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Parametric Architecture beyond Form—Klein and Price: Pioneers in Computing the Quality of Life in Housing

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Abstract: This article proposes the investigation of two case studies of 20th century residential architecture that can be considered paradigmatic due to the pioneering use of parametric thinking in architecture. It deals with Alexander Klein's plan analysis model and Cedric Price's research on housing through his concept of 24-hour economic living toy. Both cases are analyzed using contemporary parametric tools to digitally reproduce the results of the analog diagrams developed by both architects. The reproduction of the diagrams makes it possible to recognize and make visible the specific parameters that are used in each case, demonstrating an evolution of housing research throughout the two periods. While Klein shows an observation focused on the efficiency of form, Price pursues a recognition of the uses to facilitate the adaptability of the architecture according to optimal usability.

Keywords: parametricism; housing; rationalism; user-centered design; Alexander Klein; Cedric Price

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1. Introduction

The architecture cataloged as parametric—produced from parametric and relational design processes—has now reached a certain degree of popularity as a mechanism for investigating new constructive forms. For many people it has become an inherited strategy from form finding research carried out by personalities of 20th century architecture and structural design, such as Frei Otto or Heinz Isler [1–5]. The great contribution of the parametric design model is the ability to interactively modify the final result of a project thanks to the fact that it has been defined through the relationships between the parameters that configure it. In this way, the relationship system is the goal of the design, while the form is only a manifestation of the result [6]. However, this relational capacity of parametric design also has great potential as a tool to achieve simple geometric artifacts, but whose determining parameters require the adoption of optimized or customized relationships by complex qualitative or quantitative criteria. As we will see below, this article explores how this model of thinking [7]—which we can consider as parametric thinking or algorithmic thinking—was already applied by researchers in residential architecture at different times in the 20th century. We will analyze two case studies: Alexander Klein and Cedric Price.

Alexander Klein was a key figure in the search for new housing standards in the first half of the twentieth century. The grave economic crisis that engulfed all European nations following World War I instilled in architects a strong sense of social and political responsibility: design became a tool to build as much as possible with less cost. Rationalism was deemed to be an essential part of housing regulation, and Klein was a pioneer in this field. He investigated the topic of habitation in all of its complexities, including the psychological impacts of living situations. Klein's mathematical methodology in the design process started with comparing various dwellings to determine some critical parameters for evaluating the lodgings. The process of comparison consisted of many factors. The minimum requirements of the family and the person who lived in the lodgings were his focal points. In this method, any part of the area is designed for people's most basic needs. The space that is considered a "free zone area" of the dwelling is discarded. His scoring method of the successive increments was one of the most innovative parametric systems that became a manual for the design of the dwellings.

A few decades later, Cedric Price's concerns started to take shape in criticism of rationalism. His research was always aimed at pinpointing the importance of users' behavior in the living environment. Throughout his career, he approached cybernetics as a science capable of modeling behavioral data to program the modification of spaces. It can be considered the first approach to architecture from a user-centered design perspective. This aspect is heavily emphasized in one of his research projects called "towards a 24-hour economic living toy." His diagrammatic comparison resembles Klein's drawings, with the significant difference of the introduction of the parameter of time. He begins to imagine how different people will use the same space in different time zones and how the spaces will be occupied throughout the dwelling's lifespan. Cedric Price's methodology and vision vindicates the parametric value of Klein's work in search of the responsive and transformative capacity of architecture.

Parametric thinking has always been used to answer necessities in housing since the 20th century and should be considered among the innovative and experimental techniques displayed since the very beginning of Modernity. However, despite the fact that we have achieved many prospects in housing with today's advances in computational design, the technology has not made a design regulation to reach and open its full potential. With the help of current parametric tools, this essay investigates the works of these two renowned architects of the 20th century where the roots of parametric thinking flourished. This investigation aims to analyze their work by using the current parametric software. Thus, the two architects' concepts and parameters will be observed with today's digital tools, and we will be able to assess their impact and whether we are closer to user-centric design or rationalist principles.

1.1. Hypothesis and Research Objectives

The research hypothesis of this essay states that both the work by Alexander Klein and the work by Cedric Price are pioneers in parametric thinking. In both cases, investigations are being carried out on the types of housing that seek the qualitative optimization of results, and that is shown through generative tables of possibilities. Both propose in an intuitive and analogical way a parametric algorithm for the definition of relationships between the factors to be considered at every moment. In both cases it is possible to reproduce the logical process carried out and transcribe it using contemporary digital computing tools. To carry out this transcription, it will be necessary to identify both the parameters and determining factors of each investigation, as well as the operators and relationships that are proposed for optimization. Ultimately, to test the hypothesis, the most significant generative schemes of Klein and Price will be reproduced, with the aim of showing the computational algorithm used in each case. This way, it will be possible to make visible the factors that each author considers significant at every moment to address the housing problem.

For all the above, we can identify three fundamental objectives of this research:

- In the first place, the verification of the existence of a genealogy of parametric thought present in the architectural research of the 20th century and visible through key figures that we can consider especially influential.
- Second, the comparison between the scientific approach to the housing problem in the interwar period and first modernity in the Western context with the approach to the same problem in the period after World War II.
- Third, the use of contemporary parametric design tools to demonstrate their ability to compute problems of a conceptual nature—in this case, the quality of life provided by residential typologies—and not exclusively formal.

1.2. Literature Review

For the construction of this research, the state of the art of the three protagonists of the story has been observed: Alexander Klein, Cedric Price, and the concept of design and parametric thinking. In addition to the references explicitly indicated in the argumentation of the process, we want to make a brief mention of the generic bibliography that has been consulted for the most holistic approach to each of the protagonists.

In the case of Alexander Klein, the author's own writings have been observed first, highlighting those works published in the 1930s that compile his various methods of plant analysis [8,9]. Direct consultation of his first essay on the graphic method for the valuation of plants, published in Berlin in 1927 [10], has also been important. Other of his articles of the time explore in a panoramic way the conditions of minimal housing [11,12], or his theoretical and methodological positions when facing the collective housing project [13]. Apart from his own writings, a particularly interesting text to get to know the figure of Klein is the compilation carried out by Matilde Baffa Rivolta and Augusto Rossari, which documents and analyzes the methods and experiences carried out by Klein as a researcher and designer [14], and that has been consulted through the Spanish translation [15]. Finally, academic articles produced in recent years have been observed. They fundamentally review the scientific nature of his methodological approach and his contributions to the history of residential architecture [16–19].

In relation to Cedric Price's work, a bibliographic source that has been fundamental to analyze his research in housing has been the collection of projects, articles, and conferences carried out by architect Samantha Hardingham and published in two volumes by the Architectural Association of London and the Canadian Center for Architecture in Montreal [20,21]. The two volumes include both the articles produced by Price between 1970 and 1972 for the *Architectural Design* magazine—in which details of his Housing Research are displayed—as well as projects and essays that accompanied this research in a propositional way—such as the project for the Steel House Competition (1965–1966) or the housing projects for the Potteries Thinkbelt complex (1966–1967). On the other hand, the attention paid to Price by contemporary academic literature is enormous, including books that critically review his entire work [22–24], and a great set of articles that focus on some of his most significant contributions—technological conception of projects, their temporal logic., social character of their approaches, etc. [25–29].

Finally, the research has contemplated a specific observation of literature related to the concept of design and parametric thinking. Its origin has been located in the work on Patterns by Christopher Alexander, a pioneer in the approach to generative design models [30,31]. Thanks to his conceptual approach, later works focused on the algorithmic conception of the registration of patterns were possible [32–34]. Understanding the scope of algorithmic thinking in the field of architecture has been a subject extensively studied by Professor Mario Carpo, an observer of the notions of repetition, copying, and variation, implicit in the design of systems and typical of this paradigm of thought [35–37]. The concept of parametricism has been revised and incorporated into contemporary debate by authors such as Patrick Schumacher, although in relation to the definition of a possible new style, the successor of modernism [38]. In this sense, there are abundant references to the form production capacity of parametric design [39], although its ideological and political implications are also questioned [40,41]. Finally, from the approach of this article, special attention has been paid to the relationships already established between computational design and the authors considered as case studies, such as the relationship observed between Cedric Price, Christopher Alexander, and Nicholas Negroponte [42], or the relevance of cybernetics in the particular case of Cedric Price [43].

2. Materials and Methods

In this section, the reasons why Alexander Klein and Cedric Price's works deserve a contemporary review in relation to their parametric character will be presented. In their contexts, both architects based architectural research and knowledge production on methods of purely scientific nature. Both tried to objectify decision-making related to contemporary living by considering functional and environmental factors, qualitative and quantitative, with the aim of optimizing the use of the available surface, reaching the benefits and requirements of residential needs.

The following describes the work context of each of the authors, as well as the method and digital tools used for the translation into visual algorithms of two of their most representative synthetic schemes.

2.1. Alexander Klein

Although born in Russia, Alexander Klein (Odessa, 1879-New York, 1961) settled in Germany in 1920 in the full effervescence of the so-called "new objectivity" (Neue Sachlichkeit) [44,45]. After the disasters caused by World War I, the German architectural environment abandoned expressionism and the will for a new social and political commitment emerged that permeated all areas of society. By the mid-1920s, efforts to build affordable housing intensified, an area in which Klein was beginning to establish himself as an expert. In 1927 he assumed a position of responsibility in public administration of the city of Berlin, accepting the position of Baurat (responsible for building and public works) [46]. From this position, he developed management tasks related to economic issues of building, but also addressed research activities, trying to develop economic typologies of social housing, in institutions such as the RFG (Reichsforschungsgesellschaft für Wirtschaftlichkeit im Bau) [47]—organization for economic efficiency in construction.

It was a period of exploration of new standards of housing typologies and their grouping models, as well as the new conditions of rationalization of the quality of the space—attention to factors such as ventilation, sunlight, or orientation—and innovation in construction—observing the possibilities of prefabrication or modular coordination [48]. In this context, Klein's ideas always work as a scientific approach to the problem, capable of putting in the background the subjectivity of the Modern Movement to incorporate a quantifiable method for the valuation of homes.

His great contribution—and focus of analysis in this paper—is the method of valuation of housing plants that he developed in 1928 [49]. The method proposes a sequence of operations through which certain qualitative values of homes could be verified, at the same time as quantify some comparable indicators. The final objective should be the selection of the minimum dwelling (Existezminimum) [50] with the capacity to integrate the necessary benefits. To achieve this objective, three phases of work are proposed:

- First, a questionnaire is proposed that addresses two types of questions: dimensional and functional. Dimensional questions can be answered in a numerical way, while functional questions—directed to aspects related to hygiene, habitability, and comfort—are answered in a binary way (yes or no). From the application of the questionnaire, three evaluation coefficients are obtained [51]: Betteffekt (relation between built area and number of beds), Nutzeffekt (relation between useful area and built area), and Wohneffekt (relation between areas of living spaces and bedrooms and built area), and a cumulative score of positive responses to the qualitative questions.
- Second, the reduction of all projects to a single scale is proposed, taking into account the parameters of depth of the building and width of the façade. The different alternatives are represented in diagrams that show a complete picture of possibilities, adapting the houses to the determined dimensions of depth and width. In particular, this comparative look makes it possible to identify the most favorable values for the Betteffekt coefficient, and, therefore, to assign the most efficient dimensions for homes that require a certain number of beds.
- Third, a graphical analysis method is developed that allows validating the results obtained in previous stages by graphically checking the achievement of objective qualities [52]. These are: ordering of zones for corridors and route of the circulations; concentration of free surfaces; relationships between the elements of the plant; fractionation of surfaces; etc.

Figure 1 shows an example of the type of results provided by this comparative graphical analysis method. In it, each house floor is reproduced in a simplified way (interior bays and staircase). From left to right the variations are arranged depending on the depth of the building. From top to bottom the variations are arranged depending on the width of the facade. The plants are evaluated according to the criteria set out in Table 1, obtaining as a result that the variations with the highest qualification occupy the diagonal of the di-agram, where depth and width keep an adequate balance in relation to hygienic, comfort, and economic conditions. The result of the study shows the most suitable plants, indicat-ing their surface area and showing the location of the beds.

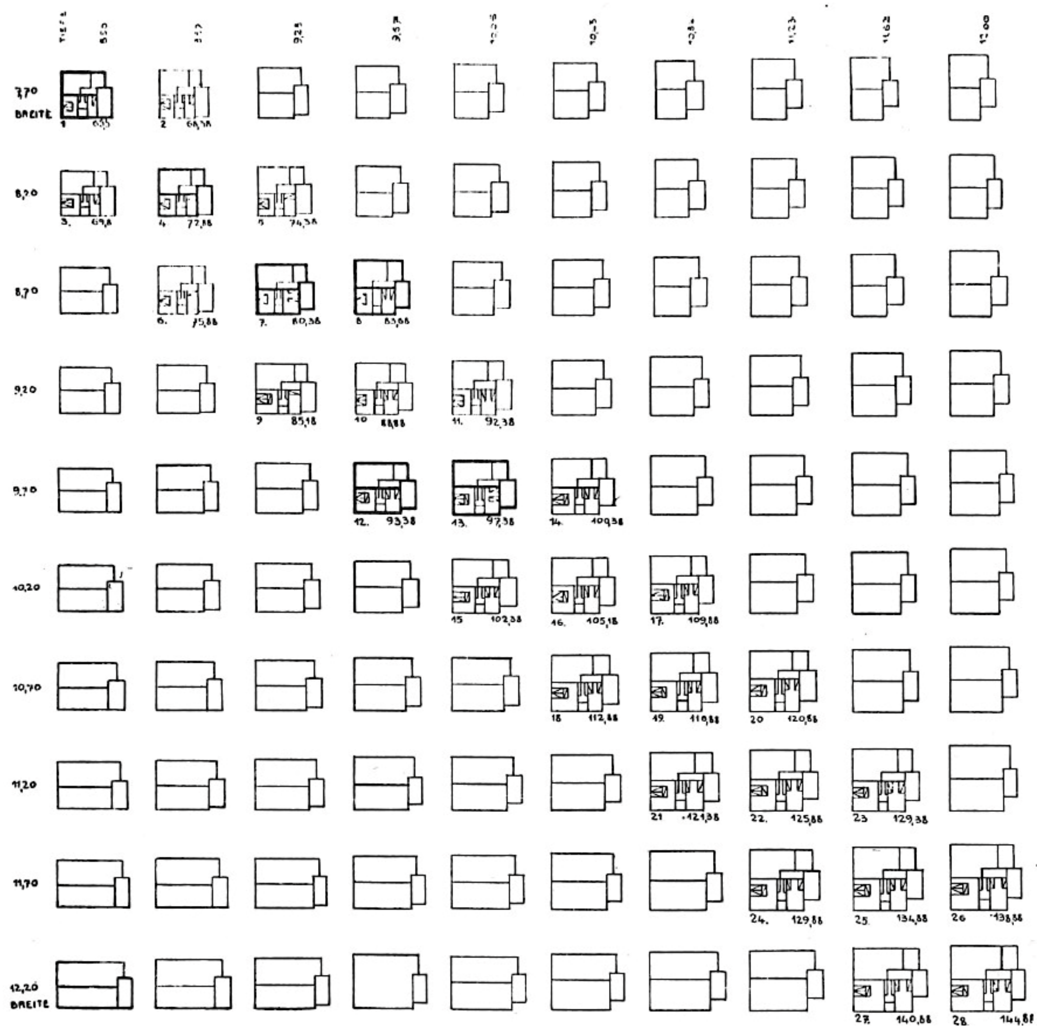

Figure 1. Plan-efficiency comparison. Source: Klein (1928).

The final objective of this analysis process is the rationalistic objectification of conditions under which affordable housing (necessary to meet social demand) must be produced. The construction of the method aims to ensure that those institutions responsible for the processes share criteria for the observation of the variables [53]. Therefore, it is a process based on the consideration of a series of parameters that are adjustable according to established coordinates to obtain comparable results. Therefore, this is an approach to complexity that today we can recognize as a parametric design process.

With regard to this research, the production of a diagram of variations of dwellings and its adaptation to variable parameters of width and depth (to achieve optimal habitability conditions according to the determined coefficients, especially the Betteffekt value), is of particular interest. This approach is clearly based on the construction of a system for the detection of housing variants that optimize their efficiency of use based on dimensional parameters. This will be the scheme that the research will reproduce to make visible the parameters and implicit operations in the system.

Table 1. Evaluation criteria for Klein's work.

	Economic Aspects																**Hygienic Aspects**				**Characteristics Regarding the Habitability**								**Spatial and Distributive Characteristics**					
	The Main Characteristics of the House							Main Rooms			Secondary Rooms				Coeff																			
PROJECT	Built area	Built volume	Used area	Amount of rooms	Amount of beds	Betteffekt 1/5	Built volume per bed 2/5	Living room's area	Bedroom's area	Resulting area 8+9	Kitchen's area	Bathroom's area	Service area	Resulting service area 11+12+13	Nutzeffekt 3/1	Wohneffekt (8+9)/1	Is the orientation homogeneous both in the living and in the bedrooms?	Shadows are avoided in the living and in the bedrooms?	Is the light sufficient?	Not-served rooms avoided?	May children be divided in base of their sex?	Is the room's dislocation good for the habitability?	Is the bathroom separated from the toilette?	Is the access to the loggia independent from bedrooms?	Is the position of doors and windows good for the furniture's disposition?	Are bathroom and WC adjacent to bedrooms and independent of them?	Are there spaces for wardrobes?	Are movement areas concentrated	Are rooms differentiated in base of use and dimensions?	Disadvantageous connections between rooms avoided?	Are rooms well connected?	Is the light aesthetically good?	Are encumbrances reduced using wall-wardrobes?	**SCORE**
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	

2.2. Cedric Price

In relation to a later historical moment, Price's case is also especially significant. Cedric Price (Stone, 1934-London, 2003) has been recognized on multiple occasions as the most influential British architect of the 20th century who built the least architectural work. It has even been said that his project with the greatest impact has been the construction of his own character [54]. He was an architect who was deeply critical of the role played by the architecture profession in relation to the social context of the second half of the 20th century. According to his own reflections, the profession had been institutionalized as a tool located at the end of the political, territorial, or urban decision-making processes, and therefore subordinate to them [55]. However, Price's professional interest was not oriented towards the productive function of architecture but focused on processes [56]. His approach to architectural projects always began by questioning the objective for which architecture should be developed, and if the final solution really should be a building [57]. He did so throughout his career and passed it onto the students who passed through his classes at the Architectural Association in London. His perception of architecture was clearly closer to a matter of social function than to a discipline of formal production [58]. Hence, he questioned the very identification of architecture with construction, and raised the time factor as an inescapable variable in intervention processes of the physical environment.

Price's proposals were always projects based on adaptability and temporality of spaces and programs. Projects where mobility and flexibility acted as key factors [59]. Two of his most significant built works were London Zoo Aviary [60] (1961) and Interaction Center [61] (1974)—this latter demolished in 1999—while his two best-known projects, although not built, were Fun Palace [62] (1960–1961) and Potteries Thinkbelt [63] (1964). However, a topic to which he dedicated a good part of his work as a researcher was the field of housing, an aspect that focuses our attention here.

Cedric Price's approach to the housing problem must be framed in the context of British society in the 1960s, the stage immediately after postwar housing policies. The effort to eradicate slums and increase the affordable housing stock through massive blocks or new towns had not met the existing demand, nor the expectations for quality architecture [64]. This was a time when the architecture department of Greater London Council (GLC) was striving to incorporate industrialized production methods and new parameters of flexibility in housing [65], while the National Building Agency (NBA) tried to standardize plans to streamline construction [66]. On the contrary, Price's work sought to provide home users with the ability to choose, to make the most of the possibilities of the available living space.

His research about housing enjoyed great popularity at the beginning of the 1970s thanks to its publication in the magazine *Architectural Design* between 1970 and 1972 [67–71] (for this, he had been invited by editor Peter Murray). In the research, he developed the conceptual and speculative project of a housing model called Short-Life House, based on the indeterminacy of uses those future occupants could make of the different spaces. It approximated a housing system model based on the diversity of choice possibilities, rather than on a definitive product. In this way, both the decisions of the inhabitants in search of optimizing their comfort, as well as future changes in the composition of the living unit could be taken care of by the system. In his own words, "the house is no longer acceptable as a pre-set ordering mechanism for family life".

In relation to his research on housing, three previous works should be mentioned in which Price addresses the fundamental concepts that will lay the foundations of his proposal. First, the residential project included in his proposal for Potteries Thinkbelt. Second, the Steel House project. Third, his essay on housing as a 24-hour economic living toy [72], which will be used in this analysis to understand the determinants factors of the architect's concerns.

Apart from previous work for the Potteries Thinkbelt project, in which Price developed housing typological and constructive variables for different situations, the Steel House project is important for understanding his ideological approach to housing. The Steel House was carried out as a proposal for the contest sponsored by the ECSC (European Coal and Steel Community), an entity that sought to collect ideas for a pre-industrialized steel house model, in a standardized way, and assembled as demountable modules. In collaboration with Milles Park, Douglas Smith and Frank Newby, Price developed the proposal for a structural skin as a continuous metallic envelope capable of integrating interior cells that could vary over time. In this way he responded to the approaches of his essay Towards a 24-hour economic living toy, on which he worked simultaneously while developing the Steel House project. The fundamental message of the essay was the realization that the house can no longer be considered as a predefined mechanism for family life. Price puts in crisis the very existence of a single predetermined family model and raises the need for the typological plan to be modified over time to adapt to the changing needs of the group of people who occupy it. While the Steel House schematics show a changing pattern of house occupancy, capable of technically adapting to these changes, the essay approaches the problem critically, developing the virtual occupancy of different apartments to recognize the patterns of use that may be apprehended by the home for modification. Therefore, it is again a parametric approach to the conception of the design, in which the determining factors of the configuration of the house are related to the occupation habits of its inhabitants.

Therefore, the occupations scheme applied to one of the typologies tested in the Towards a 24-hour economic living toy trial will be the diagram that will be reproduced with computational means in this case to make visible the parametric nature of the analysis system of home by Cedric Price.

Figure 2 shows the occupancy diagram of different types of dwelling based on their use by the occupants throughout the day. The time bands are shown in columns. The occupied areas are shown by different hatched patterns applied to the spaces in use by each type of occupant—defined based on the responses indicated in accordance with the criteria in Table 2. The result of the diagram shows the areas with high density of occupation and underused spaces, providing information to the designer for the adaptation and optimization of spaces.

Figure 2. Diagram for Towards a 24-hour economic living toy. Source: Interior Design (September 1967).

Table 2. Definition criteria by Price.

		24-Hour Cycle Performance																							
		00:00–01:00	**01:00–02:00**	**02:00–03:00**	**03:00–04:00**	**04:00–05:00**	**05:00–06:00**	**06:00–07:00**	**07:00–08:00**	**08:00–09:00**	**09:00–10:00**	**10:00–11:00**	**11:00–12:00**	**12:00–13:00**	**13:00–14:00**	**14:00–15:00**	**15:00–16:00**	**16:00–17:00**	**17:00–18:00**	**18:00–19:00**	**19:00–20:00**	**20:00–21:00**	**21:00–22:00**	**22:00–23:00**	**23:00–00:00**
OCCUPANTS	Number of occupants																								
	Type of occupants																								
	Age of occupants																								
ACTIVITY PATTERNS	Bedroom activity																								
	Sitting-room activity																								
	Kitchen activity																								
	Toilet-Bathroom activity																								
USABILITY OF VOLUMES	Storage unit																								
	Kitchen unit																								
	Cleanse unit																								

2.3. Parametric Translation and Visual Algorithm

Considering the concept of "parameter" as a catalyst element in the design process implies the identification of a series of variables whose absolute values determine a specific result. A parameter is an element of the system—one of the factors that determines the result—whose indicator allows the design to be quantitatively evaluated. For this reason, its modification by means of alternative values allows us to obtain variations of the design depending on this parameter. A geometric modeling process is determined by means of equations. We use parameters as unknowns of these equations, whose value allows obtaining variables from the result of the system, and therefore from the modeling. In short, parametric modeling—and therefore parametric design—is the mathematical system by which we can automatically generate variations in order to optimize their suitability to a defined context condition [73]. In this way, parametric design allows defining the shape of an object or structure from the relationships defined between the variables [74]. To achieve this form, a defined and finite sequence of operations must be followed as a computational method—what we know as an algorithm—in which the variables will consider the corresponding parameters [75].

The research poses a double task of algorithm construction:

- First, to verify the parametric nature of Alexander Klein's methodology, this approach to his work proposes the reproduction of his comparative diagram of project variations and the evaluation of the Betteffekt coefficient using parametric design tools.
- Second, to verify the parametric nature of Cedric Price's methodology, the partial reproduction of his scheme of the 24-hour economic living toy test is proposed as a result of a parametric algorithm. Thus, we can identify the character of the parameters used by Price for his housing proposal.

For both cases, Grasshopper digital application will be used. It is a graphical algorithm editor built into Rhinoceros 3D modeling software. As an algorithmic modeling tool, Grasshopper allows the creation of generative shape algorithms using visual parametric nodes. In this way we can make a direct translation of Alexander Klein's generative diagram to his graphical algorithm, obtaining a visual scheme in which we can recognize the determining parameters of the form. And in the same way, we can display the factors that determine the occupation of the home in the 24-hour cycle by building an algorithm that recognizes the activity patterns of the inhabitants in the example by Cedric Price.

The objective of both algorithmic translations will be to compare the nature of the parameters and variables involved in each of the cases. The contrast between these variables will demonstrate the evolution of housing concerns throughout the 20th century from the perspective of two of the architectural figures with a more scientific perspective of the design process.

3. Results

3.1. Klein's Method

The plans were grouped on the basis of some dimensional variables and the distributive scheme, in order to be "reduced to the same size," that is, to be comparable on the basis of the number of beds, according to Alexander Klein's "Method of the Successive Increments."

The planimetric diagrams were modified by increasing the length and the width of the building by constant amounts; as shown in Figure 3, they were disposed in a grid, where the rows represented the increase in depth, the columns the increase of the width.

In order to realize Alexander Klein's parametric thinking approach, the drawing of the diagram is constructed by dividing the script in many chapters using Grasshopper. The first chapter is to construct a set of plans with the increment of depth and width.

Based on the original table by Klein, the table of 10 $\times$ 10 has been created. The rectangle of 8.8 m by 7.7 has been presented as perimeter of the plan. The steps of 0.5 m have been added to each row and column in order to create 100 individual plans in the table. Based on this module, each function from further on will be applied to all of these plans individually, as depicted in Figure 4.

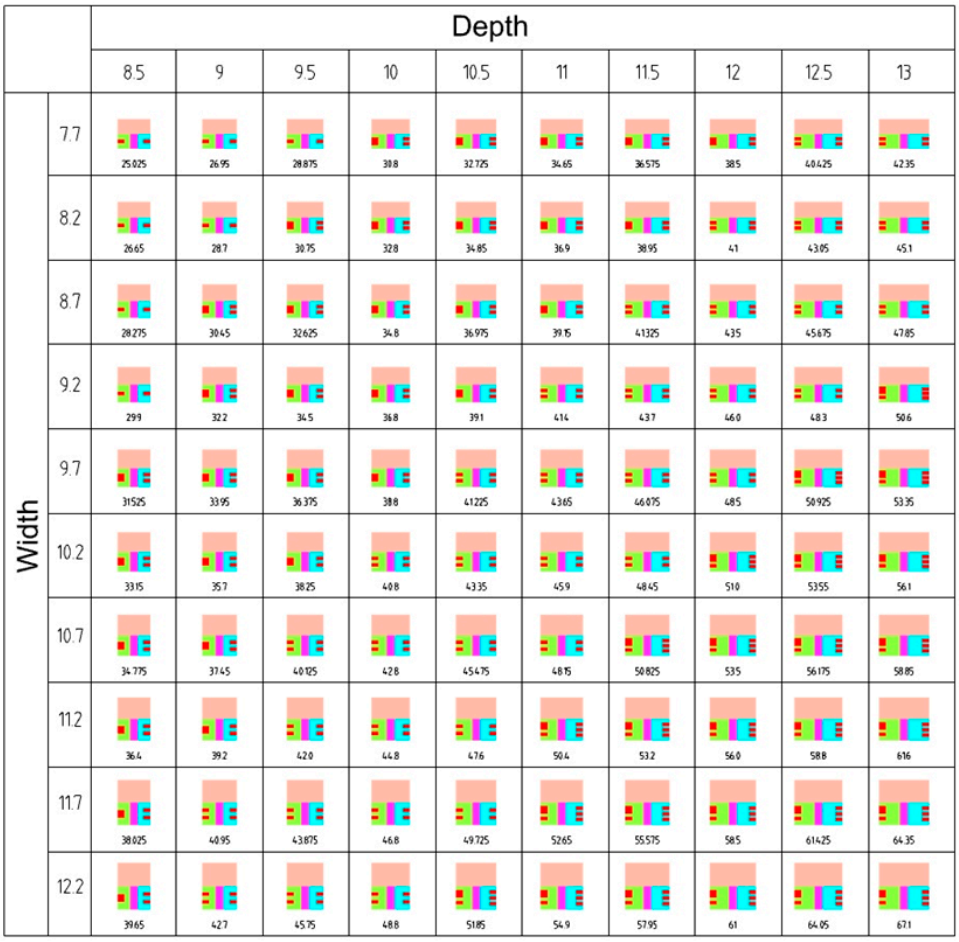

Figure 3. Method of the successive increments. Example of comparison and evaluation of several plan diagrams reduced to the same scale (1 living room, 1 bedroom for parents, 1 bedroom for children) using Grasshopper.

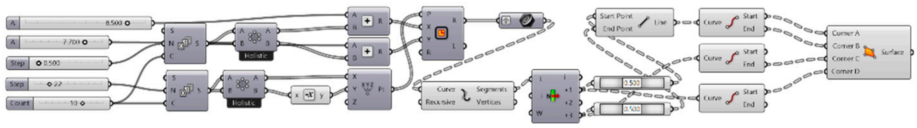

Figure 4. Creation of the rooms and the table of 10 × 10.

By dividing the width in two on each plan, the living room has been created. Each plan has been divided into two smaller plans. Half is dedicated to the living room, while the other half is dedicated to the two rooms and the corridor in between. In order to make the corridor, each length of the rectangle has been divided in two. The corridor has been added by offsetting the division line between the room. The result is a room with one liv-ing room and two bedrooms with a corridor in between. This function, depicted in Figure 5, has been created in the parametric software in seconds while Klein spent weeks creating this grid.

The way that the script is designed (Figure 6) is according to the areas of the room. If the areas are in some domains, the single bed (rectangle of 1.8 × 0.9 m) or double bed (rectangle of 1.8 × 2 m) will be added to the plans. It will detect the increase in area and determine how many beds should be added to each room. The function is designed to categorize four rooms based on four domains.

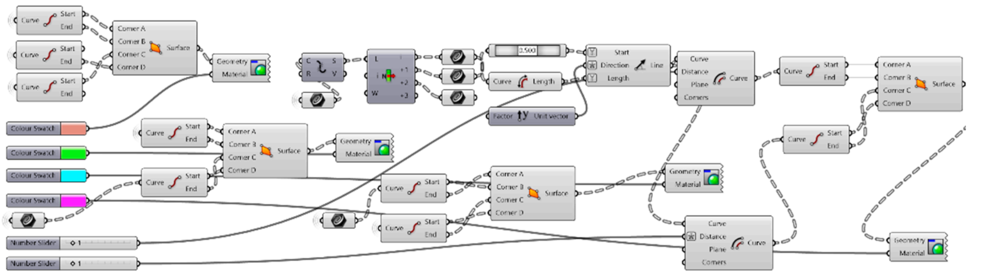

Figure 5. Creation of rooms, corridor, and living room in parametric software grasshopper. The orange color is represented as the living room while magenta color is the fixed area of corridor between the two rooms. Blue and green represent the room. All the colors correspond to the drawing that is shown in Figure 3.

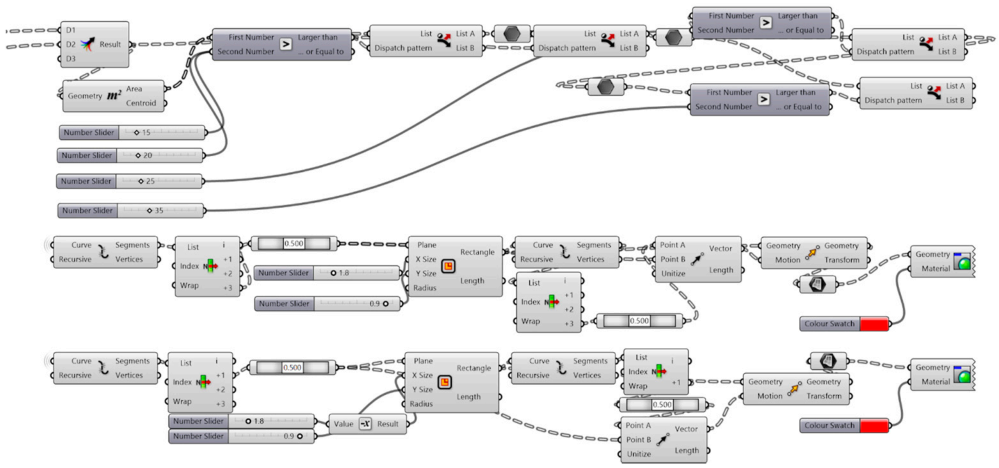

Figure 6. Part of the script in Grasshopper program. The top cluster is when the functions are added. The bottom cluster is the first division of the script where two single bedrooms are inserted following the area, which is less than 15 m2. The red color switch is the visual representation of the beds which is shown on Figure 3.

The first typology applies when the room's area is less than 15 m2. The code will add the possible minor beds inside the room, which are two single beds. When the space is between 15–20 m2, the second type will add one king-size bed to the parents' room and two single beds to the children's room. When the area is between 20 and 25 m2, the script will add two beds to each of the two rooms, and when the area is greater than 25 m2, the script will add the maximum number of beds feasible.

The script will work with any input plan and automatically generate the drawing for further comparison, as Klein wanted to achieve. Klein was producing all the drawings one by one to understand the difference and efficiency, while with the script, we can automatically detect the same conclusion. As a result, the diagram displayed in Figure 3 is obtained, which formally reproduces Klein's original drawing in Figure 1. The list of parameters used in the script would be as follows:

- Dimensions of the house
- Built area
- Amount of rooms
- Dimensions of the rooms and corridor
- Number of beds

3.2. Price's Method

On the other hand, Cedric's Price approach to parametric thinking was due to the parameter of time inside the space. Price determined how each person will use the dwelling during the day. As shown in Figure 7, this plan was reconstructed in Grasshopper in order to realize price´s method of thinking.

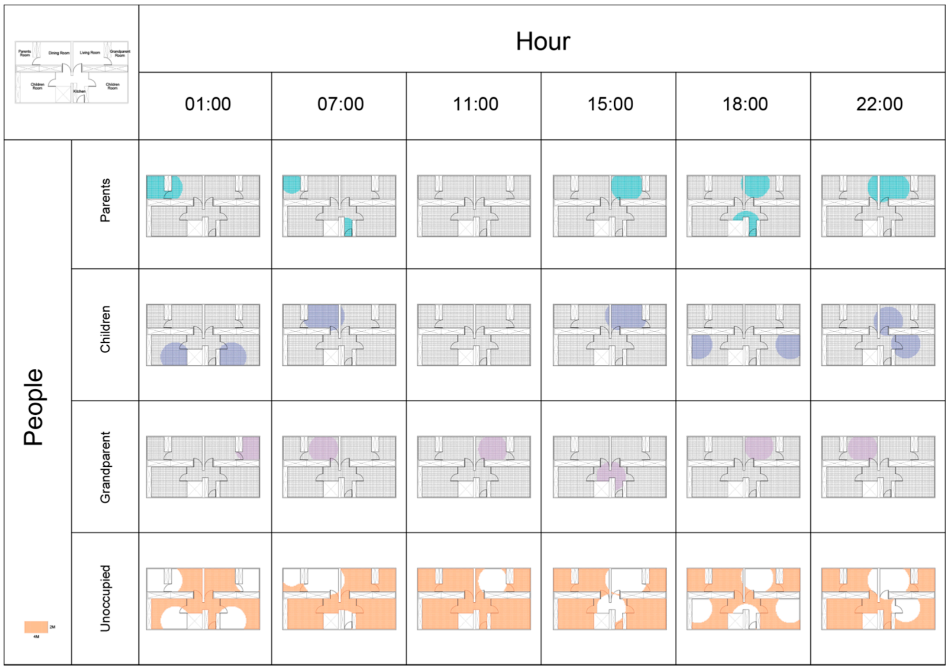

Figure 7. The square grid plans represented in Grasshopper.

Following Price's "Towards a 24-hour economic toy", the plans are constructed by using a square grid. People are represented as points inside this grid with a radius of 250 cm. By detecting each person's movement inside the space, the script automatically merges their movement and determines the unused space inside the dwelling.

The algorithm depicted in Figure 8 is based on breaking the plan into many small squares. The width is divided by 150, while the width is divided by 900. Each plan consists of 135,000 squares. This will help form a Boolean parameter that generates an on/off function. By adding a radius of 250 cm to each point, the boundary of people's movement is created. Using a function called "point in curve," the squares that have been inside this boundary curve will be removed, and the unused space will be determined.

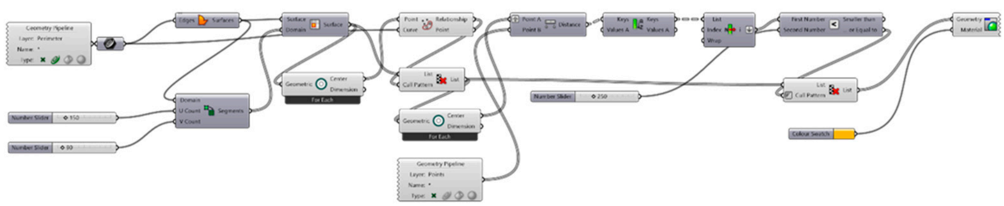

Figure 8. The algorithm that creates the unused spaces inside the plan.

As a result, the diagram displayed in Figure 6 is obtained, which formally reproduces Price's original approach in Figure 2. The list of parameters used in the script would be as follows:

- Number of occupants
- Type of occupants
- Age of occupants
- Activity patterns
- Used area
- Movement of occupants

4. Discussion

The comparative observation of the results allows us, in the first place, to identify the character of the parameters that are used as variables in both cases. Table 3 shows a summary of the main factors used in the parametric calculation in relation to their use by each of the authors. Affirmative use is identified by the symbol [•], while negative use is identified by the symbol [-].

Table 3. Quantitative and qualitative parameters.

	Dimensions of the House	**Built Area**	**Used Area**	**Amount of Rooms**	**Dimensions of The Rooms**	**Number of Beds**	**Number of Occupants**	**Type of Occupants**	**Age of Occupants**	**Activity Patterns**	**Time**	**Movement of Occupants**
Alexander Klein [apartment evaluation method]	•	•	-	•	•	•	-	-	-	-	-	-
Cedric Price [24-h performance analysis]	-	-	•	-	-	-	•	•	•	•	•	•

As can be seen, Alexander Klein makes use of dimensional and purely quantitative parameters. However, it should be clarified that this observation refers exclusively to the work corresponding to phase 2 of his work (reduction of all projects to a single scale), in which Klein identifies the variables that best adapt to the Betteffekt parameter. Work phase 3 of his would complete this purely quantitative work, qualitatively validating the graphic selection.

In the case of Cedric Price, the parameters necessary for the reproduction of his thought mechanism make it necessary to use both quantitative and qualitative factors. The need to incorporate a classification of the type of occupants, their age, and their activity patterns within the home emerges. In this definition, it is necessary to construct a matrix determined by the time variable, in which the uses of the home by each occupant are converted into joint use densities.

It should be mentioned that Price's work has occasionally been criticized for the predetermination of the parameters of change, which determines predictable architectural solutions, limiting the concept of flexibility or freedom for the user that is being promoted [76]. In that sense, his proposal has come to be considered as close to neoliberal paradigms, observed from a contemporary perspective [77]. However, as we can see, his work in this sense is oriented above all to the visibility of the need for change, giving the inhabitants the ability to obtain information on use, and therefore facilitating decision-making in the face of future changes.

While Klein's work offers as a result a base of dimensions and proportions, which is the premise on which to check usability qualities, Price's work does the reverse: it recognizes the patterns and needs of use of each user from the activities in the home themselves to identify the architectural spaces that require certain qualities due to their density of use, and the architectural spaces with other potentials of use due to their current underuse.

Therefore, Klein's exercise subordinates the usability of architecture to the efficiency of its form, while Price's exercise subordinates the form to the use that the inhabitants make of it. The geographies of occupation that Price's work results in are the premise for future modifications of the architecture itself and, therefore, presuppose the capacity of the domestic space to self-configuration based on use. In other words, Price in the domestic context is applying the same thinking parameters of a project as celebrated as the Fun Palace, in which cybernetics had to provide architecture with the capacity for data collection, machine learning, and technical mobility necessary to facilitate its own formal evolution.

Finally, the observation of all these aspects must be completed with a critical consideration of the methodology used. The proposal of an algorithmic translation of the works of Klein and Price has been carried out in a rigorous way thanks to the fact that the docu-mentation and bibliography available from both authors includes information and graph-ic diagrams in which it is possible to identify the parameters that later have been able to be used in Grasshopper scripts. However, during the re-engineering process of the design methods, it has been observed that visually similar results could be achieved without the full participation of the same parameters (altering the dimensional conditioning factors in the case of Klein or simulating different activity patterns in the Price case). This demon-strates, on the one hand, the potential of using contemporary tools for retrospective analy-sis, and on the other, the risk that the manipulation of historical readings could entail. While re-engineering as an algorithmic translation of documented parameters involves the heuristic use of primary documentary sources and their computational analytical testing, a possible use of parametric tools as a reverse engineering method lacking primary documentary sources could lead to biased or distorted historical readings.

5. Conclusions

According to the starting hypothesis, it is shown in any case that the work of both architects, Alexander Klein and Cedric Price, was carried out under a model of scientific thinking that today we can recognize as parametric thinking. In both cases, work is done on the search for optimal housing proposals—Klein optimizes the form, Price optimizes the use. Both make use of recognizable parameters and therefore their experiences are reproducible and replicable. This replicability allows incorporating in both cases different context conditions (dimensional premises in the case of Klein, conditions of the family occupation model in the case of Price) that facilitate its application in different situations.

For all these reasons, the research demonstrates the replicability of parametric design methodologies as support in making creative decisions that do not have to be exclusively formal (there is a parametric architecture beyond form). Although Price himself develops this type of parametric thinking to be able to be used by advanced technologies for the achievement of adaptive architectures—as cybernetics was at the time and today it could be artificial intelligence—its use in the field of architecture is yet to be fully developed.

Despite so, the landscape of contemporary architecture does already have adaptive and collaborative design tools that can be considered heirs to the pioneering parametric thinking of authors such as Klein and Price. Experimental generative housing projects de-veloped by Jeroen Van Ameijde, Sidewalk Labs, or Van Wijnen Groep; companies that offer customized parameterized housing such as Cover or Daiwa House Industry, or adaptive design platforms and applications such as Finch (https://finch3d.com, accessed on 21 December 2021) or Wikihouse (https://www.wikihouse.cc, accessed on 21 December 2021) show the potential of parametric architecture for contemporary housing production, designed in a customizable and adaptable way. We see in these new paradigms of housing design and production the same parametric thinking of Klein and Price.

The research also shows that current computational tools allow the reproduction in a simple way of the complex thinking of two personalities ahead of their respective times. This also makes it possible to claim the intuitive capacity of both to foresee the future computing capacity for solving architectural problems.

On the other hand, it has been shown how this genealogy of thought eloquently evolves through the two case studies. We have detected this triple condition:

- Design model focused on form versus design model focused on the use that people make of architecture. While form constitutes the origin of residential design in Klein's proposal, this center shifts to the use of architecture by individuals in Price's case. Therefore, there is a shift towards a user-centered design model (UCD), a label that will become popular in the 1970s with the emergence of the concept of usability in information technologies [78,79].

- Static architecture versus dynamic architecture. While the concern for the housing problem in the interwar period was situated in the quantitative production, and therefore in the maximum efficiency of reproducible architectures and with static and standardized typological models, the concern from the second half of the century begins to incorporate the need for a responsive architecture in relation to the changing needs of use.
- Standard family model versus coexistence group diversity. In a very concrete way, we can observe how evolution shows a particularly eloquent parameter in relation to family models. While Klein works with the hypothesis of a nuclear family as a demographic standard, Price converts users into variables of occupation and, therefore, of architecture. The architectural variables end up responding to the diversity of uses made by various coexistence groups.

Therefore, we can conclude with one last reflection: the exploration of the house from a parametric systematization allows incorporating the conditions of uncertainty and contingency as factors that intervene in the design processes, demonstrating their diffuse nature [80].

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