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Emerging transformative design in healthcare architecture: Integrating space syntax and shape grammar in Maggie's centers

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Abstract

Healthcare architecture must balance operational efficiency with environments that nurture well-being, empathy, and dignity. This study introduces a computational framework that integrates space syntax and shape grammar to uncover the design "DNA" behind Maggie's Centers—a network of cancer care facilities celebrated for their human-centered approach. Through quantitative spatial analysis and rule-based generative modeling, we identify recurring patterns that position communal hubs (e.g., halls and kitchens) at the core, while establishing peripheral zones for privacy and specialized functions. The resulting "dominant genotype" not only validates the empirical performance of these spaces but also offers a replicable design blueprint that can be adapted to diverse healthcare settings. This integrative methodology empowers architects and planners to create healing environments grounded in measurable spatial strategies and generative processes.

Keywords: Space Syntax; Shape Grammar; Healthcare Architecture; Maggie's Centers; Computational Design

1. Introduction

The design of healthcare environments strongly influences patient well-being and staff satisfaction, particularly under stressful conditions [1,2]. Evidence shows that spatial qualities such as access to natural light, intuitive layouts, and supportive social areas can reduce patient stress, enhance comfort, and promote faster recovery times [1]. Maggie's Centers exemplify how human-centered design principles can foster both emotional support and operational functionality [3].

Computational methods have emerged as powerful tools for decoding and shaping these environments [4]. Among these, space syntax provides quantitative measures of spatial connectivity and integration [4,5], while shape grammar describes and generates designs via rule-based transformations [6,7]. Yet, few studies combine both approaches within healthcare contexts to produce evidence-based and reproducible design guidelines. Consequently, this paper proposes an integrated methodology, focusing on Maggie's Centers as a case study to illustrate how space syntax and shape grammar can be synthesized to inform future healthcare architecture.

1.1. Computational Design in Architecture

Computational design integrates algorithmic thinking, data-driven analysis, and generative strategies to explore vast solution spaces in architecture [8]. Historically, architecture has relied on intuition and precedent; however, today's computational methods can reveal hidden spatial patterns, optimize layouts, and even encode an architectural "language" into generative systems [9,10].

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One facet of computational design examines configurational properties—how rooms, corridors, and nodes connect to influence movement and social interaction [4,5]. Another facet targets form-making rules—the stylistic or functional constraints that shape a building's geometry [6,7]. When used in tandem, these computational tools can systematically evaluate design concepts before they are built, offering architects predictive insights into user experience, wayfinding, and operational efficiency [8,9,10].

1.2. Space Syntax

Space syntax was introduced by Hillier and Hanson to quantify how spatial layouts affect social and behavioral patterns [4]. By measuring parameters such as integration (the relative accessibility of a space within a network) and connectivity, space syntax helps predict pedestrian flow, wayfinding ease, and the potential for social encounter [5]. Early applications ranged from urban planning to museum design, demonstrating how small alterations in layout can significantly transform user experience [4,8].

Healthcare architecture quickly recognized the value of space syntax analyses [11]. Studies show that corridor configurations, placement of nursing stations, and visibility between units can affect staff efficiency and patient perceptions of safety [12,13]. Specific research has highlighted how high-integration zones (e.g., a central kitchen in a cancer care facility) become crucial social nodes, promoting communal interaction [14]. Conversely, private areas often appear in lower-integration zones, offering respite and privacy for patients [15].

Recent contributions to space syntax highlight its ability to measure nuanced interactions, such as patient aggression risk [16] and workplace violence prevention [17]. By pinpointing potentially stressful or confusing circulation points, designers can adjust layouts for enhanced patient and staff well-being. Beyond interiors, space syntax extends into the urban fabric, helping create walkable neighborhoods around hospitals to encourage physical activity and better community integration [18,19].

1.3. Shape Grammar

While space syntax clarifies how spaces function socially and operationally, shape grammar delves into why architectural forms appear as they do [6,7]. Introduced by Stiny [6], shape grammar dissects the "language" of an architectural style or typology into formal production rules. For example, a grammar might specify how windows, doors, and courtyards combine to create distinct spatial patterns [9].

In healthcare architecture, shape grammar enables designers to encode best practices—such as the adjacency of a nurse's station to patient rooms or recommended proportions for communal lounges—into formal rules that generate new yet contextually aligned designs [7,10]. This approach shifts design from a purely intuitive exercise to a repeatable, rule-based process that maintains stylistic coherence while adapting to different sites or programmatic demands [14].

Researchers have also used shape grammar to balance empathy and warmth with clinical imperatives [20]. By embedding "healing" design cues (e.g., domestic-scale kitchens, garden views, home-like finishes) into the grammar, healthcare facilities can retain institutional efficiency without feeling impersonal [21].

1.4. Applications in Healthcare Architecture

Healthcare facilities epitomize the complexity of architectural problems, combining stringent safety, clinical, and workflow requirements with the emotional and psychological needs of patients and staff [1,2,11]. Studies using space syntax have found that more intelligible layouts reduce wayfinding errors and stress, especially in high-urgency zones like emergency departments [17,22]. Similarly, shape grammar has been applied to decode hospital designs or generate prototypes that balance standardized clinical modules with local cultural preferences [14,20].

Significant research also points to the therapeutic potential of nature integration, daylight, and communal kitchens in cancer care environments [1,3]. These elements, once seen as purely aesthetic, are now understood to influence stress levels, social connectivity, and patient satisfaction [2,23]. In pediatric intensive care, for example, an open layout can foster mutual support among families but must still preserve private spaces for respite [24].

Across cultural contexts, from Australia to China, studies reveal that layout intelligibility and cultural specificity both matter for patient-centered care [19,25]. Additionally, the planning of outdoor spaces and the urban interface can encourage physical activity and social support networks, thereby extending a healthcare facility's impact on public health [18,26].

1.5. Maggie's Centers as Case Studies

Maggie's Centers stand at the forefront of human-centered, healing design [3]. Established to support individuals affected by cancer, each Maggie's Center blends domestic-scale architecture, natural light, and communal "kitchen-table" living to foster emotional comfort alongside clinical support [15]. While each facility reflects the vision of a different architect, recurring spatial patterns emerge—such as a welcoming central kitchen, accessible gardens, and fluid transitions between public and private zones [3,15].

Applying space syntax to Maggie's Centers reveals consistently high-integration nodes around the kitchen and central hall, emphasizing communal interaction [14]. Shape grammar studies similarly point to reproducible form-making rules—e.g., the adjacency of gardens or courtyards to living areas—that reinforce physical and emotional connectivity [20]. By synthesizing these computational insights, designers can identify a "spatial-functional genotype" that transcends individual design variations, offering lessons for broader healthcare settings.

1.6. Integrating Space Syntax and Shape Grammar

Although space syntax and shape grammar each contribute valuable insights, their combined application in healthcare architecture remains underexplored [16]. Space syntax quantifies how spatial configurations drive movement, social interactions, and even clinical outcomes [13,16,17]. Shape grammar, in turn, codifies why these configurations arise stylistically and functionally, defining a generative "language" that can be adapted to new contexts [6,9,20].

In Maggie's Centers, for example, space syntax identifies the core kitchen area as a high-interaction node, while shape grammar rules illustrate how certain volumetric or plan-based relationships consistently produce intimate, welcoming interiors [14,15]. By merging these findings, architects can replicate the centers' person-centered qualities—communal belonging, intuitive navigation, and quiet refuges—in future designs without resorting to direct imitation [3,21].

This methodological synergy also facilitates stakeholder engagement. Designers can present shape grammar–based variants, pre-evaluated via space syntax metrics, to patients, clinicians, and community members for feedback [23,27]. Such a process ensures that proposed layouts address both the operational and emotional imperatives of healthcare, grounding every decision in measurable, adaptable rules.

2. Methodology

This study employs an integrated methodological framework that unites Space Syntax and Shape Grammar to identify and codify transformative design principles in healthcare architecture. By focusing on six Maggie's Centers—renowned for creating supportive environments for individuals affected by cancer—the research reveals underlying spatial patterns and generative rules that can guide future healthcare designs.

2.1. Research Design

A mixed-method approach was chosen to combine:

- *Quantitative Spatial Analysis (Space Syntax)* – measuring how layout affects movement, wayfinding, and social interaction (e.g., integration, connectivity, visibility).
- Rule-Based Generative Analysis (Shape Grammar) – deconstructing and reproducing the architectural "language" of Maggie's Centers to understand the formal logic governing their layouts.

By synthesizing these two computational perspectives, the methodology illuminates both the empirical performance of spaces and the underlying generative logic of architectural forms.

2.2. Case Selection

Six Maggie's Centers (Figure 1) were purposively chosen to capture diversity in design approaches, program elements (e.g., presence or absence of healing gardens), and years of construction: Livsrum Maggie's Cancer Counseling, Maggie's Lanarkshire, Maggie's Southampton, Maggie's Centre Toronto, Maggie's Cancer Centre Manchester, Edward Williams Maggie's Center.

Despite their variations, these centers share a common ethos of creating healing, community-oriented environments. Key selection criteria included:

- Varied Layouts: Modular, cruciform, linear, and hybrid forms.
- Architectural Approaches: Different architects and design philosophies over time.
- Program Diversity: Inclusion or omission of certain programmatic elements (e.g., private counseling rooms, integrated gardens).

This range helps ensure that any recurring patterns identified are robust rather than coincidental.

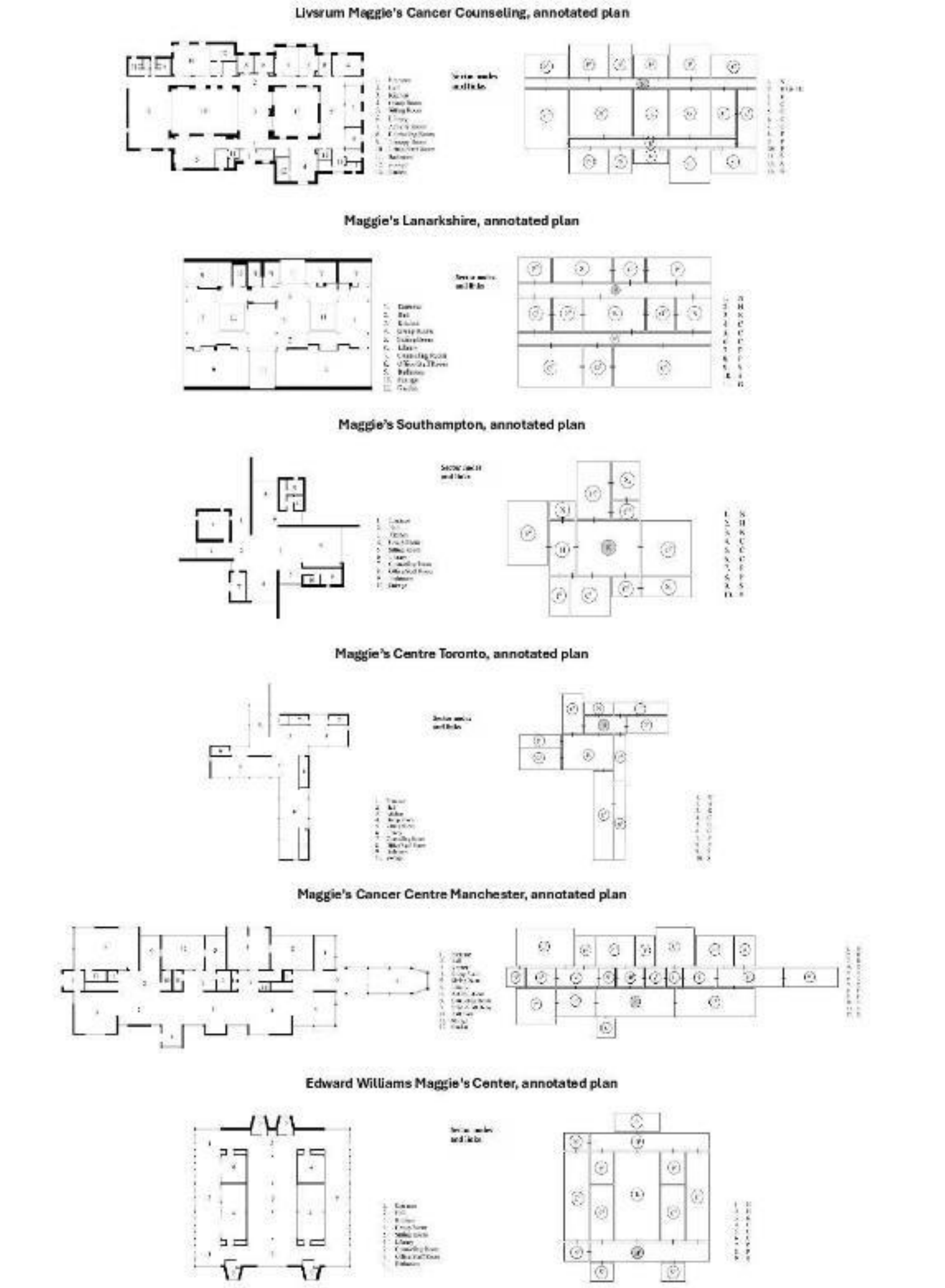

Figure 1 Six Maggie's Centers annotated plan; Labeled functional sectors with Maggie's common taxonomy

2.3. Data Collection and Preparation

Floor plans, elevations, and sections were gathered from publicly available sources (official websites, monographs) and verified CAD or vector PDFs when possible. Each center's layout was standardized by:

- Aligning scales and orientations consistently.
- Labeling functional sectors with Maggie's common taxonomy: Entrance (N), Hall (H), Kitchen (K), Common (C), Private (P), Service (S), Garden (G), Exterior (E).
- Ensuring consistent digital representations of room boundaries and door openings for accurate syntactic calculations.

2.4. Space Syntax Analysis

Spatial configurations were evaluated in DepthmapX to create Justified Plan Graphs (JPGs) and compute key syntactic measures:

- Integration (i): How easily a space can be reached from all others; identifies social or functional hubs (often H or K).
- Mean/Total Depth: Reflects a space's "distance" from others, forming privacy gradients.
- Control Value (CV): Indicates how a node influences movement/choice; higher CV often aligns with corridor hubs.
- Visibility Graphs (if applicable): Capture lines of sight and potential for visual permeability.

By comparing these measures across centers, the study pinpointed consistent patterns, such as high-integration H/K nodes and more secluded P/S areas.

2.5. Shape Grammar Analysis

A Shape Grammar approach, implemented in Rhinoceros 3D with Grasshopper, extracted the generative rules underlying each center's layout:

- Node-Set Definition: Each functional sector became a node label (e.g., H, K, C1, C2).
- Rule Extraction: Plans were dissected to see how core spaces (H, K) spawn adjacent areas (C), ultimately branching to P, S, or G at the peripheries.
- Comparative Synthesis: Rule sets from all six centers were aligned to reveal a stable "spatial DNA"—a genotype that explains consistent adjacency, hierarchy, and geometry.

2.6. Integrating Space Syntax and Shape Grammar

Quantitative metrics from Space Syntax (integration, control) were mapped onto the rule-based expansions of Shape Grammar:

- Syntactic measures validated the significance of the "core" (often H/K) and the peripheral privacy gradient.
- Generative steps confirmed that each center began with a high-integration hub, branching outward to lower-integration areas.

This cross-referencing ensured the final "dominant genotype" was both empirically supported and formally reproducible.

2.7. Massing Development

Findings from the 2D analyses were translated into 3D massing principles:

- Core Block (H + K): Central, open volumes supporting communal life and intuitive orientation.
- Transitional Wings (C): Moderately integrated volumes around the core, maintaining partial visibility.
- Peripheral Volumes (P, S): Lower-integration blocks at the building's edges, ensuring privacy and calm.
- Garden (G) (if included): An accessible yet tangential retreat, usually peripheral but visually connected to communal nodes.

2.8. Reliability and Validity

- Multiple Centers: Analyzing six designs from different architects/eras ensures that consistent patterns reflect genuine shared logic.
- Standardized Metrics: Uniform coding, consistent plan orientation, and repeated measures bolster internal validity.
- Iterative Grammar Testing: Reapplying the extracted rules to hypothetical layouts confirmed replicability and alignment with Maggie's ethos.

3. Results

3.1. Syntactic Integration Across Cases

To understand how each spatial sector (Entrance, Hall, Kitchen, Common, Private, Service, Garden, Exterior) functions in the six Maggie's Centers, table in Figure 2 presents the integration values (i_{RRA}) for each node, along with the relative difference factor (H*). These metrics quantify the ease with which one can reach a given space from all others. Higher i_{RRA} values indicate more central or "integrated" nodes, while H* highlights each layout's overall inequality or hierarchy.

- The first graph in Figure 2 illustrates the most integrated node in each center, confirming that either the Hall (H) or Kitchen (K) tends to dominate.
- The second graph in Figure 2 shows the *difference factor (H)** for each case, highlighting variation in the degree to which certain nodes exert a stronger spatial influence.

Overall, across the cases, Hall and Kitchen emerge as frequent integration "hubs," supporting previous evidence that communal and social areas anchor Maggie's Centers.

* Integration values (i_{RRA}) of all sector nodes of each case and its relative difference factor (H*)

	E	N	H	K	C	P	S	G	Mean	H*
Case 1	[illegible]	1.67	3.85	2.23	1.20	1.07	1.20	2.08	1.06	0.7712
Case 2	[illegible]	2.14	2.62	2.35	1.02	1.12	1.12	1.12	1.30	0.8450
Case 3	0.65	0.56	1.17	1.65	0.88	0.34	0.47	0.00	0.74	0.6121
Case 4	0.70	1.17	2.67	2.31	1.48	0.08	0.63	0.00	1.21	0.6786
Case 5	[illegible]	1.35	1.65	2.41	1.75	0.97	1.12	0.89	1.45	0.8406
Case 6	0.79	1.15	1.80	1.14	1.14	0.65	0.70	0.00	0.67	[illegible]
Mean	[illegible]	1.37	2.2	2.01	1.27	0.65	0.87	[illegible]	1.32	[illegible]
SD	0.56	0.57	1.07	0.51	[illegible]	[illegible]	0.31	[illegible]	0.47	[illegible]

Figure 2 Integration Values and Spatial Inequality Across Maggie's Centers

3.2. Summary of Syntactical Analysis Results

Figure 3 consolidates the syntactic analysis by showing both integration (i) and control values (CV) for each space across the six centers. The control value (CV) indicates how much a node influences movement or choice within the layout:

- Hall (H) displays notably high integration (mean i = 8.75) and often above-average CV (4.76), reaffirming its dual role as a key sociospatial hub.
- Kitchen (K) similarly shows strong integration (mean i = 8.06), although its CV (1.72) varies more, suggesting different layout strategies among architects for bridging or funneling traffic from K to adjacent rooms.
- Entrance (N) exhibits moderate mean i (5.27), aligning with a well-managed transition from exterior to interior.
- Private (P) and Service (S) nodes appear in lower-integration zones (mean i range ≈ 3.75–3.96), consistent with Maggie's emphasis on providing quieter, more secluded areas.

These combined i and CV values indicate that Maggie's Centers systematically create communal cores and privacy gradients, aligning quantitative measures (i, CV) with observed design intentions.

Case		*1*	*2*	*3*	*4*	*5*	*6*	*Mean*	*SD*
E	*i*	8.14	7.58	2.37	2.29	6.24	2.87	4.92	2.71
	CV	0.57	0.51	0.16	0.50	1.00	0.66	0.57	0.27
N	*i*	7.43	8.27	1.96	3.93	7.00	3.00	5.27	2.63
	CV	0.59	1.10	0.20	1.16	0.50	1.16	0.79	0.41
H	*i*	17.10	10.11	3.75	9.17	7.97	4.40	8.75	4.82
	CV	9.50	3.50	3.53	4.20	3.50	4.33	4.76	2.35
K	*i*	10.06	9.10	5.63	7.86	11.55	4.13	8.06	2.78
	CV	0.16	1.26	3.67	3.16	1.73	0.31	1.72	1.45
C	*i*	5.34	3.96	3.00	5.00	8.56	2.87	4.79	2.10
	CV	0.09	0.47	0.36	0.36	0.53	0.66	0.41	0.19
P	*i*	6.11	4.33	1.96	3.44	4.28	2.36	3.75	1.51
	CV	0.07	0.45	0.20	0.16	0.16	0.16	0.20	0.13
S	*i*	6.11	4.33	1.61	3.24	5.92	2.54	3.96	1.83
	CV	0.07	0.45	0.50	0.20	0.36	0.14	0.29	0.18
G	*i*	10.06	4.33	0.00	0.00	4.28	0.00	3.11	4.00
	CV	0.16	1.12	0.00	0.00	0.16	0.00	0.24	0.44
Mean	*i*	8.79	6.50	2.54	4.37	6.98	2.77	5.32	2.50
	CV	1.40	1.11	1.08	1.22	0.99	0.93	1.12	0.17

Case 1: H (17.10) > K (10.06) = G (10.06) > E (8.14) > N (7.43) > P (6.11) = S (6.11) > C (5.34)
Case 2: H (10.11) > K (9.10) > N (8.27) > E (7.58) > P (4.33) = S (4.33) = G (4.33) > C (3.96)
Case 3: K (5.63) > H (3.75) > C (3.00) > E (2.37) > N (1.96) = P (1.96) > S (1.61)
Case 4: H (9.17) > K (7.86) > C (5.00) > N (3.93) > P (3.44) > S (3.24) > E (2.29)
Case 5: K (11.55) > C (8.65) > H (7.97) > N (7.00) > E (6.24) > S (5.92) > P (4.28) = G (4.28)
Case 6: H (4.40) > K (4.13) > N (3.00) > E (2.87) = C (2.87) > S (2.54) > P (2.36)

Figure 3 Summary of syntactic analysis results

3.3. Inequality Genotypes and Radar Charts

To visualize how each functional node contributes to the overall spatial hierarchy, Figure 4 provides radar charts of the "inequality genotypes" for each Maggie's Center (1 through 6). The red polygon on each chart accentuates the relative prominence of certain nodes (e.g., H, K) versus more peripheral ones (P, S, G). Notably:

- Livsrum Maggie's Cancer Counseling Center (Case 1) reveals a pronounced spike at H, consistent with its integrated social core.
- Maggie's Centre Toronto (Case 4), by contrast, shows slightly more balanced values but still a notable emphasis on H and K.
- Maggie's Cancer Centre Manchester (Case 5) integrates a garden (G) more centrally than some others, raising its visual/spatial presence while still maintaining H/K dominance.

Overall, these spider (radar) plots confirm that, despite stylistic variation, a core "DNA" exists where Hall and Kitchen hold higher integration relative to peripheral sectors.

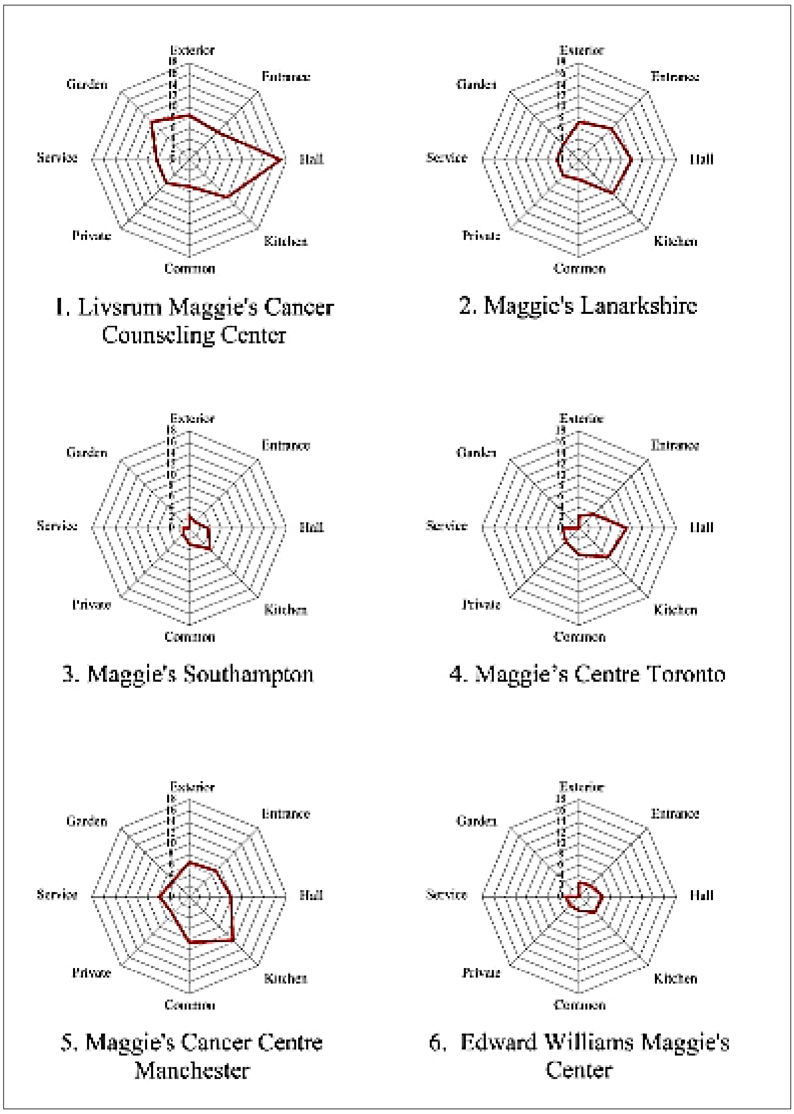

Figure 4 Charts representing the inequality genotypes of Maggie's Centers

3.4. Topological Typologies and JPG Grammars

3.4.1. Four Topological Types of Spaces

Figure 5 classifies each space in the six cases by topological link type (a-type, b-type, c-type, d-type). These types refer to how each node is attached in the plan's justified graph:

- d-type nodes often serve as branching or hub-like connectors; a-type nodes tend to terminate a spatial sequence.
- A summary reveals that Hall is frequently d-type (75% of the time), consistent with its role as a connectivity hub, whereas Private (P) nodes are predominantly a-type (≈88%), confirming a consistent "terminal" position in the privacy gradient.
- The Garden (G), when present, tends to be d-type or c-type, reflecting its partial integration but still at a peripheral position.

Case	1	2	3	4	5	6	Summary-Nodes	Comparison
Exterior	c-type	d-type	a-type	a-type	c-type	c-type	d-type (16%) c-type (50%) a-type (34%)	c > a > d
Entrance	c-type	d-type	b-type	b-type	c-type, d-type	d-type, d-type	d-type (50%) c-type (25%) b-type (25%)	d > b = c
Hall	d-type, d-type	d-type, d-type	c-type	c-type	d-type, d-type, d-type, c-type	d-type, d-type	d-type (75%) c-type (25%)	d > c
Kitchen	c-type	d-type	c-type	c-type	d-type	d-type	d-type (50%) c-type (50%)	c = d
Common	a-type, a-type, c-type, c-type, c-type	c-type, c-type, d-type	c-type, a-type, b-type, b-type, a-type	c-type, a-type, a-type, b-type	d-type, a-type, a-type, c-type, c-type	c-type, d-type, a-type, a-type	d-type (12%) c-type (38%) b-type (12%) a-type (38%)	a = c > b = d
Private	a-type, a-type, a-type	c-type, a-type	a-type, a-type	a-type, a-type	a-type, a-type, a-type, d-type	a-type, a-type, a-type	d-type (6%) c-type (6%) a-type (88%)	a > c = d
Service	a-type, a-type, a-type, a-type	c-type	a-type, a-type	a-type, a-type	c-type, c-type, c-type, a-type	a-type, a-type	c-type (27%) a-type (73%)	a > c
Garden	c-type, c-type	d-type, d-type, d-type, d-type	—	—	a-type, a-type	—	d-type (50%) c-type (25%) a-type (25%)	d > a = c
Summary-Cases	d-type (10%), c-type (42%), a-type (47%)	d-type (66%) c-type (26%) a-type (6%)	c-type (23%) b-type (23%) a-type (54%)	c-type (25%) b-type (16%) a-type (58%)	d-type (30%) c-type (35%) a-type (35%)	d-type (40%) c-type (13%) a-type (46%)		
Comparison	a > c >	d > c > a	a > c = b	a > b > c	a = c > d	a > d > c		

Figure 5 Four topological types of spaces

3.4.2. Justified Plan Graphs (Head, Local, Global)

Figure 6 shows JPGs of the six centers at three grammatical stages (head, local, global). These diagrams illustrate how each plan grows from an initial "head" node (often the Hall or Kitchen) to more detailed local expansions (Common spaces, connectors), and finally a global configuration (including Private, Service, or Garden). Across all cases:

- Head Stage typically anchors H or K.
- Local Stage branches out to Common spaces (C), capturing moderate-integration zones.
- Global Stage culminates in more a-type links (Private, Service, possibly Garden), finalizing the building's privacy gradient.

These incremental expansions confirm the repeated generative logic observed in Maggie's Centers: an "open" or "hub" core radiating out to quieter, specialized peripheries.

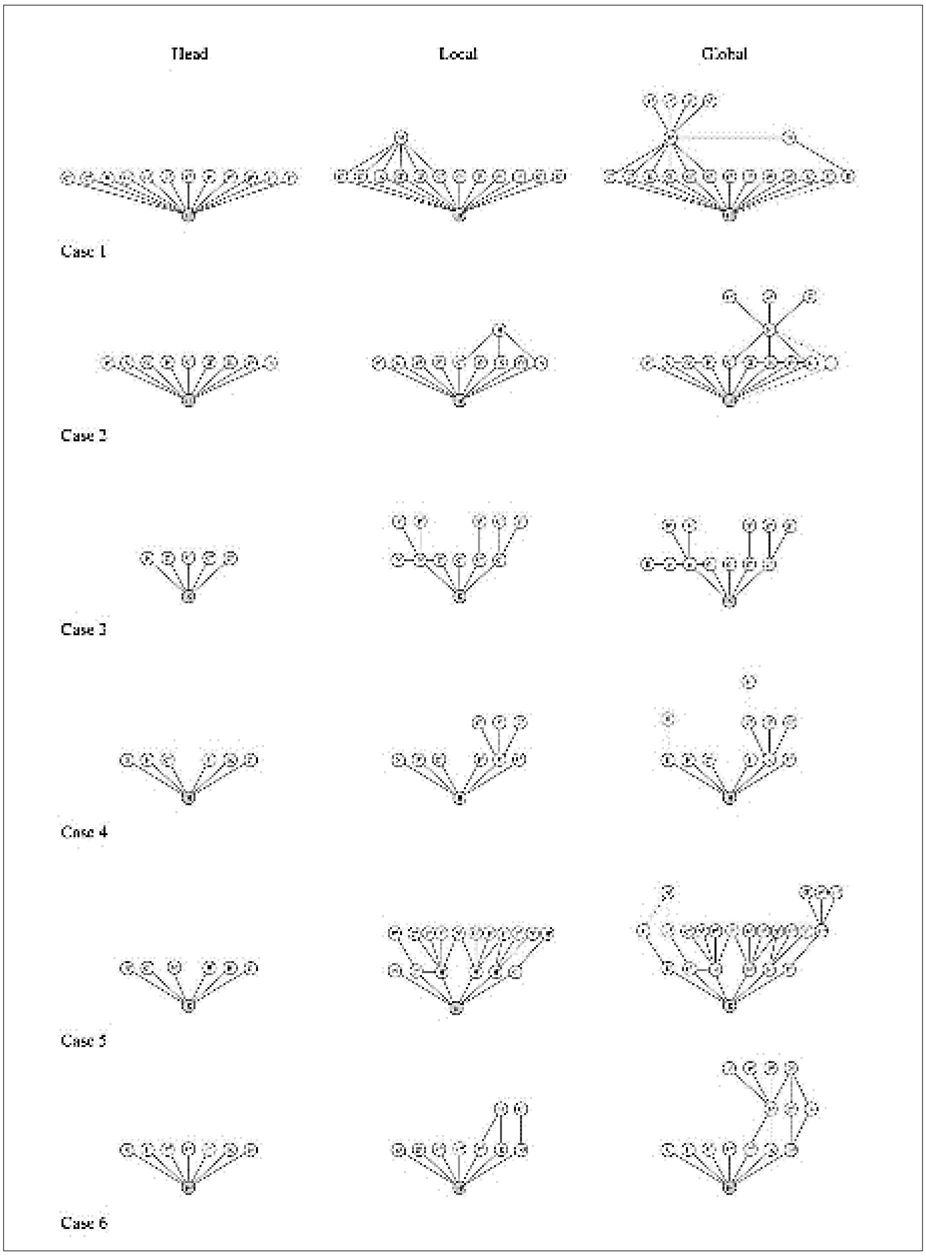

Figure 6 JPGs at three grammatical stages: head, local, and global syntax

3.5. The Dominant Maggie's Center

Bringing together these syntactic and topological insights, a composite or "dominant Maggie's Center" emerges, capturing the most frequent patterns. Figure 7 demonstrates the syntactical data for this hypothetical center—listing mean (or representative) values for Total Depth (TDn), Mean Depth (MDn), Relative Asymmetry (RA), Integration (i), and Control Value (CV). Key takeaways:

- H2 (a second Hall node) shows the highest integration (i = 8.25). This implies that a multi-hall arrangement can still preserve a single overarching hub.
- Kitchen (K) follows closely (i = 7.07), reinforcing its social significance.
- Private (P1, P2) and Service (S1, S2) occupy the deeper end of the layout (i ~ 3.30–2.91), aligning with lower interaction areas.

No.	Node	TD_n	MD_n	RA	i	RRA	i_{RRA}	CV
0	E	25.00	2.27	0.28	3.54	0.96	1.04	0.66
1	N	25.00	2.27	0.28	3.54	0.96	1.04	0.66
2	H^1	19.00	1.73	0.16	6.19	0.55	1.83	0.40
3	H^2	17.00	1.55	0.12	8.25	0.41	2.43	0.42
4	K	18.00	1.64	0.14	7.07	0.48	2.09	0.36
5	C^1	18.00	1.64	0.14	7.07	0.48	2.09	0.36
6	C^2	28.00	2.55	0.34	2.91	1.16	0.86	0.20
7	P^1	26.00	2.36	0.30	3.30	1.03	0.97	0.16
8	P^2	28.00	2.55	0.34	2.91	1.16	0.86	0.20
9	S^1	26.00	2.36	0.30	3.30	1.03	0.97	0.16
10	S^2	28.00	2.55	0.34	2.91	1.16	0.86	0.20
	Maximum	28.00	2.55	0.34	8.25	1.16	2.43	0.66
	Mean	23.45	2.13	0.25	4.64	0.85	1.37	0.34
	Minimum	17.00	1.55	0.12	2.91	0.41	0.86	0.16
	H							0.8378
	H^*							0.3568

Figure 7 Dominant Maggie's Center, syntactical data

Figure 8 (3D chart) and Figure 9 (radar + bar chart) depict these metrics, confirming that the final genotype arranges Hall(s) and Kitchen at the core, with Entrance/Exterior as moderately integrated gateways, and Private/Service spaces in low-integration zones.

Thus, the “dominant Maggie’s Center” highlights a stable design principle: an accessible communal hub, transitional communal areas, and peripheral private/service nodes. By identifying consistent adjacency sequences and integration hierarchies, this analysis verifies the rule-based “genotype” that underpins Maggie’s success as a healing environment. This genotype transcends stylistic variation, consistently embodying Maggie’s values of comfort, belonging, and dignity.

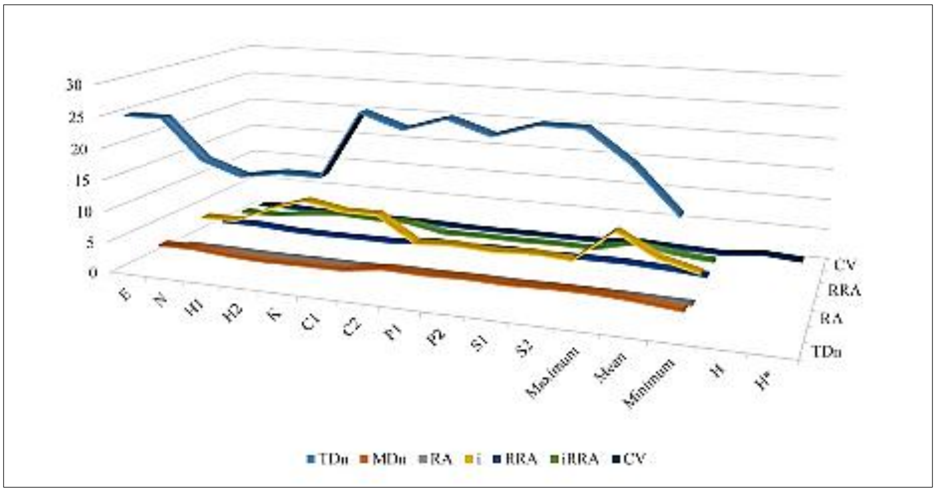

Figure 8 Illustration of syntactical data, dominant Maggie’s Center

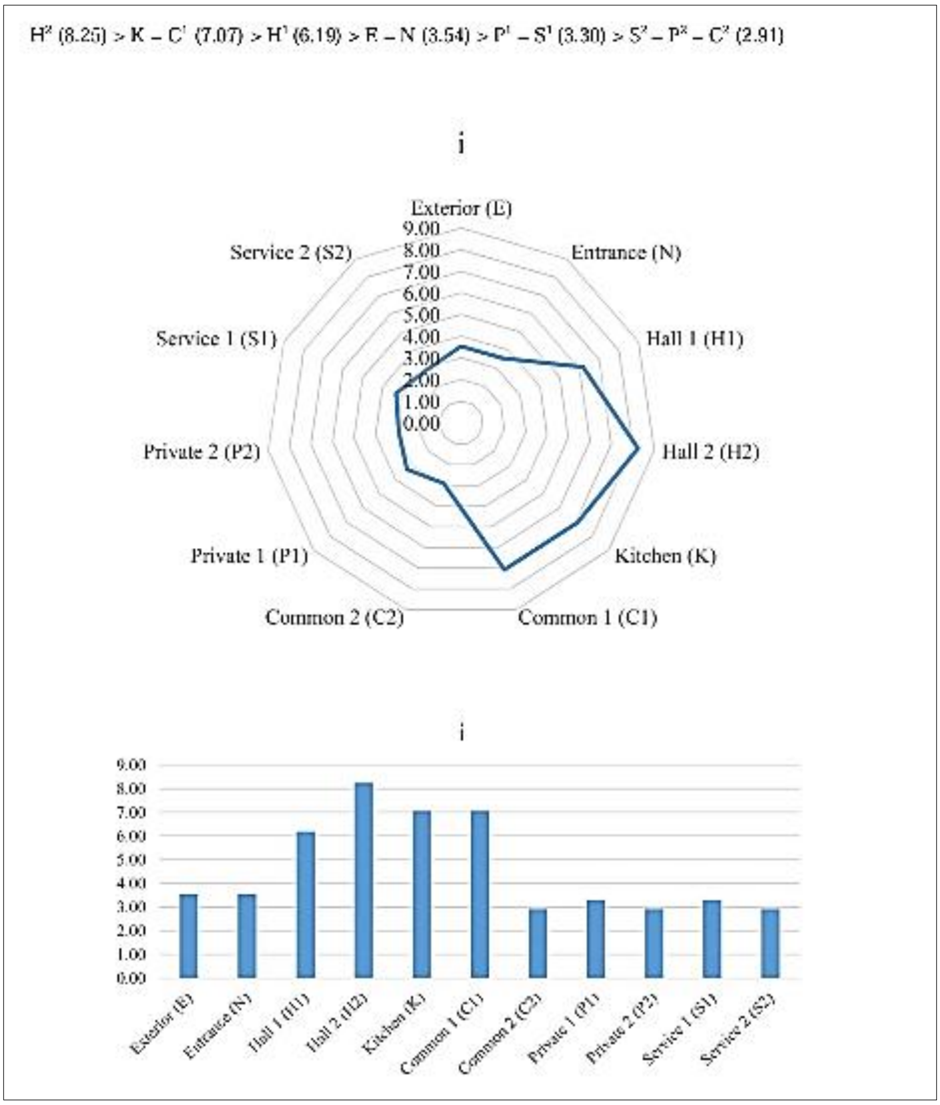

Figure 9 Inequality genotype of dominant Maggie's Center

3.6. Summary of Findings

- Hall and Kitchen almost always occupy top integration ranks, acting as sociospatial anchors.
- Entrance is moderately integrated, ensuring easy navigation without dominating the layout.
- Common (C) spaces cluster around or near the core, providing flexible communal activities while preserving quieter retreats.
- Private (P) and Service (S) consistently appear at deeper or terminal positions, maintaining a supportive privacy gradient.
- Garden (G), when included, is semi-integrated but tangential to the main core, offering a natural retreat.
- Shape Grammar and Topological Link Types confirm that these spatial roles are not accidental; they form a replicable grammar, validated quantitatively by Space Syntax metrics.

By uniting quantitative space syntax results and generative shape grammar rules, the study validates a replicable design genotype that underpins Maggie's Centers' recognized success as healing, human-centered spaces. With these data-driven insights, designers can adapt the essential Maggie's Center "DNA" to new healthcare projects—balancing communal openness, intuitive circulation, and privacy needs to enhance patient well-being and staff efficiency.

4. Discussion

The findings from this research underscore the transformative potential of combining space syntax and shape grammar to demystify the underlying spatial logic of Maggie's Centers. Quantitative measures—such as integration and control values—consistently highlight the pivotal role of communal spaces (halls and kitchens) as central social and functional hubs. Simultaneously, the generative rules derived from shape grammar explain the systematic expansion from these hubs toward less integrated, more private or specialized zones. This dual analysis not only reinforces the architectural ethos of Maggie's Centers but also offers a robust, evidence-based framework that can be generalized to other healthcare projects [28].

By synthesizing these computational perspectives, the study contributes to a deeper understanding of how spatial configurations influence user experience and operational efficiency in healing environments. This integrated approach moves beyond aesthetic considerations, advocating for a design process that is both empirically informed and dynamically generative.

4.1. Future Work

Future research should extend this methodology by expanding the case base to include additional Maggie's Centers or similar healthcare facilities, thereby further validating and refining the proposed "spatial genotype." This approach is consistent with the findings of Rahimi, who advocates for the incorporation of emerging technologies in healthcare design to enhance user experience and operational efficiency [29]. Additionally, leveraging advanced simulation tools, virtual reality, or machine learning to test design variations in real-time and predict user responses could significantly enhance the design process [30].

4.2. Potential Challenges

While the integrated framework shows promise, several challenges warrant attention. Ensuring the availability of standardized, high-quality architectural data is crucial for accurate space syntax and shape grammar analyses [27]. Moreover, the dual analysis approach may demand significant computational resources, particularly when scaling the method to larger or more complex facilities, as noted by Acican and Dino in their discussion of computational design tools [31]. Furthermore, translating computational findings into actionable design guidelines requires close collaboration between architects, healthcare professionals, and computational designers. [32]. Additionally, the integration of user feedback into the design process, can foster a more inclusive approach that aligns with the needs of diverse user groups [33].

Addressing these challenges in future studies will be key to enhancing the practical utility and adaptability of this computational framework for transformative healthcare design.

5. Conclusion

By integrating Space Syntax and Shape Grammar, this methodological framework reveals how Maggie's Centers achieve their recognized blend of operational functionality and emotional support. The quantitative syntactic measures pinpoint communal, high-traffic areas and necessary privacy gradients, while shape grammar rules articulate the step-by-step form-generation that underpins the centers' architectural DNA. Translating these insights into massing principles offers architects a replicable yet flexible blueprint for designing transformative, patient-centered environments in healthcare. This combined approach highlights the potential of computational tools to formalize "healing" design features, ensuring that empathetic, human-centered care remains grounded in evidence-based spatial strategies and generative processes. Future research may incorporate additional Maggie's Centers or apply this genotype in new healthcare contexts, further refining and validating the principles uncovered here.

Compliance with ethical standards

Disclosure of conflict of interest

The authors declare no conflicts of interest.

Author Contributions

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