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Discretisation strategies in architectural design process: a procedural classification system

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ABSTRACT
This study addresses the issue of optimizing architectural production processes through discretisation methods. The primary aim is to develop a classification system for these methods, facilitating their application in digital design and robotic assembly. The central research questions are: What are the fundamental discretisation methods in architecture? How can these methods be classified for practical application? To answer these questions, we conduct a comprehensive review of existing discretisation methods and evaluate their core attributes. Our methodology involves a detailed evaluation of these methods, focusing on their adaptability, geometric predictability, and broadly repeatability. The findings highlight the potential for digitally controlled discretized design processes to innovate architectural practices, making construction faster, more affordable, and capable of producing complicated geometries. The significance of this study lies in its contribution to integrating digital design and modular discretisation in architectural production, moving toward advanced and adaptable production systems.

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Discrete design; digital design; modular architecture; computational design; parametric architecture; digital fabrication

1. Introduction

1.1. Discretisation: tracing the roots

In the later decades of the twentieth century, profound shifts were evident in the field of architecture, not just in the tools and techniques employed for design, but also sparking debates about the role of architecture in its own industrial production chain (Kumsal et al. 2021). Subsequently, the Fourth Industrial Revolution, catalyzed by the emergence of intricate technologies, brought about a blending of the digital, natural, and physical specifications (Schwab 2017). In the architecture, for instance, Artificial Intelligence (AI) has been influential by powering generative design software. This tool uses defined wide range of parameters such as spatial needs, material types, and budget to create multiple design options, illustrating a blend of the digital and physical realms (Caetano, Santos and Leitão 2020). Meanwhile, the development of cloud computing and the Internet of Things (IoT) has enabled real-time monitoring and control of infrastructural systems, typifying the merging of the digital and physical worlds (Bibri and Krogstie 2017). The incorporation of an array of new technologies across diverse industries has led to significant modifications in manufactoring techniques, further stimulating inventions and improvements in production chains (Effoduh 2016). For instance, Robotics and 3D printing could potentially change the typical construction processes, facilitating an optimized physical world through the digital domain (Wu, Wang and Wang 2016).

As a result of the developments in automated systems and digital technology, digital-related manufacturing operations have experienced a rapid transformation. On one hand, the optimization of production chains has historically been regarded as a driving force behind technological progress and more creative machinery (Freeman and Soete 1997). On the other hand, the emergence of a new era marked by increased proficiency is perceived to be a result of technological advancements that have created greater efficiency and enhanced capabilities, propelled by the integration of mathematical methodologies across a wide range of fields, including but not restricted to architecture and design (Morel 2019).

During the 1990s, the widespread adoption and democratiza tion of computers led to an extensive diversification of CAAD (Computer-Aided Architectural Design) endeavours, spanning a broad spectrum (Koutamanis 2005). This included everything from assisting with the end-use of computer systems to theoretical computations, and also encompassing the development of advanced, specific applications in collaboration with other specializations in architecture, building, or design.

In the wake of the 2008 global financial crisis, the integration of digital technology in the field of architecture became linked to a contentious neoliberal ideology, which was labelled as the 'first digital turn' by Carpo (Carpo 2017a, 2013). The emergence of the 'second digital turn,' as recognized by Carpo, brought about a transformation in the approach of digital architects towards implementing distinctive design techniques and algorithms in their work (Carpo 2017b). This development is a clear indication of the continuing progression of the digital era, specifically in design world.

The shift away from traditional approaches and towards digital and computational technologies has fundamentally changed the design field. Computerization largely employs computers

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as tools for precise representation modelling, whereas digital computation uses computational capability for algorithmic processing (Leach 2019). The core of the digital characteristics is defined by objectivity and measurability, thus removing subjectivity (Terzidis 2014). The digital domain does not impose a specific style, and despite giving distinct skills, it limits independent action or impact (Gibson 1979). Unlike the stylistic approach, which restricts design choices to a personal and subjective point of view, the digital domain does not impose a designer's style but rather allows for design outcomes based on an objective, logical framework (Leach 2019).

1.2. Discretisation: manifestation

The mentioned digitalization context sets the base for exploring the concept of discretisation. Discretisation can be natural progression in a digitization procedure, bridging the gap between computer-based design and modular construction (Picon 2020). Its ultimate goal is to scrutinize the complete production chain while considering the possibility of transforming it into an architectural process framework, consist of different material and construction techniques (Picon 2020).

Retsin theorizes that the notion of discretisation can be interpreted as 'understanding the nature of the parts in architecture' (Retsin 2019). According to this particular viewpoint, the implementation of discretisation has the potential to introduce novel design characteristics. A design process can start with the identification of individual parts or basic elements, which are subsequently included in a more extensive and intricate system or structure through successive stages of integration (Kolarevic 2001). This facilitates increased flexibility and adaptability during the design phase and also the inclusion of smaller components within the system facilitates alterations or adjustments to individual parts without compromising the integrity of the overarching design (Willmann et al. 2012). Digitally controlled design processes have the potential to generate innovative architectural possibilities, particularly in terms of optimizing architectural systems to allow for faster, more affordable constructions with complex geometries (Manahl, Stavric and Wiltsche 2012). Modular discretisation can be characterized as a design method that involves dynamic, open, geometrically predictable, adaptable, reusable, and connectable architectural components and configurations (Carpo 2019). According to Retsin, the discretization process aims to optimize the effectiveness of architectural production chain by exchanging 'scalability,' 'impact,' and 'action' with 'resolution,' 'formal distinction,' and 'excitement' (Retsin 2019).

1.3. Discretisation: mathematics

The process of converting continuous geometry into smaller discrete parts through discretisation, facilitates the manipulation of complex geometric relationships and enables the ease of design, manufacturing, or assembly processes (Jonas and Alan Penn and Paul Shepherd 2014). Discretisation, a process of transitioning from continuous to discrete mathematical models, has been pivotal in heralding what scholars such as (Hughes 2012; LeVeque 2007) term the 'era of effectiveness'. This move towards computational methods not only challenges conventional human-centric mathematical paradigms but, as (Morel 2019) notes, emphasizes the 'unreasonable effectiveness' of computers in scientific pursuits. With the advent of artificial general intelligence (AGI) and its potential to encompass vast existing knowledge, this trend seems poised to persist. A profound comprehension of discretisation requires an exploration of foundational computational principles, ranging from algorithmic complexity to information theory. These tenets, as highlighted by (Sacks, Girolami and Brilakis 2020), not only set the stage for the evolution of superintelligence but also redefine data processing, decision-making, and model prediction across myriad domains.

2. Materials and methods

2.1. Research direction

The formulation of a design into discretized components can bring various advantages to architectural designers, given that every part can be scrutinized individually to promise proper dimensions, structure, and placement (Klemmt and Sugihara 2018). Using discretization in the architectural industry could cut costs associated with fabrication, lessen excess waste, and improve assembly procedures (Retsin 2016; Retsin and Garcia 2016). Given the context, the present study endeavours to discern and contrast diverse methods of discretisation design to effectively incorporate them into practical application.

This study delves into the fundamentals of discretisation in architectural design via an inductive approach. We introduce a categorization system emphasizing procedural nuances in discretisation techniques, encompassing a breadth of methods, notably those examining topological and geometric connections between modules. Our classification offers a streamlined framework for these methods, addressing the subsequent questions:

What are the main discretisation methods in architecture?

What are the fundamental characteristics of them?

How can these methods be classified for practical application?

The implementation of this methodology has the potential to advance the creation of novel, economically feasible, and highly effective architectural frameworks that leverage the computational capabilities of design software and the manufacturing benefits of digital fabrication techniques.

2.2. Methodology

This study delves into the potential of digital discretisation design in enhancing adaptability and sustainability in architecture. Instead of starting with predetermined notions, an inductive research approach is taken, analysing existing methods. The goal is to discern procedural nuances in discretisation techniques, highlighting their limitations and potentialities, whilst investigating their ties to parametric principles. This involves identifying specific features, computations, and tools related to each method, focusing on their academic context. However,

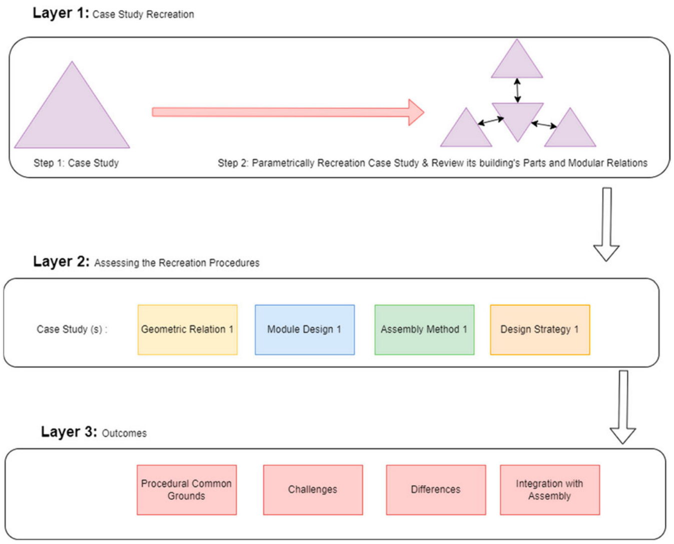

Figure 1. Research methodological framework. Credited by Erfan ZamaniGoldeh.

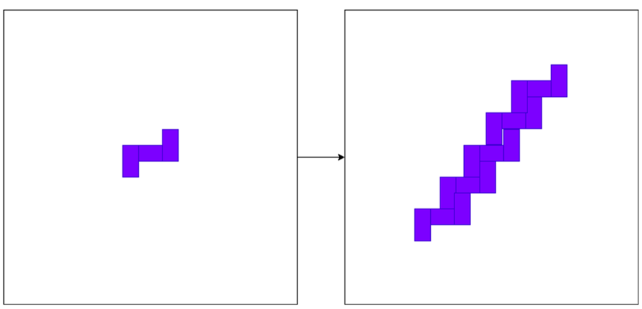

Figure 2. Cellular Automata is a model in computational mathematics, in which space is divided into discrete cells, each of which has a state. The state of the cells evolves over discrete time steps according to a set of rules based on the states of neighbouring. Credited by Erfan ZamaniGoldeh.

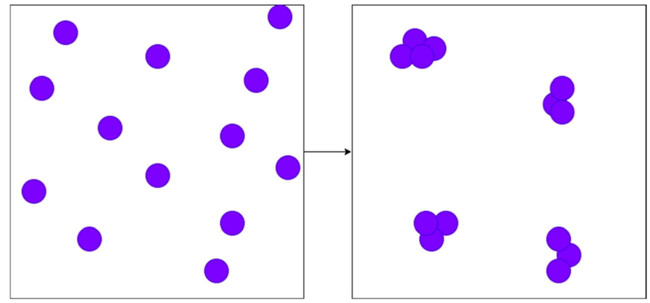

Figure 3. DLA is a model of stochastic growth typically implemented in a lattice, with applications ranging from the formation of snowflakes to urban growth. The particles perform a random walk until they come into contact with the seed (or any other particle that has stuck to the seed). Once they collide with the aggregated particles, they stick and become part of the aggregate. Credited by Erfan ZamaniGoldeh.

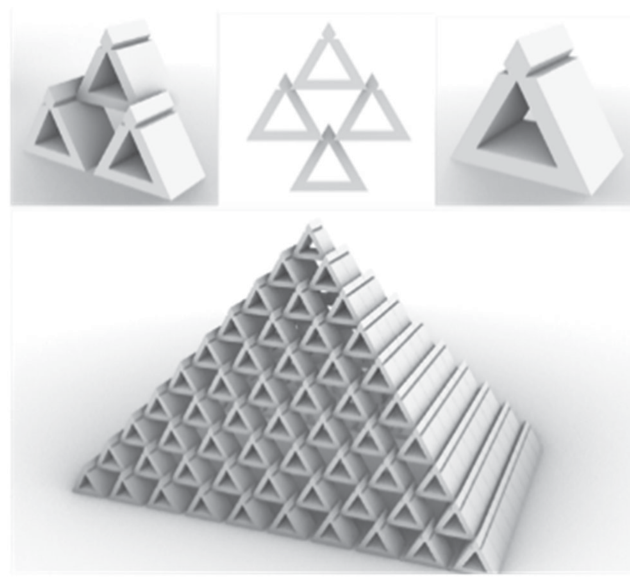

Figure 4. Recreated by Erfan ZamaniGoldeh. Algorithm-based growth can be used to recreate some built structures, such as TLDC Tsumiki Pavilion, architect: Kengo Kuma.

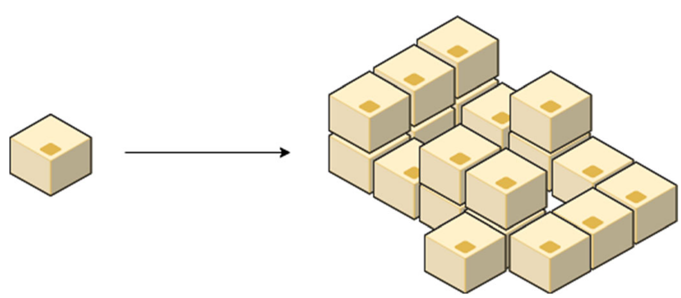

Figure 5. Growth driven by algorithms can yield a multitude of modules, created either haphazardly or in accordance with a pattern, all derived from a single predesigned module. Credited by Erfan ZamaniGoldeh.

applying these techniques on a larger scale may pose challenges, such as the need for advanced equipment, skilled workforce, and potential resistance from traditional building methods. Extensive testing and new regulations might be crucial for safe and reliable implementation. To ensure a comprehensive and rigorous review of the existing discretisation methods, a structured literature search was conducted.

The study's methodology consists of three phases. First, case studies using or potentially using discretisation are recreated parametrically. Next, sub-geometric relationships, components, and assembly methods are identified. Finally, findings are categorized, showcasing similarities, processes, and differences. This research offers a classification system for discretization strategies, providing a comprehensive framework that highlights their versatility and digital capabilities in architectural design (Figures 1–9).

2.3. Discretisation and robots

In recent decades, advancements in digital technology and computer-aided design have reshaped architectural procedures (Oxman 2012; Kolarevic 2004). Discretisation could become a central design approach in response. The shift towards sustainable construction has further bolstered discretisation's adoption in architecture (Klemmt and Pantic 2019). Through discretisation, design flexibility, cost-effective maintenance, and the ability to dismantle and reuse building elements have been realized, aligning with the circular economy principles in construction (Claypool et al. 2021).

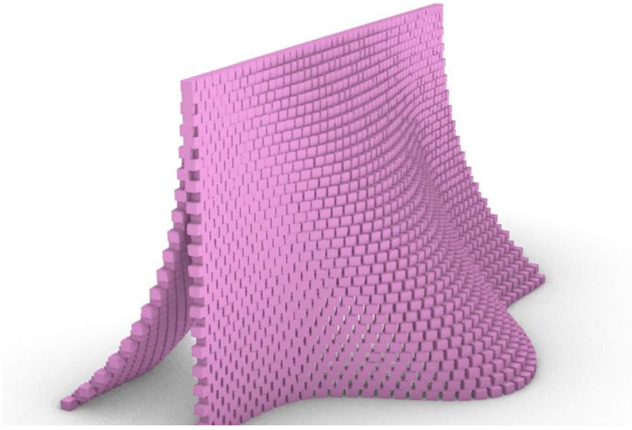

Figure 6. Recreated by Erfan ZamaniGoldeh, Serpentine Pavilion 2016, through Tessellation method.

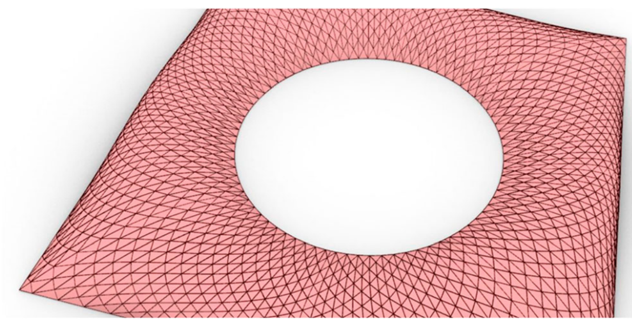

Figure 7. Recreated by Erfan ZamaniGoldeh, British Museum Court Roof, through Subdivision method.

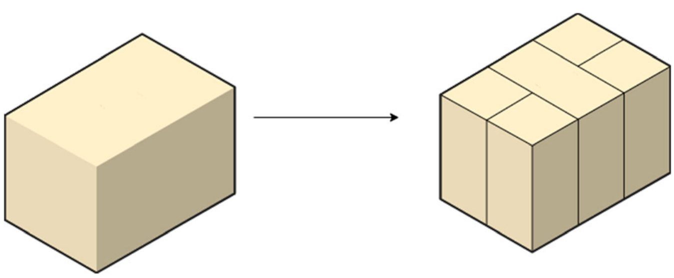

Figure 8. Subdivision techniques can be utilized to produce distinct modules, which may or may not bear geometric similarities, originating from a larger shape of either regular or irregular proportions. This approach is applicable to both surface and mass designs. Credited by Erfan ZamaniGoldeh.

2.3.1. Discretisation association with robotic technologies

The uptake of discretisation has grown notably in robotic assembly and construction automation. The introduction of robots into architectural design bolsters precision, operational efficiency, and cost-effectiveness whilst trimming construction timelines (Bock and Linner 2015). Merging design, analysis, and assembly has the potential to expedite building times and curtail human errors (Kolarevic 2011). discretisation aligns with innovative techniques such as 3D printing, offering significant shifts in the architectural sphere (Fratello and Rael 2020). Through discretisation, designers are equipped to assess a plethora of fabrication options, including nested connections and pick-and-assembly tactics, allowing them to be involved in both design and construction phases concurrently (Kolarevic 2003). As the industry progresses, there's a mounting need for adept professionals, underlining the requirement for bespoke training tailored for architects and engineers (Kolarevic 2003a).

2.3.2. Discussion of the relationship between discrete design and fabrication in architecture

Digital design and fabrication in architecture, spurred by innovative solutions, have seen remarkable advancements, emphasizing the synthesis of discrete modules and geometric relations (Kolarevic 2003). Such a holistic approach allows architects to explore intricate and previously challenging designs, boosting flexibility and adaptability of structures, thus extending their lifespans (Retsin 2016, 2019). Proficiency in advanced software and understanding of fabrication is increasingly demanded in architects (Kolarevic and Klinger 2013).

The utilization of fabrication technologies, namely CNC milling, 3D printing, and laser cutting, has demonstrated indispensability in realizing complex digital designs with exceptional precision and expediency (Sass and Oxman 2006). The implementation of sophisticated technological solutions enables the fabrication of bespoke parts, amalgamating them into intricate configurations, thereby fostering innovative architectural designs and spatial embodiments (Oxman, Rivka 2010; Oxman, R. 2006). Another technique to integrate design and fabrication is Contour Crafting as the layered fabrication technology that holds tremendous potential for automating the construction process, encompassing both entire structures and their individual components. Behrokh Khoshnevis in (Khoshnevis 2004) highlights how Contour Crafting can significantly increase efficiency and reduce construction costs by utilizing advanced

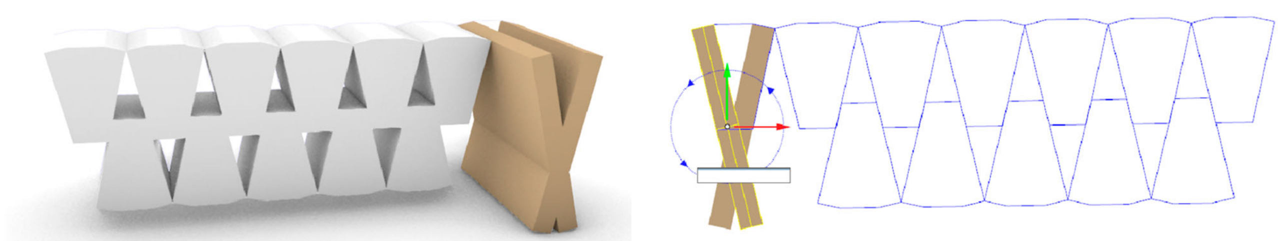

Figure 9. Cross-section methods create volume across one or two dimensions by rotating various planes and trimming them along the intersection lines. Credited by Erfan ZamaniGoldeh.

robotics and information technologies. By precisely depositing layers of building materials according to digital models, Contour Crafting enables the creation of complex architectural forms with exceptional accuracy and speed. Furthermore, pre-manufactured modules facilitate the acceleration of the construction process while reducing waste (Kizilörenli and Maden 2021a). This is due to the ability to fabricate such modules away from the actual construction site, subsequently assembling them on-site (Kieran and Timberlake 2004).

However, current tools present challenges in interoperability, causing inefficiencies (Eastman et al. 2011). Moreover, material constraints and regulatory frameworks can hinder these innovations (Oxman, Rivka 2010). As the sector progresses, the integration of AI and ML, along with advanced manufacturing, is expected to reshape architectural design, necessitating an understanding of cultural and social context (Agkathidis and Gutiérrez 2016).

3. Strategic framework

Discretisation methods transform continuous functions into discrete formats for computational use, covering a myriad of calculations. Various discretisation methods exist, from building construction to urban planning scales. These methods are grouped by their mathematical rationale and their parametric translations. Each method's evaluation stems from a deep dive into relevant concepts. The categorization of these methods considers both commonalities and differences in parametric strategies. This research, through an in-depth review of digital discretisation, seeks to bolster understanding regarding their potential applications and limitations.

3.1. Computational growth

In the realms of design, art, and architecture, computational expansion aims to create innovative, intricate, or visually striking geometries, sometimes meeting specific functional needs (Klemmt and Pantic 2019). This growth is made possible by integrating generative systems via exploratory search algorithms (Krish 2011) and facilitates iterative geometric evaluations, leaning towards more substantial mass accretion (Klemmt and Pantic 2019).

Several growth calculation models, such as Cellular Automata (CA) and Diffusion Limited Aggregation (DLA), have been devised (Witten and Sander 1981). This modelling uses significant part-to-whole mathematical logic. While initially intended for two-dimensional meshes, DLA is often applied freely within three-dimensional spaces (Witten and Sander 1981).

In architecture and urban planning, many attempts have been made to apply these models, as indicated by studies, e.g. (Al-Qattan, Yan and Galanter 2017; Adilenidou 2015; Kuo and Zausinger). In (Herr and Kvan 2007) authors suggest that while such methods can generate complex structures from basic geometry, transforming a general CA algorithm into a specific design tool remains poorly understood. Experts often note that computer-aided systems are adapted to achieve the best architectural design results. Addressing the voxelized geometries produced by Cellular Automata, as (Rafler 2011) introduced Smooth Life in its multicellular, neighbouring form.

Differential growth methods in architecture have been deeply analysed, focusing on how individual cells move in 3D space. This uses a vertex structure of polylines or mesh surfaces (Klemmt and Pantic 2019). The resulting geometries are useful for digital art, 3D printing, and can be scaled variably. (Klemmt and Sugihara 2018) used cell growth algorithms to create a mosaic panel installation. In a further study, (Klemmt 2019) based his methodology on a 3D point cloud, where each module's centre acts as a cloud point. These modules, through iterative repositioning, can sometimes lead to cell division.

According to (Retsin 2016), serial repetition and the amalgamation of distinct components remain highly recommended practices, emphasizing the importance of volumetric and resolved figures in design, instead of surface area and topology frequently observed in parametric designs. The 'WASP' parametric tool introduced a growth-centric strategy for 3D aggregation (Rossi and Tessmann 2017b). It melds geometric relationships with module shapes in a reversible manner, granting planners enhanced oversight during fabrication and assembly. The new WASP plugin links the digitized model to the tangible world.

(Tibbits 2012) suggests a system using intelligent blocks that define borders, operating concurrently. (Leder et al.) showcases a module-based arrangement using voxelized modules for non-standard concrete structures. These methods exemplify the flexibility of aggregation methods, showing prowess in detailed design creation. Modules can merge cohesively, forming a sealed mould for concrete pouring. Post-use, these modules can be disassembled and reused. Dodecahedrons, with their many sides, offer numerous unified configurations, giving a plethora of interface options (Leder et al.).

In the pursuit of innovative and functional geometries in architectural design, the investigation and implementation of different computational growth models, along with the utilization of aggregation-based technologies, have demonstrated significant potential. With the advent of artificial intelligence and its integration, the prospects of digital art, 3D printed creations, and adaptable construction techniques are bound to expand, exerting their influence on the trajectory of architectural design and production in the future.

3.1.1. Common ground in computational growth

Architecture has seen major advancements by adopting iterative evaluations and emphasizing design flexibility (Klemmt 2019). Algorithmic module expansion offers numerous opportunities for developing unique, complex structures (Rossi and Tessmann 2017a). Continuous assessment of geometric designs ensures the final result balances form and function (Klemmt and Sugihara 2018). Incorporating algorithmic growth methods, like differential growth, has expanded architectural design potential, enabling the creation of intricate geometries and 3D printed art at various scales (Tessmann and Rossi 2019; Rossi and Tessmann 2019).

3.2. Subdivision surfaces

Form and production's relationship has brought new challenges requiring intricate geometry (Pottmann, Wallner and Brell-Cokcan 2007). 'Tessellation' is the gap-free covering of surfaces using geometric shapes (Kizilörenli and Maden 2021b)

Using this, one can apply a subdivision method to refine geometry (Pottmann, Wallner and Brell-Cokcan 2007). The work of (Sauer 1970) exemplified the utilization of distinct modules for the purpose of constructing networks comprising related curves on a surface. Theoretical links exist between split plane interfaces and splines, with techniques segmenting edges and adding vertices to divide meshes, refined using a weighted system (Hertzmann and Zorin 2000).

Initial studies into irregular meshes were by (Doo and Sabin 1978) and (Sederberg et al. 1998), later applied by (Stam 1998) to produce quad meshes bridging surface and form. (Alliez et al. 2003) detailed quad-dominant mesh computation using smooth principal curvature lines, aiming for near-pristine flatness and optimal planar face configurations. In (Pottmann, Wallner and Brell-Cokcan 2007) authors built on this with conic meshes, enhancing quad meshes for planar or conical faces.

In a more recent approach, (Liu et al. 2020) explored neural division systems using a nonlinear method for triangular networks, offering an alternative to traditional linear algorithms. These conventional methods involve combinations of face splitting, point adding, and edge twisting, followed by vertex repositioning based on local means. Subdivision methods, as analysed by (Karčiauskas and Peters 2018), focus on interface continuity and availability. In practice, tools showcase interfaces while modellers aim to control the broader plane (Liu et al. 2020).

Moreover, users have the capability to manipulate the surface by incorporating points or curved edges in addition to adjusting vertices (Hoppe et al. 1994). Although non-interpolation techniques, such as have gained popularity, there exist other interpolation techniques that provide similar levels of smoothing confidence (Dyn, Levine and Gregory 1990). However, the maintenance of equity can prove to be a considerably challenging task within certain contexts. The utilization of linear approaches in construction and analysis has been noted to possess ease and assurance of smoothness. It places the burden of assembling intricate details on the modeller or an anticipated procedural function (Velho et al. 2002).

Numerous approaches have been devised to enhance these fundamental practices for better precision in modelling and regulation. (Schroeder, Martin and Lorensen 1998) have extensively investigated adaptive techniques.

Furthermore, there are some investigations into the utiliza tion of robotic technologies for fabricating traditional Chinese timber joints, the paper – probes into the viability of the structural rationale of the Dougong and its potential application within contemporary timber framework structures. The underpinning of this research is grounded in diminishing the mass of a structure by removing superfluous units (Zhao, J. et al. September 2021).

3.2.1. *Common ground in subdivision surfaces*

The utilization of parting surfaces as a discretisation and approximation method for intricate geometries in the field of architectural design frequently involves employing both linear and non-linear techniques that entail the manipulation of vertices, control points, or curved edges to guarantee a seamless workflow (Hoppe et al. 1994). Adaptive techniques have been developed which facilitate mesh refinement solely when occasion demands, thereby enhancing computational efficiency and enabling efficacious depiction of intricate shapes (Dyn, Levine and Gregory 1990). The current steps in the subdivision of surfaces manifest an amalgamated endeavour by the architecture to establish enhanced and proficient strategies for managing multifaceted undertakings, consequently steering the course of the architectural design and production landscape.

3.3. *Cross section*

Polyhedral forms, as highlighted by (Kanel-Belov et al. 2010a), are foundational in the moving cross-section approach, using square mesh networks and modules. Module positioning is based on the mesh edges, and (Pfeiffer, Lesellier and Tournier 2019) describe a method to convert planes into modules. Their process allows for creating versatile polyhedral modules compatible with planar meshes. The potential lies in their adaptability and the potential interconnection of nested elements. Planar grids can help combine discrete slices, with a topology influenced by module sides, as detailed by (Wang and Liu 2009). It's advised to avoid X and Y motions in module construction, with CAD methodologies refining this cross-sectional system, notably (Tessmann 2012) and (Bejarano and Hoffmann 2019) exploring this. The latter also introduced midpoint and height values to enhance modular control.

Beyond consistent curvatures, this technique advances geometric configurations. Academically, (Manahl, Stavric and Wiltsche 2012) offer a method for quickly producing discrete meshes. Their goal blends design rationalization with form research, focusing on planes tangent to surfaces. The merger of digital design advances with novel geometric methods is reshaping architectural design, promising innovative, flexible, and efficient buildings.

3.3.1. *Common ground in cross-section*

The utilization of polyhedral forms and planar surfaces facilitates the advancement of sophisticated and adaptable frameworks that can serve diverse purposes in architectural endeavours (Kanel-Belov et al. 2010b). Moreover, the prioritization of scrutinizing topological and geometric correlations among modules promotes the production of intricate and effective arrangements, thereby amplifying the capabilities of these inventive methodologies (Bejarano and Hoffmann 2019). The incessant progression of computer design tools and digital fabrication techniques holds great potential in the transformation of architectural design while offering novel prospects in the creation of multifaceted, versatile, and productive structures; as emphasized by (Manahl, Stavric and Wiltsche 2012).

4. Discussion

In early human dwelling construction, individuals cleverly adapted to available resources, crafting shelters from stones and wood. These primitive structures predated the use of now essential materials like glass and concrete. Early humans displayed growing knowledge in building using manageable elements like rocks and branches, laying the groundwork for the architectural

Table 1. Discretisation classification.

Computational Growth	Subdivision Surfaces	Cross-Section
Cellular Automata (CA) Growth	Tessellation	Polyhedral Planner Grids
Diffusion Limited Aggregation (DLA)	Repetitive mesh shaping	Topological Interlocking System
Rule-based/ Generative Aggregation	Discrete Differential Geometry	Curvature Moving
Differential Growth	Curvature Network	Intersection of Tangent Planes
	Planner Surface	
	Liner Triangular Mesh	
Common Ground	Common Ground	Common Ground
1. Mass Approximation 2. Form Finding 3. Boundary Control 4. Geometrical Complexity 5. Interlocking Joints	Underlying Geometry 2D Modular Units Control Surface Based Repetitive Modular	Overlapping Planner Group Control Joints Complexity Modular Boundaries

principle of discretisation. With technological advances, standardized modules emerged, shaped by resource availability and equipment evolution.

By the late twentieth century, especially during the 1980s, discretization matured, echoing the modularity of Lego blocks, employing uniform units to craft diverse configurations. Originally, discretisation was a practical solution to craft intricate shapes by breaking the main geometry into smaller modules, maintaining their geometric relationships. A prime example is the Great Court Roof at the British Museum, designed by Foster and Partners. Modern architectural discourse recognizes discretisation not just as a form-finding solution but as a bridge between design and production.

Usually, constructing a structure involves various elements like windows and columns. Yet, imagine a building made from 50,000 identical sticks, akin to large Lego pieces. This idea stems from the 'retrospection' theory proposed by Mollie Claypool (The Bartlett and Claypool 2019). Gilles Retsin further emphasizes the potential for discretization to revolutionize architectural production (Retsin 2019), viewing it as an overarching method rather than just a design tool (Table 1).

5. Conclusion

The late twentieth century marked a pivotal shift in architecture, with the advent of digital capabilities signalling a new era of innovation. Discretisation techniques promise to shape a future of sustainable, innovative, and eco-friendly architectural practices. Merging discrete digitalization with advanced technologies, like 3D printing and robotic assembly, the construction realm anticipates greater efficiency, profitability, and quicker project completion. Understanding discrete architectural systems paves the way for insights into modular computer-based design. Subsequent research by this paper's authors will delve into modularization's core concepts, highlighting its benefits and challenges. This work's implications touch upon robotic Design for Manufacturing and Assembly (DfMA), with future studies set to enhance modular design within discretisation systems, building upon the tools and methods presented here.

5.1. *Future works*

This paper sets a foundation for several potential research avenues. Firstly, there's a need to delve deeper into the parametric facets of modular discretisation, encompassing both fabrication methods and assembly processes. This involves examining parametric tools in the creation and analysis of modular units and exploring a cohesive approach merging digital design with robotic assembly for enhanced reliability and customization. The outlined framework for designing and optimizing these systems offers ample scope for expansion, particularly by blending computational geometry, optimization techniques, and assembly design. Its capability to swiftly produce tailored solutions while reducing operational challenges offers promising areas for investigation. Future studies should also focus on creating adaptable modular systems suitable for a variety of sectors. Finally, practical application testing of these modular systems across different scenarios will cement their effectiveness and demonstrate their transformative potential in the realm of discretisation systems, catering to diverse applications and sectors.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Data availability statement (DAS)

The data that support the findings of this study are openly available in data.mendeley.com at 10.17632/4bd7fcfwrs.1.

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