it into three grid layers — passability, floor membership and visual permeability — at one tile per 0.5 m (Fig. 1).

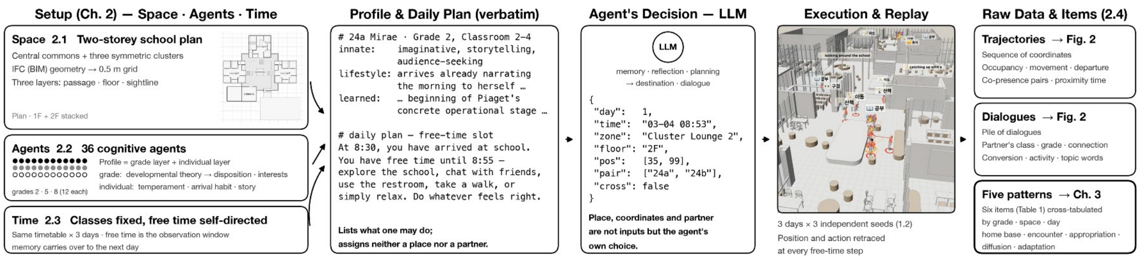

Fig. 1. The setting and the output of Cognitive Inhabitation Analysis

2.2 Occupant

The groups are three, grades 2, 5 and 8, with clear intervals of developmental stage between them: twelve agents to a grade, 36 in all. On the cycle of memory, reflection and planning (Park et al., 2023), each agent is given an individual profile that adds a personal temperament, habits of coming to school and a background description to the disposition, interests and vocabulary level of its grade, grounded in developmental theory (Piaget & Inhelder, 1969; Erikson, 1963). The profile designates no place and restricts no companion, and even its free-time entry only gives examples of what might be done. The choices of space and the exchanges reported in Chapter 3 are therefore the product of judgements the agents made for themselves through the LLM.

2.3 Time

In the temporal environment the times of arrival, lessons, lunch and leaving are fixed by a timetable, and observation takes place in the free time between the fixed lessons. A day of the same timetable runs three times over; because each agent stores the day's experience as memory and acts upon it again the next day, time becomes a coordinate axis alongside space.

2.4 Items of Analysis

What the simulation leaves behind is a list of coordinates and a heap of dialogue, and the setting of the items of analysis — what is to be counted, and how divided — is itself this method's way of reading. The raw data were aggregated mechanically into the six items of Table 1. Co-presence is the state of two agents being in the same room at the same time; proximity is co-presence within 8 m; the link rate is the share of student pairs that talked at least once within the three days; the conversion rate is the number of conversations divided by the time spent together; and activity words are the nouns extracted from the dialogue in order of frequency. Cross-tabulated by grade, space and day, five patterns were read repeatedly, and these form the sections of Chapter 3; anchoring, encounter, appropriation, diffusion and adaptation are not a framework set up in advance but names for phenomena that emerged after the fact.

Figures in the text are from seed 1 unless otherwise noted, and results common to all three seeds are marked *all seeds*. The raw data (trajectories and conversation logs), the ledgers behind the tables and figures, and the replay are published at cognitiveinhabitation.com/paper1.

Table 1. The items of analysis for the two records, and the phenomena read from them

Record	Item of analysis (measure)	Phenomenon read
Trajectory	Dwell distribution by space · intensity of movement · maximum excursion distance	Anchoring, appropriation
Dialogue	Class composition of the companion · pair link rate	Anchoring
Trajectory	Number of co-present pairs · time in proximity	Encounter
Dialogue	Where the conversation occurs · grade of the companion · conversion rate	Encounter
Dialogue	Frequency of activity words · kinds of collaborative topic	Appropriation, diffusion
Trajectory + dialogue	Movement of topic words by day and by space, and adoption rate	Diffusion, adaptation

3. Observation

3.1 Anchoring

Each grade's cluster lounge worked as the anchor where the time of the grade gathered, and as the place where bonds were made at the scale of the grade, across the boundary of the class. Agents spent between one half and two thirds of their free time inside their own cluster, and within it the lounge was the single room dwelt in longest in all three clusters (20–33%, all seeds). Conversations among classmates stay inside the classroom, whereas conversations with a student of another class leave the classroom and gather in the lounge (Fig. 2a). The share of student pairs that talked at least once within the three days was 100% for the same class, 71–75% for a neighbouring class of the same grade and 11–13% across grades (all seeds); there were no isolates, and the unit of bonding widens from the class to the grade. The anchor, then, is where the ties and the identity of a grade are made, and the divergence by grade in §3.3 takes place against this bonding.

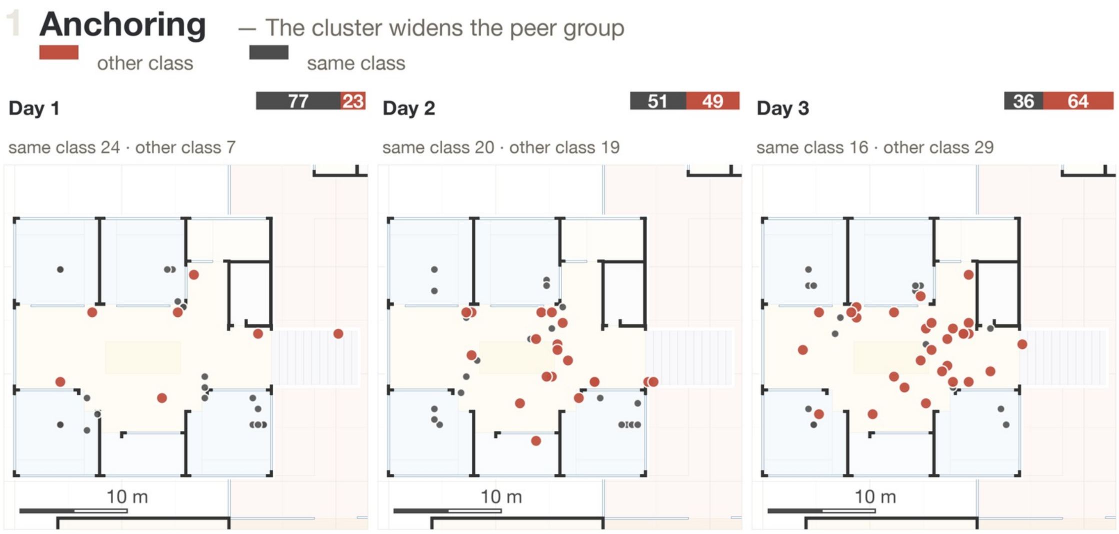

Fig. 2a. Anchoring — the cluster widens the peer group (three days, seed 1)

3.2 Encounter

The central commons worked as almost the only place where the boundary between grades broke down. Between 95 and 98% of cross-grade conversations occurred in the shared zone, against 7–13% of same-grade conversations, and 98.8% of cross-grade pairs were co-present in the central commons (Table 2, Fig. 2b). Dividing the number of conversations by the time spent together, same-grade pairs across the building converted into conversation about 3.4 times as often as cross-grade pairs; confining the comparison to the inside of the central commons, the ratio falls to 1.3 (95% CI 2.70–4.52 → 0.73–2.26). Of the 3.4-fold homophily, then, 2.6-fold is the proximity component of a layout that has the same grade meet in a dense cluster and other grades meet in a sparse centre, and this component is significant in all three seeds (all seeds 2.2–3.7 fold, lower bound of the 95% CI 1.4–2.2). Since the central commons sets the opportunity to meet and the layout sets the proximity, encounter between grades is an outcome set by layout more than by disposition.

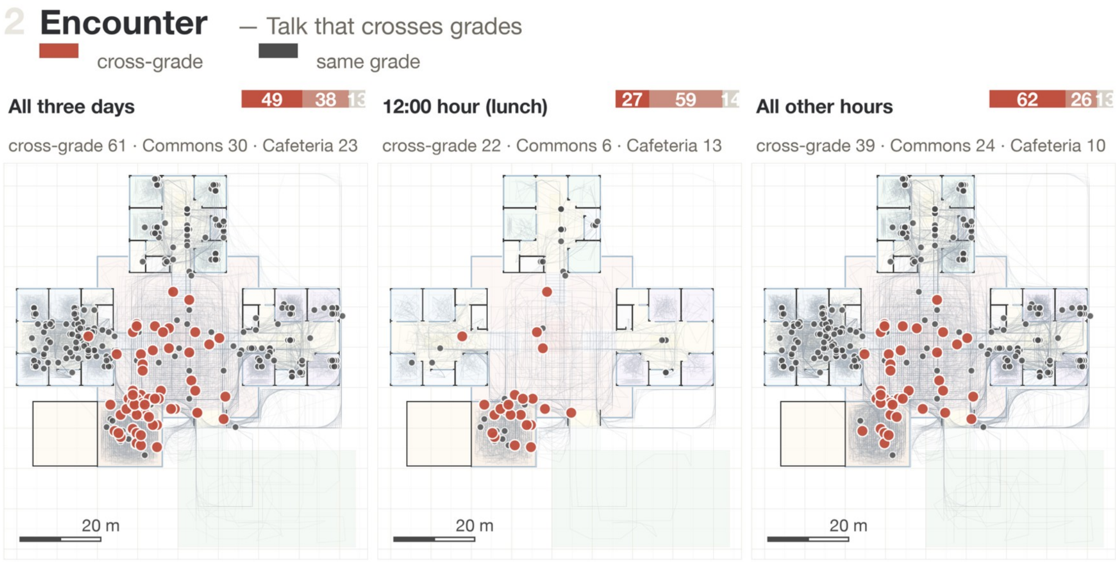

Fig. 2b. Encounter — talk that crosses grades (seed 1)

3.3 Appropriation

The three clusters were planned with an identical composition, yet their actual use diverged from grade to grade (Fig. 2c). Grade 2 moved the most within its cluster, more than twice as much as grade 5; grade 5 dwelt longest in the lounge, at 31%; grade 8 made the greatest use of the group room and the classroom, and the use of the group room rises with the grade, 5 → 13 → 17%. Movement and conversation diverge in opposite directions: grade 2, which moves most, converses least, and grade 5, which moves least, converses most (25.9 and 31.0 conversations per agent). The activity words show that this difference is one of kind rather than of quantity. Grade 2 is marked by bodily imaginative play such as treasure hunts and pirates, grade 5 by collaborative making such as murals and quotations, and grade 8 by formal work such as presentations and visual material. What repeats across all seeds is the category of activity, while the specific vocabulary is generated anew in each trial; the divergence is therefore not a replay of the input sentences but the expression, in activity and in place upon the space, of the developmental disposition that was given as input.

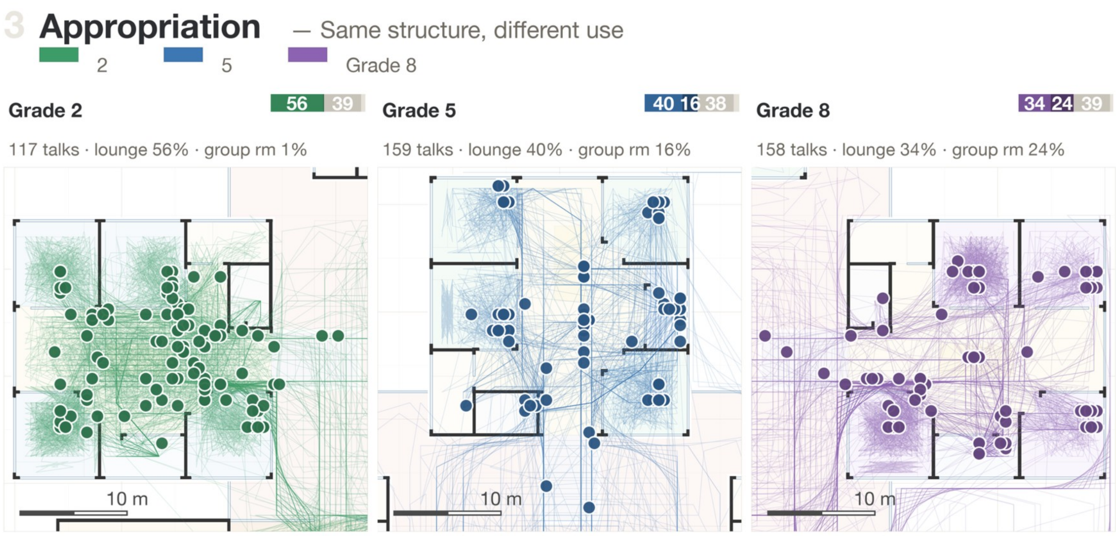

Fig. 2c. Appropriation — same structure, different use (seed 1)

3.4 Diffusion

Collaborative topics originating in each cluster moved to other grades through people. About half of the conversations that crossed grades took place in the central commons alone (49%; all seeds 49–54%), and tracing a single topic shows that same-grade discussion is already spread across the grade on the first day, while cross-grade conversation accumulates in the shared zone as the days pass (Fig. 2d). Diffusion, then, is not a process radiating out of the cluster but one that accumulates as exchange between grades, with the central commons for its interchange.

The topics carried across, however, were not adopted by every grade. Normalising the degree to which each grade's representative topic is adopted in the same-grade conversation of another grade, with self-adoption set at 100, between 7 and 17% crosses over between grades one step apart (2↔5 and 5↔8), whereas between grades two steps apart (2↔8) the figures are 0.4% and 0.6% in both directions, effectively severed (mean of all seeds). Since the break occurs at two steps whichever grade is the origin, the cause of the blockage appears to be the interval of developmental stage.

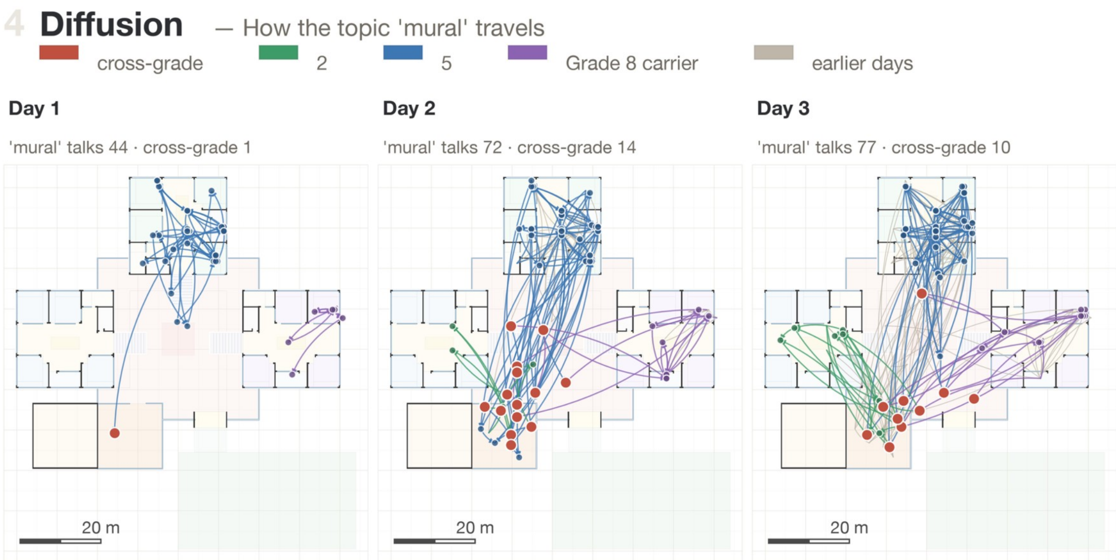

Fig. 2d. Diffusion — how the topic 'mural' travels (seed 1)

3.5 Adaptation

The four patterns above are not static distributions; they accumulate as the days pass. Within the cluster, the share of same-grade conversations held with a partner from the neighbouring class rose each day, 40 → 49 → 59% (all seeds, §3.1). Conversations crossing grades (§3.4) likewise rose from 13 on the first day to 22–23 on the second, and then stayed at that level (mean of all seeds). Time, then, is an observable axis that form-based analysis does not possess.

4. Analysis

4.1 Convergence

To see whether the findings of Chapter 3 conflict with what is already known, Table 2 sets a space-syntax analysis of the same proposal beside the observations of Chapter 3. As the subject is an interior, the room was taken as the unit; adjacency was composed from the IFC room coordinates and the openings, with a lounge open to the atrium taken as adjacent to the central commons; and the measures were computed against depthmapX 0.9.1. Dwell over the whole three days correlated with global integration at r = 0.62 (Fig. 3), and the number of co-present pairs with choice at r = 0.67. Because integration falls into three tiers — hub, lounge and leaf — this correlation is a convergence at the level of tiers.

The three grade lounges are identical local cores and gateways (Table 2), and that standing was realised as the anchoring function of §3.1. The visual structure differs: the first floor is a single visual field cored on the central commons, while the second divides into three fields, one per grade, and standing in the lounge brings almost the whole of one's own grade territory into a single view. The structure, then, is one in which circulation divides by grade while sight is shared.

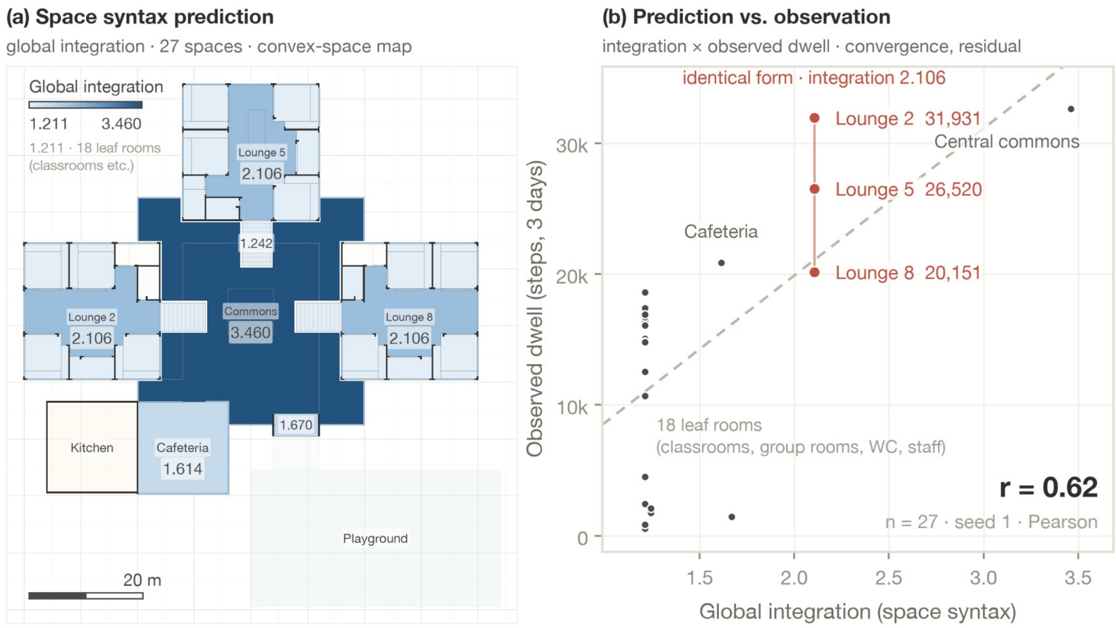

Fig. 3. (a) Global integration; (b) integration against three-day dwell (dashed line: least squares)

Table 2. The predictions of space syntax against the observations of the simulation

Prediction of space syntax	**Observation of this study**	**Correspondence**
Central commons: highest global integration (3.460) and highest choice	Dwell r = 0.62 (Fig. 3) · co-presence r = 0.67 · 98.8% of cross-grade pairs co-present in the central commons (§3.2)	Agrees
Three lounges: identical local cores and gateways (R3 2.16 · control 7.62)	The lounge is the longest free-time dwell in each cluster (20–33%) · the share of the neighbouring class in conversation within the cluster increases (§3.1)	Agrees
First floor a single visual field; second floor three fields, one per grade	A division of function between bonding in the cluster and diffusion at the centre (§3.1, §3.4)	Agrees
The three clusters topologically identical (symmetrical)	Use of space and content of activity diverge by grade (§3.3)	Extends

4.2 Extension

If the first three rows of Table 2 are the realisation of a potential that form predicted, the last row is of another character. Where form-based analysis judged the three clusters to be the same, behaviour diverged by grade; this is not convergence but the place where observation extends beyond the prediction of form. Since the profile is the only setting that differs systematically among the three grades, the divergence is attributable to the occupant.

Setting out, for each of the five patterns of Chapter 3, the place where form-based analysis is empty gives Table 3. Form-based analysis has no occupant to turn potential into outcome, and so has neither the trajectories nor the conversations that an occupant leaves; nor has it the coordinate axis of time.

Table 3. Where form-based analysis cannot answer, in each of the five patterns

Pattern	**Axis of measurement required**	**Why form-based analysis lacks it**
Grade bonding at the anchor	Occupant (trajectory + dialogue)	Nodes carry no membership of class or grade
Decomposing encounter into proximity and preference	Occupant (trajectory + dialogue)	It predicts co-presence but cannot see the conversion into talk
Divergence by grade in topologically symmetrical space	Occupant (trajectory + dialogue)	Where topology is identical, the judgement is identical by definition
Propagation of topics and the two-step block	Occupant (trajectory + dialogue)	It predicts flow but does not carry dialogue
Adaptation across the days	Time	It has no concept of change at all

5. Conclusion

This study housed 36 cognitive agents for three days in a school design proposal not yet built, and demonstrated Cognitive Inhabitation Analysis, which reads space from their autonomous conduct. The output answered to space, to occupant and to time alike. Where form predicts, it converged with space syntax, and the agents gathered where form had predicted they would: within a grade, each cluster's lounge became the anchor, and encounter between grades took place in the central commons. Where form cannot answer, Cognitive Inhabitation Analysis distinguished that encounter to be a product of layout rather than of disposition; showed that the use of three clusters identical in form, and the adoption of topics, diverge with developmental stage; traced the route by which a topic crosses grades through people; and confirmed that bonds and exchange accumulate as the days pass. Cognitive Inhabitation Analysis thus brings inhabitation, visible until now only after completion, forward into the design stage, and separates — before building — what layout governs, what is attributable to the occupant, and what time accumulates.

This is a demonstration study confined to three days of observation on a single proposal with a single LLM, and because the profiles were set by the researchers their subjectivity is carried into the results. Two tasks remain. Measuring several proposals of differing layout by the same rule, under the same settings of occupant and time, would make the measures of this study a ground for comparing alternatives; and establishing measures of how an occupant perceives and remembers space would carry this method from the observation of conduct to the observation of cognition.

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