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# A Biomimetic Sketch-Based Form Finding Tool

## Biomimetik Eskiz Tabanlı Bir Form Bulma Aracı

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***Öz***

*Eskizler, tasarımda yaratıcı düşünme, problem çözme ve iletişim için temel temsillerdir. Mimarlık alanında, eskizler fikirlerin kavramsal olarak oluşturulmasından yapı inşasına kadar olan dönüşümünü kapsar. Hızlı, açık uçlu ve belirsiz doğaları ile el eskizleri, soyut kavramlar ile somut tasarımlar arasında vazgeçilmez bir köprü görevi görürken, erken tasarım aşamalarından nihai ürüne kadarki ilerlemeyi yönlendirirler. Ancak, tasarım sürecinde önemli potansiyele ve kilit rolüne rağmen, bilgisayar teknolojilerinin yaygın kullanhımı ile birlikte el eskizleri sıkça geleneksel ve dijital tasarım metodolojileri arasındaki süregelen tartışmalarda göz ardı edilmiş ve hızla terkedilmiştir. Bu çalışma, el eskizlerinde başlangıç tasarım kavramlarından detaylara kadar gömülü bilgiyi açığa çıkarmak hedefiyle, bir hibrit dijital form bulma aracı kullanmaktadır. Form arayışında sürü algoritmalarının kullanılmasıyla, el eskizleri ile çizilen kavramsal fikirlerin sınırlarının genişletileceği öngörülmektedir. Bu amaçla, Java kodlama dili kullanılarak Processing ortamında geliştirilen bir algoritma ile sezgisel bir arayüz geliştirilmiştir. Araştırma, biyomimetik, eskizleme teknikleri ve el eskizlerini dijital mecralara aktarma araçları konularını içeren kapsamlı bir literatür taramasıyla başlamaktadır. Ardından, Processing ortamında oluşturulan algoritmanın ayrıntılı açıklaması yapılmıştır. Aracın etkinliği, aynı eskizler üzerinde çeşitli parametre ayarlarının ayarlanmasıyla yapılan deneyler ve yedi inşa edilmiş tasarımı temsil eden mimari eskizlere uygulama ve sonuçların yorumlanmasıyla değerlendirilmiştir. Algoritmanın temel mantığı ve Processing'in gelişime açık yapısı sayesinde, biyomimetik parametrelere temellenen bu aracın istenen yönde geliştirilebileceği ve tasarımcının farklı form arayışlarına olanak tanıyabileceği düşünülmektedir.*

***Anahtar Kelimeler: Biyomimetik tasarım, Eskiz, processing, Sürü davranışı, Biçim bulma***

**ABSTRACT**

*Sketches are fundamental in design and crucial representations for ideation, problem-solving, and communication. In the realm of architecture, sketches encapsulate the evolution of ideas from conceptualization to construction. Hand-drawn sketches, characterized by their open-ended, ambiguous nature and rapid production, are indispensable in bridging the gap between abstract concepts and tangible designs, guiding the progression from early design stages to final product realization. However, despite their significant potential and pivotal role in the design process, hand sketches have often been overlooked and swiftly abandoned in the ongoing discourse surrounding traditional versus digital design methodologies, particularly with the widespread integration of computer technologies. This study endeavours to unlock the wealth of information embedded within hand sketches, from initial design concepts to intricate manufacturing details, using a hybrid digital form-finding tool. By employing swarm algorithms in the quest for form, it is anticipated that the boundaries of conceptual ideas delineated by hand sketches will be expanded. This is facilitated by an algorithm developed in Processing using the Java coding language, complemented by an intuitive interface. The research commences with a comprehensive literature review encompassing biomimetics, sketching techniques, and tools for transitioning hand sketches into digital realms. Subsequently, a thorough elucidation of the algorithm, crafted within the Processing environment, is provided. The tool's efficacy is assessed through experimentation involving adjustments of various parameters on identical sketches and application to seven architectural sketches representing built designs, with subsequent interpretation of the outcomes.*

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*It is posited that the adaptability of the algorithm's core logic, coupled with the development-friendly environment of Processing, holds immense potential for empowering designers to steer sketches in desired directions through tailored enhancements.*

***Keywords: Biomimetic design, Sketching, Processing, Flocking, Form-finding***

## **INTRODUCTION**:

The architecture and construction sector has experienced a significant shift due to the adoption of diverse digital tools, now essential for design processes. Embracing these technologies has streamlined operations, boosted efficiency, and raised the design standard. However, this digital evolution has also widened the gap, extending beyond access to tools and software. It encompasses the vital integration of traditional design methods across various domains, from urban development to architecture.

The transformation of the manual, tool-based structure of architectural practice into a computer-aided, form-based application (Terzidis, 2006) has paved the way for new explorations in design and practice regarding what could be possible in terms of form, material, function, and technique (Iwamoto, 2009; Dunn; 2012). The use of computers as design tools alongside the development of information and communication technologies has led to changes not only in production but also in architectural thinking. Computational design tools have eliminated simple geometric constraints and increased the producibility of complex forms. With computers becoming a part of everyday life in the 1980s, rapidly evolving digital interfaces in the 1990s, and the addition of information technologies in the 2000s, computer-aided design, which has evolved into a design partner, has transformed the process of form generation in architecture into a process of form finding (Kolarevic; 2003).

Discussions at this point have focused on the potential creativity gaps that could arise from the departure from tradition and the evolution towards the digital, leading to the development of various approaches for transferring traditional methods into digital environments. Consequently, designers have developed new skills and sometimes prefer to remain outside these developments. Although the idea that computer-aided design tools may inadequately convey the designer's intuition predominates, many studies also highlight their strengths in rapidly generating a wide range of alternatives in the early stages of design (Güney, 2015; İslamoğlu & Değer, 2015). Advanced modelling tools enable designers to realize designs that are difficult to produce and perceive using traditional methods (Dunn, 2012).

Moreover, generative design facilitates exploring diverse solutions by establishing design-specific representations and generative rules and behaviours, enabling a bottom-up iterative design process. Some of these methodologies draw inspiration from biological principles (Frazer, 1995; Janssen, 2005; Fernando, 2014), and given the ongoing evolution of biological theories (Noble, 2015; Laland et al., 2015), it becomes necessary to reassess the terminology within this context to incorporate emerging biological concepts. Biomimetics offers techniques for translating biological concepts into design, thus fostering innovative approaches in architectural design (Knippers et. al., 2016). Morphological processes aimed at form-finding have previously been investigated within digital morphogenesis (Roudavski, 2009; Menges, 2007; Hensel et al., 2006).

In light of all these discussions, it is considered that the hand sketch, one of the fundamental elements of traditional design, is an important research topic for questioning the possibilities of creativity and development in digital environments. Therefore, this study aims to create an algorithm that will enable hand sketches as a tool for form-finding in digital environments by using biomimetic data as input. Thus, while the freedom in hand drawing is reflected in the computer environment, it is thought that the three-dimensional form potentials of sketch studies in the initial stages of design will be explored with a nature-powered hybrid tool without choosing between traditional/digital opposition.

## 1. A biomimetic analogy for the sketching process: swarm intelligence

Sketches, in design disciplines, are fundamental representations for thinking, problem-solving, and communication. Architectural sketches represent a thought process from design to construction. Open-ended, blurry, rapidly produced hand drawings are among the most important tools for transforming ideas from abstract to concrete, serving as crucial tools from the early design stage to the final product. Sketches, which are as important as the design problem itself (Kahn, 1931), are tools of exploration that serve as the starting point for synthesis in design (Graves, 1977). Therefore, a designer should use hand drawings to solve design problems and as a primary thinking tool in interacting with their drawing (Herbert, 1993). Supporting these ideas, Goldschmidt (1991) discusses sketching as a two-way activity. Designing with sketches involves a dialogue, with the designer constantly receiving feedback from what they draw, interpreting it, deriving new ideas from it, and advancing the design process.

Since including computers in the design process, the transfer of sketches to the computer environment has been a subject of discussion and research. The initial studies in this regard involved directly transferring sketches to the screen and converting hand-drawn contours into two-dimensional lines and shapes using an interface (Eggli et al., 1997). Subsequent studies have included examples where hand-drawn shapes are approximated to defined shapes, such as lines and circles in a digital environment (Li et al., 2016), and where drawings of different views of an object are transferred to the computer environment to obtain a three-dimensional surface (Li et al., 2018).

Unlike the mentioned studies, in this research, rather than creating a final form or refining hand drawings by converting them into defined shapes, new potentials are explored by utilizing sketches as images. In this aspect, the study supports the form-finding mentioned earlier and aims to open up new research areas by exploring form behaviour.

In form-finding studies, it is a common approach to be inspired by the rules of nature. The underlying algorithmic logic in natural structures and the geometric principles can be abstracted with digital models for architects who have always looked to nature for inspiration (Symeonidou, 2018). Due to the cyclical/comprehensive nature of the conceptual design process, which is not linear but feedback-driven, this study focuses on exploring the potential of sketch-based form generation through coding to support the flexible and creative nature of sketches using inspirations from biology.

Biology encompasses a spectrum of viewpoints ranging from dynamic to static perspectives. Dynamic viewpoints delve into the reasons behind organismal evolution and developmental processes, while static viewpoints examine biological entities at specific moments. This duality is mirrored in biomimetics by translating material, structural, process, or system aspects from nature into technology. Computer science serves as a conduit, linking biological concepts to architectural applications. Evolution and natural selection, hallmark life features, continuously enhance the biosphere by fostering resilience, adaptation, and development. These attributes are also sought after in architectural design processes. The strategic application of evolution as an optimization strategy traces back to the 1970s (Rechenberg, 1971; Goel & Mc Adams, 2014). Within architectural discourse, the integration of evolutionary computation into generative design processes is founded on the introduction of Genetic Algorithms (Holland, 1973) and Genetic Programming (Koza, 1990), both of which have become integral to architectural design tool scripting.

Recent advancements in computer science, leveraging grammatical evolution (Muehlbauer et al., 2017; O'Neil et al., 2010; Byrne,2012), expand the repertoire of generative design strategies, employing an evolutionary approach even for intricate design scenarios. Drawing from rule-based approaches like shape grammar (Stiny, 1972), these systems can drive computational designs through bottom-up processes based on behavioural systems. Biomimetics, an emerging field facilitating the strategic transfer of information from biology to technology, provides a generic framework and methodology for establishing meaningful analogies between disparate domains. Biomimetics is an innovation methodology that entails fundamental research, principle abstraction, and principle application across various fields. While biomimetics encompasses materials, structures, and systems, its primary focus lies in extracting knowledge about functions, mechanisms, or concepts that designers then apply or interpret by engineers. Furthermore, the interdisciplinary nature of biomimetics holds promise for fostering radical innovations and sustainable products and technologies (VDI, 2011). Over the past decade, biomimetics has garnered increasing attention in urban design, architecture, design, and the arts, with a discernible biological paradigm shaping current trends in design research (Gruber, 2011).

One of the groundbreaking research projects on this was done in 2010. A cohort of biologists investigated Physarum polycephalum, a singular, gelatinous organism resembling a fungus (Tero et al., 2010). Their inquiry involved depicting downtown Tokyo amidst surrounding urban centres and distributing oat flakes nearby. Over five hours, the slime mould systematically explored the immediate area surrounding Tokyo, extending its tendrils methodically yet randomly. By the eleventh hour, it had expanded its exploration, exhibiting a preference for specific routes while disregarding others deemed ineffective. Subsequently, after twenty-six hours, the organism had consolidated its myriad pathways into a select few highly efficient routes. This experiment essentially mirrored the challenge perennially confronted by urban transportation designers: the optimization of routes between disparate locales within a transport network. Physarum polycephalum's plasmodium behaves like a decentralized colony despite being a unitary structure. Each component undergoes rhythmic expansions and contractions, manipulating the internal fluid dynamics. When encountering attractive stimuli, such as nutrient sources, the plasmodium exhibits accelerated pulsations and expands; conversely, encountering aversive stimuli, like light, results in diminished pulsations and contraction. Through the collective integration of these stimuli, the plasmodium navigates towards the most favourable direction, devoid of conscious cognitive processes, thereby exemplifying the principles of decentralized decision-making akin to crowdsourcing. The research team posits that elucidating the mechanisms underlying the slime mould's problem-solving capabilities could give urban planners novel insights into addressing complex design challenges (Tero et al., 2010).

Similarly, in this research, an algorithm developed in Java language within the Processing environment provides three-dimensional visualizations based on sketches. Rather than making a direct translation of sketches, the fundamental idea has been to run the sketch like a living organism capable of growth to explore its potential.

A continuous dialogue, change and adaptation concept similar to the sketching process can be found in swarm intelligence in nature. This behaviour states total interdependence among the elements, meaning that any change in one element immediately affects all the rest of the elements and the whole system. Without a differentiation between elements, each is equally influential and significant within the system (Girdhar, 2015).

## 2. Flocking as a swarm intelligence sketch behaviour

Swarm Intelligence (SI) is inspired by natural swarms, which involve collective behaviour by similarly-sized beings aggregating to solve survival-related problems. The emergent collective intelligence of simple agents analogous to the animals in a swarm characterizes SI. These agents can be hardware devices or software programs operating within distributed control systems, solving problems through interactions with each other or the environment. Software agents make simple decisions to address issues (Girdhar, 2015). SI relies on three fundamental properties: decentralization, self-organization, and collective behaviour, as well as five principles: proximity, quality, diverse response, stability, and adaptability (Millonas, 1994).

Among many examples, ant colony optimization, artificial bee colony and flocking behaviour are the most common swarm intelligence types preferred in current research (Girdhar, 2015).

The ant colony optimization algorithm is inspired by ants' foraging behaviour (Colorni et al., 1991). Ants find optimal paths to food sources using pheromones, which mark trails for others to follow. A higher pheromone density increases the likelihood of the path being chosen, creating positive feedback. If not reinforced, the pheromone evaporates, providing negative feedback. The ants' movement is influenced by the distance to the next node and the pheromone level, and this process continues iteratively until all nodes are traversed in a cycle, after which the pheromone levels are updated.

The artificial bee colony algorithm (Karaboga, 2005) models bee foraging behaviour. It involves three types of bees: employed, onlookers, and scouts. Employed bees exploit discovered food sources, onlooker bees choose food sources based on nectar richness, and scouts search for new sources. This process of exploration and exploitation continues until a food source is exhausted, prompting employed bees to become scouts and find new sources.

The flocking behaviour observed in birds involves coordinated movement to avoid predators, find food, and optimize environmental conditions. Birds, despite poor eyesight, move in flocks to navigate obstacles. This collective behaviour is modelled in simulations using simple rules: separation (avoiding crowding and collision), alignment (steering towards the average direction of neighbours to stay with the group), and cohesion (moving towards the average position of neighbours in the same direction) (Reynolds, 1987) (Figure 1). These rules enable realistic and complex flock movements without central control. In this behaviour, individual organisms exhibit collective behaviour properties when their coded behaviours affect complex adaptive behaviour, different from individual behaviour but dependent on these properties. Reynolds (1987) creates the term 'boid' for bird-like organisms. Each boid can move within a defined area but only responds to its flock mates within a certain radius.

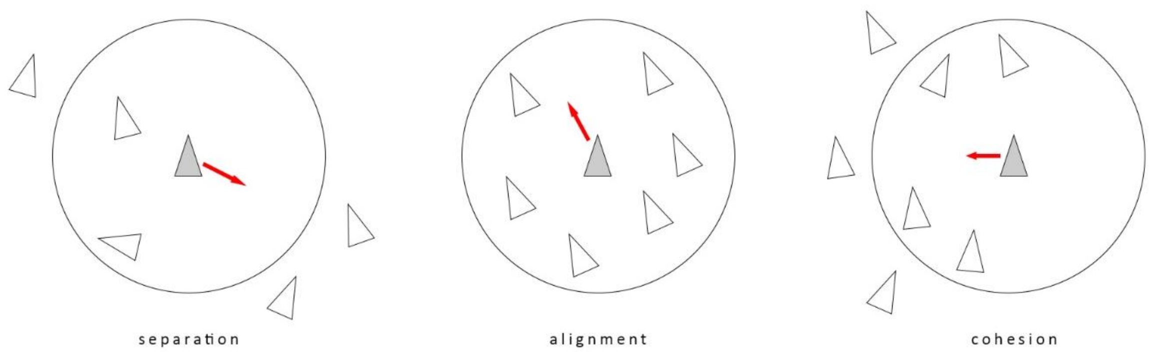



Figure 1: Flocking behaviour rules (adapted from Reynolds, 1987).

In flocking simulations,  there is no central control;  each bird behaves autonomously. In other words, each bird has to decide which flocks to consider as its environment. This independent choice mechanism enhances creativity levels when interpreted in terms of complexity. Therefore, in this study, the flocking behaviour is selected as the biomimetic analogy for sketching behaviour because of their similarities in complex problem-solving decision-making processes that are affected by many parameters simultaneously. The basic model has been extended in several ways since it was proposed. Shiffman (2012) reinterpreted Reynolds's (1987) algorithm in the processing environment for three-dimensional results. This study has adapted Shiffman's (2012) Flocking algorithm in the Processing environment to gather the three-dimensional results from sketches.

## 3. A Biomimetic Sketch-Based Form-Finding Tool

The biomimetic form-finding tool aims to investigate the possibilities of generating forms through coding based on sketches by keeping the cyclical and comprehensive nature of the conceptual design process. The goal is to enhance the flexibility and creativity inherent in sketches by drawing inspiration from swarm intelligence principles. For this purpose, an algorithm using pixel values in sketches based on the flocking behaviour of birds has been utilized with seven phases and 12 steps. A simple interface developed for this algorithm facilitates the easy realization of various form exploration alternatives. The working principle of the algorithm is depicted in the flowchart in Figure 2.

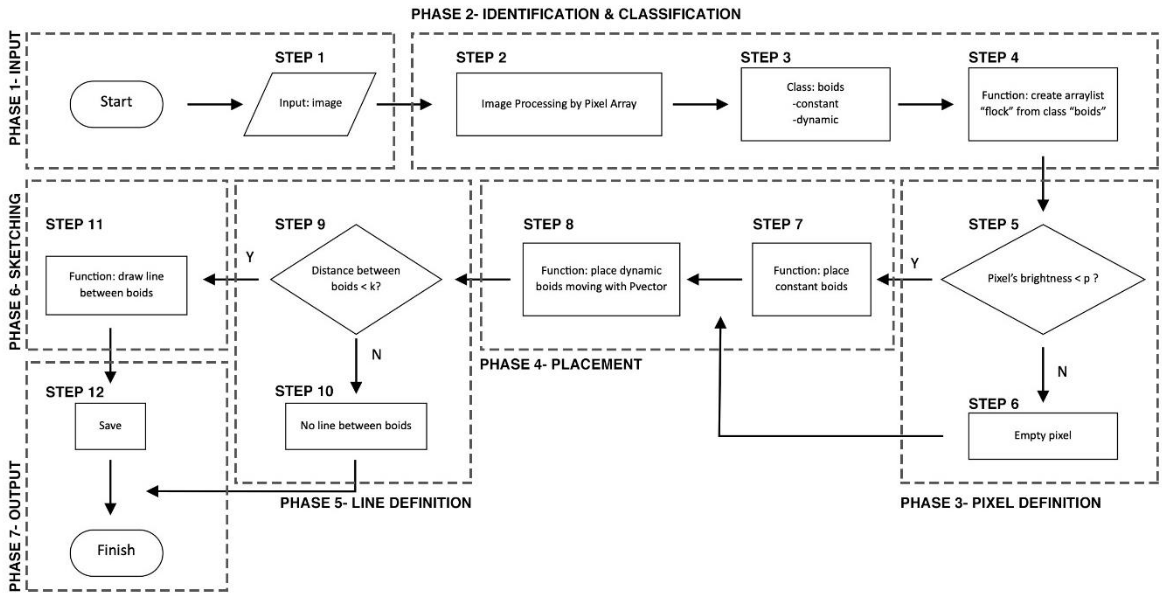
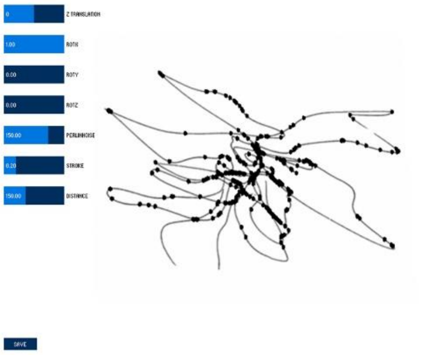



Figure 2. Algorithm flowchart.

When opening the tool in the Processing environment, the algorithm asks for sketch inputs to work on (Phase 1). The system inputs should be hand sketch images in PNG format (Step 1). After uploading the desired image, Pixel array algorithms utilize sketch drawings (Step 2). With these algorithms, the pixels of the image are first classified as constant and dynamic boids (Step 3), then stored in a two-dimensional array and converted into information that the algorithm will read (Step 4). The converted pixel information lets the algorithm decide (Phase 3) whether the pixels are too bright (empty parameter- Step 6) or dark enough to be worked on (Step 5). According to the classification and definitions of Phases 2 and 3, fixed flock elements are placed (Step 7) following the rules that will provide the desired density corresponding to the dark-coloured pixels in the sketch.

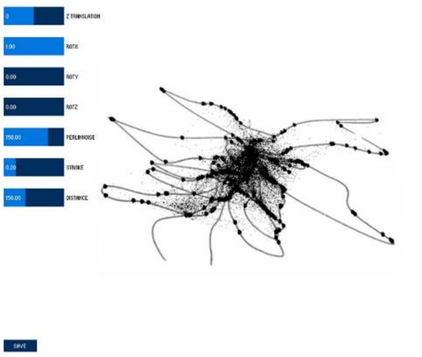
During this action (Phase 4), Z values are assigned for the boid class defined in Shiffman's Flocking algorithm, and Z values are defined for the PVector inputs for movement in the third dimension to transfer boids to the third dimension. Then, a new constructor is created for the fixed boid class elements that provide ground connection in forming corresponding to the starting pixels of the drawing. During movement, a boundary region is defined to keep the boids within a specific volume (Figure 3).



```
void draw() {
  image(img,0,0);
  flock.run();
  loadPixels();
  img.loadPixels();
  for (int i = 0; i < width; i++)
  {
    for (int j = 0; j < height; j++)
    {
      float b = brightness(drawing[i][j]);
      if ((i % 10 == 0) && (j % 10 == 0))
      { if(b<50)
        {
        pushMatrix();
        translate(-width,-height,0);
        pushMatrix();
        translate(i,j,0);
        popMatrix();
        popMatrix();
        }
      }
    }
  }
}
```

Figure 3. Boundary definition of the algorithm.

In addition to fixed boids, dynamic boids must be added to form the shape (Step 8). These added new boids are elements that provide flexibility in forming. When placing these dynamic elements in the coordinate system, X and Y values are taken from the information obtained from the image (Phase 2), while the Z value is taken from Perlin noise randomness (Phase 4). A new function (Phase 5) is defined to draw lines between boids (Step 9), allowing for visualization enhancement. Lines are drawn between boids (Step 11) if their distance satisfies a variable condition (Figure 4).



```
 void cizgi(ArrayList<Boid> boids)
 {
   for (Boid other : boids) {
     float d = PVector.dist(position, other.position);

     if((d>0) && (d<m)){
       fill(0);
       stroke(50,100);
       strokeWeight(k);

 line(position.x, position.y, position.z, other.position.x,
other.position.y, other.position.z);
     }
   }
}
```

Figure 4. Line drawing rule of the algorithm.

In the designed simple interface, features such as approaching/moving away from the model and rotating can be controlled (Phases 4 and 5). The distances and thicknesses of the lines drawn between boids can be adjusted (Phases 5 and 6). The current view can also be saved as a screenshot in PNG format (Phase 7- Step 12).

## 4. Testing The Biomimetic Sketch-Based Tool

The flocking-behaviour-powered form-finding tool seeks the potential of creating designs through coding based on sketches while maintaining the iterative and holistic nature of the conceptual design process. It aims to boost the flexibility and creativity found in sketches by drawing inspiration from swarm intelligence principles. Therefore, two tests were applied to check the ability of the form-finding tool to search its ability: (1) to develop various alternatives with changing parameters and (2) to capture the designer's intuition.

### Test 1- The ability to develop various alternatives

The first test was applied to explore the tool's ability for alternative development. A basic hand sketch was used to input generations in the first test phase (Figure 5). Six alternatives were developed while keeping the Z translation, rotation X, Y, Z, and perling noise values the same for each trial in the same amount of time with the same design borders. For visual comparison, in Figures 5A- 5B and 5C, the distance values are changed to 50,200 and 100 while keeping the stroke value as 0.02. In Figures 5D and 5E, the distance values are changed to 100 and 50, while the stroke value is 0.2. In Figures 5E and 5F, although all the parameters are the same, the development time is longer in the 5F alternative.

When 5A/5E and 5C/5D are compared, it can be observed that the stroke value affects the complexity of the design while creating more nodes in crowded areas. Although the distance between each boid creates more significant gaps, a similar complexity increase is visible between 5A- 5B - 5C and 5D - 5E with the effect of the increase in the distance value. The design became more complex as the duration increased, with more movement in a defined zone.

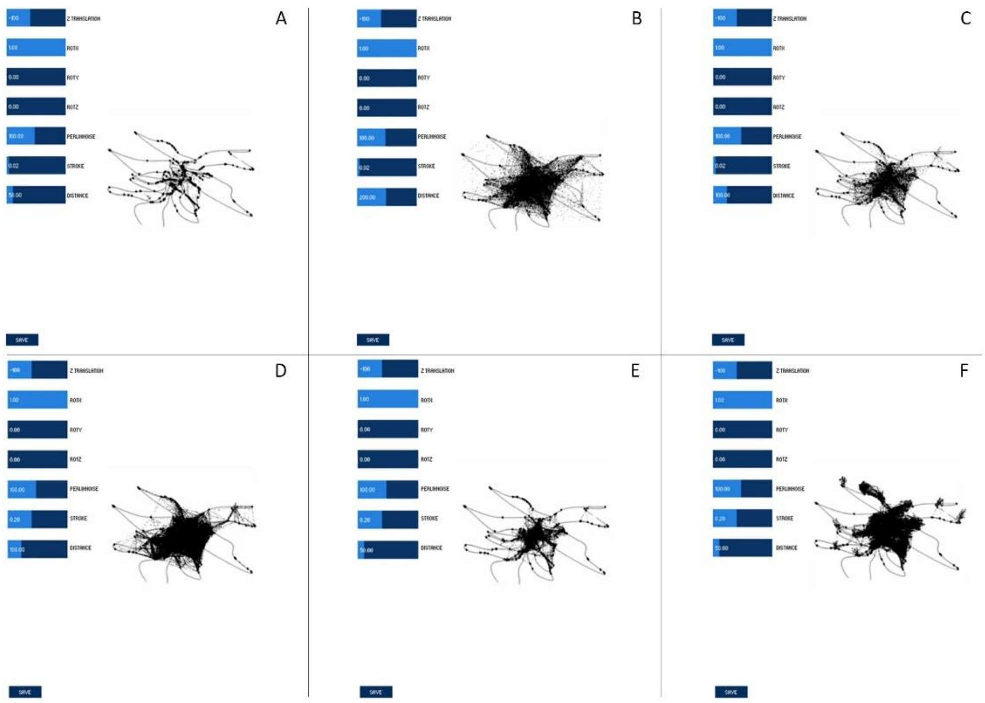



Figure 5. Test 1 results.

**Test 2- The ability to capture the designer's intuition**

After understanding the effects of stroke, distance and duration values, the algorithm was run using sketches of seven buildings with different forms, functions, areas, and configurations to observe better and interpret the tool's potential (Figure 6). The selected sketches were all collected from well-known built designs to compare the designer's intuition and the tool's output. All parameters, including the stroke, distance and duration, were kept the same in this second test. At the same time, the height and design area values were changed according to the actual heights and plan sizes of the buildings. 2 of the sketches represented plan organization (Zaha Hadid / Ordrupgaard Museum Extension and Bernard Tschumi / Carnal Hall at Le Rosey), and 5 belonged to section/elevation design ideas (Zaha Hadid / MAXXI: Museum of XXI Century Arts,  Frank Gehry / Frank Gehry's House, Frank Gehry / Walt Disney Concert Hall, Le Corbusier / Chapel of Ronchamp, Renzo Piano / Kum & Go Headquarters). For the implementation of Test 2, the accessed sketches were first reproduced to create digital versions, and subsequently, these digital versions were pixelated to make them usable by the form-finding tool.

When comparing the plan sketches among themselves, it is observed that although they do not contain information regarding elevations or views, sketch 6A, with lower height, produces results closer to the building constructed than the higher-height 6C. In comparing elevations, it is seen that the influential

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factor is not the height parameter but whether the building has amorphous or more defined geometries. Sketches 6E and 6F, with more linear, defined geometries, yield results that are more similar to those of 6D and 6G compared to each other.

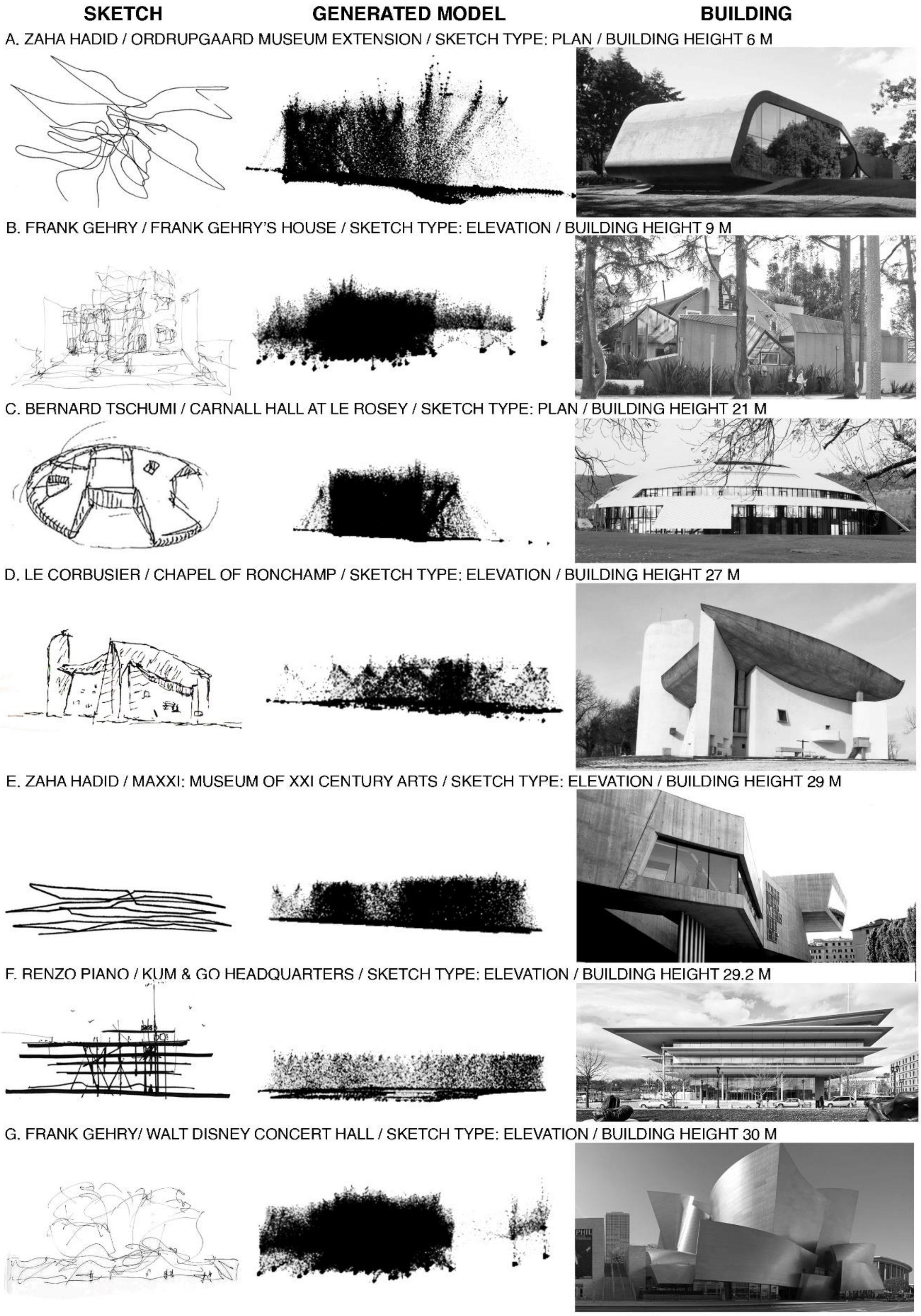


Figure 6. Test 2 Results (Photos of buildings are from the archive of the researchers and free to use images for academic purposes gathered from URL's 1-2-3-4 and 5).

**DISCUSSION**:

In this study, a sketch-based form-finding algorithm and a user-friendly interface for this algorithm have been designed using Processing. The algorithm generally defines movable flock elements on sketches transferred to the interface in PNG format while staying within the specified volume. Form variations are created with lines generated between fixed and moving flock elements. A productive system is achieved by altering the basic steering parameters of the flock behaviour model.

In the experiments conducted within the scope of the research, although no significant similarity was observed between the final product and constructed buildings or sketches, converging interpretations were made. This situation has been regarded positively for supporting creativity and flexibility, suggesting that results capturing the designer's intuitive approach could be achieved with different parameters. Through quantitative observation of the examples, it can be inferred that the alternatives generated for shorter and linear sketches approximate the final product. This similarity can be interpreted as approaching understanding designer instincts and generating proposals close to reality in terms of form.

In future studies, the structures resulting from these visualizations can provide outputs that can be transferred to 3D modelling programs that have the potential to transform into solid models that design themselves. As discussions about bio-digital architecture emerge nowadays, self-shaping designs based on the genetic parameters of nature can be an excellent input for future studies. Furthermore, thanks to the open processing environment, additional enhancements can be made to the algorithm's basic logic, offering significant potential for designers to develop sketches in the desired direction of exploring form types. This study used the flocking behaviour of birds. However, according to the designer's intuition, other behavioural patterns, such as fish, ants, and snowflakes, could easily be embedded into the source code. This study is believed to create an alternative to keep the traditional sketching and the effect of the designer still on the table in the era of artificial intelligence in design.

***Çıkar Çatışması:*** *[TR] Yazar / yazarlar, kendileri ve / veya diğer üçüncü kişi ve kurumlarla çıkar çatışmasının olmadığını veya varsa bu çıkar çatışmasının nasıl oluştuğuna ve çözüleceğine ilişkin beyanlar ile yazar katkısı beyan formları makale süreç dosyalarına ıslak imzalı olarak eklenmiştir.*

*[EN] The author(s) declare that they do not have a conflict of interest with themselves and/or other third parties and institutions, or if so, how this conflict of interest arose and will be resolved, and author contribution declaration forms are added to the article process files with wet signatures.*

***Etik Kurul İzni:*** *Bu çalışma için etik kurul iznine gerek yoktur, buna ilişkin ıslak imzalı etik kurul kararı gerekmediğine ilişkin onam formu sistem üzerindeki makale süreci dosyalarına eklenmiştir.*

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