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Dear architect, Design for Adaptability! *DfAD* as a Biomimicry design practice

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Abstract: This article emphasizes Design for Adaptability (*DfAD*) as a disruptive design alternative on the rise, aiming to comprehend to what extent design strategies from two lenses relate. The first focus on a theoretical investigation of Adaptability in Human Architecture and the description of adaptable design strategies (DS) released by the *Adaptable Futures Research Group*. The second is inspired by the field of Biomimicry, exploring adaptable design strategies in Animal Architecture (DSN). Therefore, as both strategies are intimately related, it positioned an understanding of *DfAD* as a Biomimicry design practice to be applied in Architecture to maximize a building's future performance. Finally, a *Letter to Young Architects and Designers in Support of DfAD* was launched.

Keywords: Design for Adaptability - Architecture - Biomimicry - Animal Architecture - Climate change

[Resúmenes en castellano y en portugués en las páginas 113-114]

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1. Introduction

Nature has been perfecting itself for more than 3.8 billion years without consuming fossil fuels or polluting habitats, generating less cost to the planet (Benyus, 1997). Although desired, Nature is vulnerable and its resources finite, which demands humans' responsibility (Mazzoleni, 2013) to create an ecological and sustainable balance between innovation and the existent (Papanek, 1993). Human actions, mainly after industrialization, increased CO^2 emissions in the atmosphere and overtook Earth's regenerative capacity (Wahl, 2020). As a result, climate change culminated in irreversible planetary consequences (IPCC, 2021) during the Anthropocene Era (Kolbert, 2021). "Take urgent action to combat climate change and its impact" (UN, n.d.) is one of the critical points of the *UN Sustainable Development Goals* (point 13–Climate Action). This problem characterizes the Contemporary Environmental Challenge (CEC), a turbulent situation between human actions and the existing environment.

Thereby, the stimuli in contemporary debates considering designers' and architects' role has been defined as central in front of CEC by the study and interpretation of the past (Kolbert, 2021); the search for environmentally friendly decisions in early design stages (Mackenzie, 1991); the direct relationship with the customer and the importance of teaching in its transforming action – the ecological literacy (Papanek, 1995); and the increased relationship with biology and exploration of concepts such as interconnectedness (Mazzoleni, 2013; Myers, 2012).

Increasing the gaze into Nature as a model, a measure, and a mentor, creating human environments with functional qualities of natural systems has been considered urgent (Benyus, 1997). As McDonough and Braungart (2002, p. 16) stated, "Nature doesn't have a design problem. People do". This context has extended interest in Biomimicry, or "the implementation of good design based on nature" (Vicent, 2012, p. 28). In general, the Design centralized in Nature aims to enlarge man's relationship with the habitat (Soares &

Arruda, 2018). Pawlyn (2016) argues that there must be a balance in the application of Biomimicry so that there is no unbridled romanticism or skepticism towards Nature, which disregards human advances. However, that natural values must be seen in their relevance in the current context, source of solutions, and references.

The focus of this paper lies in the protagonism of the building sector. To achieve the Paris Agreement, construction decarbonization efforts must significantly increase, preferably by 2050 (GABC, 2021). In a parallel perspective, Climate Transparency (2022) reinforces the importance of the insurgence of zero policies, energy codes for new buildings, and retrofitting. This context justifies why this research highlights the implementation of Design for Adaptability (DfAD), that is, "the process of extending the life of our built environment" (Adaptable Futures, n.d.), as an alternative to the planetary climate emergency, by improving a building's future performance and reducing energy consumption.

Buildings are not static (Schmidt III & Andy, 2015; Brand, 1994), but in many contemporary projects, the conformation of spaces generally bases on unique and specific functions, which generate fixed and immutable environments (Sinclair *et al.*, 2012), without considering the human dimension in design stages (Scuderi, 2019). This conventional way of designing leads to the premature demolition of buildings (Andrade & Bragança, 2019; Ross *et al.*, 2016). Therefore, Adaptability in Architecture emphasizes the focus on future value (Geraedts *et al.*, 2014) and is defined as "the capacity of a building to accommodate effectively the evolving demands of its context, thus maximizing its value through life" (Schmidt III & Austin, 2016, p. 45).

This article presents the results of a concluded master's dissertation (Henriques, 2022) concentered on the investigation of *DfAD* according to two lenses of analyses: (1) DfAD in Human Architecture; and (2) DfAD in Animal Architecture. The main objective was to reflect on the question '*to what extent do design strategies of both lenses relate?*' and seek to analyze lessons arising from Nature through a transdisciplinary debate between the fields of Architecture, Design, and Biology. The specific objectives of this paper are:

1. To develop a theoretical background on the theme of *DfAD* in Architecture;
2. To describe the adaptable design strategies, or DSs, defined by the *Adaptable Futures Group* (Lense 1: Human Architecture);
3. To summarize adaptable design strategies in Nature, or DSNs (Lense 2: Animal Architecture);
4. To compare DSs and DSNs, in between similarities and differences.

2. Methodology

This research undertook a qualitative approach in four stages following the objectives previously mentioned. Firstly, a literature review was conducted based on crucial books on the subject and recent publications -later organized and analyzed using *Mendeley* and *NVivo* integrated software. To develop the theoretical background of DfAD, the central review aimed to observe how Literature conceptually comprehends the term as a design

practice in Architecture and underline emerging trends- as a topic on the rise, there are many definitions and interpretations.
Second, for the characterization of DfAD in Human Architecture, it was made a description of adaptable design strategies (DSs) defined by the Adaptable Futures Research Group at Loughborough University. Schmidt III and Austin (2016, p.90) describe design strategies as "an overarching approach towards a way of doing things that can be defined through a set of characteristics and tactics." Concerned with the life extension of the built environment, the AF Group has established itself as one of the global references in the study of Adaptability in Architecture with activities that include, for instance, literature reviews, workshops, interviews with practitioners and academics, and case studies.
Later, based on a literature review on Animal Architecture and focusing on having Nature as a model, measure, and mentor (Benyus, 1997), it summarized adaptable design strategies (DSNs) in animal dwellings. The selection of houses followed a cut-off criterion: when approaching design strategies that allow the extension of the valuable life of dwellings, that is, the increase of future performance. In some cases, the strategies were not mentioned explicitly or minimally discussed in the sources used in the review, so they were disregarded. The authors counted on a partnership with the *Biodesign Lab* at the Federal University of Pernambuco to accomplish this stage.
The final stage was the analysis of both lenses' strategies (DSs and DSNs). Comparative methods allow the investigation of facts or phenomena to verify similarities and explain differences (Gil, 2008; Marconi & Lakatos, 2003). This stage was made according to their general goals (e.g., an ability transmitted to the building) to comprehend their relations. The connection was indicated when the objective was the same or similar - by the authors' interpretation. The intersection of the strategies allowed the inference of considerations to improve a building's future performance *(See Figure 1)*.

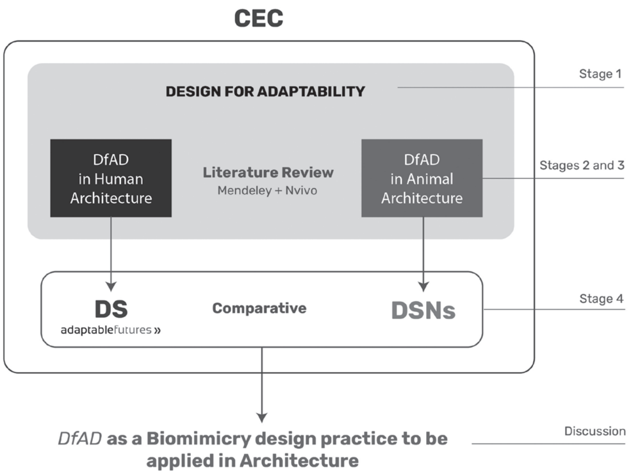

Figure 1. Research draw (Note. Made by the authors, 2023).

3. Results

3.1. Design for Adaptability as an architectural design practice

Askar *et al.* (2021, p. 12) conceptualize Adaptability as "the capacity of a building to accommodate change in response to emerging needs or varying contextual conditions, therefore prolonging its useful life while preserving the value for its users over time." The authors point out the relationship between the concept and change, the adaptation of buildings to the different demands; and time, with consideration for the lifecycle and long-term strategies, being linear (long and short term) or cyclical (such as day, night/ weekday, weekend), but reflecting the context. The connection with both factors unfolds typologies of Adaptability: Adjustable, change of task; Versatile, change of space; Refitable, change of performance; Convertible, change of use; Scalable, change of size; Movable, change of location (Schmidt III & Austin, 2016).

In general, Literature indicates: Adaptability is context-specific (Van ellen *et al.*, 2021), with its enablers and inhibitors often connected; Adaptability is not recent (Gunawan, 2019; Estaji, 2017); Adaptability and Sustainability are connected (Manewa *et al.*, 2017); Adaptability is still not a clear concept, thus existing overlapping concepts, one of the most cited being Flexibility (Askar *et al.*, 2021); Adaptability presupposes positioning the user as the protagonist (Sinclair *et al.*, 2012).

Given this investigation, Adaptability must be understood as a fundamental part of the design process and not just as an additional positive objective. Lüley *et al.* (2019) explored Adaptability in architectural education with a design methodology based on scenarios (scenario-based design loop) – the current context (current context), the projected context (designed context), and the altered context (altered context). For the authors, it is essential to generate critical thinking in students, primarily because of the dynamics of contemporary lifestyles and the impacts of the construction sector on climate change.

Moreover, many studies have pointed out the benefits of Design for Adaptability (Rockow, 2020). Although DfAD has been characterized as an Architecture and Planning goal since the 1960s, it is still considered a particular niche (Herthogs *et al.*, 2019). The recent interest in Adaptability by Design, justified by an increase in thematic publications since 1990, is highlighted by Heidrich *et al.* (2017). DfAD represents an alternative to increasing performance (Loonen *et al.*, 2013; Gosling *et al.*, 2013) and providing life extension of the built environment (Melton, 2020; Schmidt III & Austin, 2016). Although this growing interest in the topic, the non-regulation of Adaptability as a design parameter results, as stated by Schmidt III and Dainty (2015), in a non-priority consideration of it by designers.

Table 1 summarizes the concepts of DfAD according to recent publications. It is highlighted (also based on Literature):

a. *DfAD* in between benefits, as increased building longevity and user satisfaction; and barriers, as built-in additional costs and uncertain financial return (Charitini, 2019).

b. *DfAD* as a response to the issue of obsolescence and redundancy in buildings. In the context of the life cycle, it appears as a redesign alternative to modify, renovate, recon-

figure, expand, or reuse (Rockow *et al.*, 2018), mainly considering economic, social, and environmental impacts (Sanchez & Haas, 2018). If "obsolescence is a plague; [and] adaptability is a cure" (Chen, 2016, p.6), architects and designers are supposed to act as adaptation warriors (Conejos *et al.*, 2014).
c. *DfAD* towards the *Open Building* (OB) approach, by the separation of building elements into "base building", or support, and "infill" (Geldermans, 2016). Appeared in the 1960s by *Stichting Architecten Research*, OB has been explored by several professionals around the world, mainly as a response to the adoption of rigid functionalism and in searching for designing common spaces, support housing, and the increase in teaching/ research in the area (Kendall, 2015; Habraken, n.d.).
d. *DfAD* and the notion of circularity considering end-of-life scenarios (*End-of-Life* or EoL) in the built environment at different scales and throughout the design process (Askar *et al.*, 2022). For Geraedts and Prins (2015), the beneficial relationship between Adaptability and Circularity has become increasingly urgent with global pressures on CO^2 concentration in the atmosphere. Thus, it is important to consider product cycles and reuse instead of discard (Geldermands, 2016).
e. *DfAD* in the pursuit of legacy impact. Brown and Cresciani (2017), for instance, observe that Adaptability has become a priority in the design of Olympic constructions, mainly related to different demands during games and after (post-use stage): a balance between strategies of short and long terms that reveals debates between temporary and permanent structures.
f. The application of *DfAD* mainly in the early stages of design. Scuderi (2019) addresses that decisions in the early stages generate lower costs and more significant impact. Heidrich *et al.* (2017) highlight the importance of interrelationships between different adaptive strategies, especially those initially integrated into design practice. Thompson *et al.* (2014) state that considering adaptation earlier in projects leads to increased effectiveness. At the same time, Brown and Cresciani (2017) observe that the design decisions taken in this initial phase can increase a building's capacity to respond to changes, even for Olympic buildings.
g. *DfAD* in a quantitative approach through assessment tools for Adaptability. Askar *et al.* (2022) argue in favor of a greater applicability of the theme that goes beyond the theoretical field, pointing out that, recently, there have been a small number of quantitative models, which is harmful because they can help in design decisions (a point also addressed by Charitini, 2019).

PUBLICATIONS	THE CONCEPT OF *DFAD* (*DFA*)
Askar et al. 2022	*DfA* is considered a key enabler for other circular design strategies such as design for disassembly (DfD), multi-functionality, spatial transformability, and design reversibility (abstract) *DfA* relies on visualizing the end by developing evidence on possible end-of-life (EoL) scenarios early in the design process (p.3) *DfA* is the intentional design of buildings to be easily modified throughout their lifecycle in response to emerging needs and future circumstances (p.3) *DfA* as an essential prerequisite for circularity realization in buildings and subsequently for developing design-support tools to promote circular buildings and evaluate end-of-life options (p.5)
Askar et al. 2021	Design for adaptability comes about the issue of building obsolescence that is evidently associated with environmental and economic impacts resulting from resource consumption and material loss (p. 15) Design for adaptability handles issues of buildings obsolescence and redundancy by employing a lifecycle thinking in order to extend the useful life of buildings and building components (p.20)
Melton, 2020	Design for adaptability—intentional strategies for supporting multiple potential uses (p.7) The primary goal of design for adaptability is to lengthen a building's lifespan by making it possible to adapt the space with minimal disruption (p.7) Design for adaptability happens at the beginning of the building's lifespan; it means intentionally designing the building so that adapting it for future uses is not impossible or cost-prohibitive (p.14)
Rockow, 2020	Design for Adaptability is intentionally designing a building or space for future adaptation Design for Adaptability (DfA) embraces the inevitability of change by intentionally designing buildings that can be readily modified to suit future needs (p. 49) The phrase "Design for Adaptability" or "DfA" is used to describe the intentional design of buildings that can be readily changed to support future needs and preferences (p.50)
Femenias & Geromel, 2019	Design for adaptability is related to higher up-front costs and also to uncertainties regarding the actual economic benefit (p.2)

Heidrich et al., 2017	Design, in its broad sense, is no longer only focused on technologies and performance, but it is user-centered and focused on aggregating functions and spaces, providing smart solutions for working, studying and teaching. This new concept of design involves adaptability, as a means to delivering building spaces able to host multiple functions and activities (p. 296)
Geldermans, 2016	DfA guidelines are rooted in enhanced resilience of the built environment on the one hand, and the associated constructive implications on the other (p. 301) 'open building' approach is often seen as the basis for Design for Adaptability (DfA) concepts, in which a strong sense of flexibility is paramount (p. 304) Dimensions and connections are two main 'Design for Adaptability' themes strongly related to circular building (p.305)
Chen, 2016	Designing for adaptability and deconstruction (DfAD) is a design strategy that plans for the reuse of building components at the end of a structure's service life […] Incorporating DfAD into our designs would address adaptability at a component level (pp. 13-14).
Schmidt III & Austin, 2016	The process of extending the life of our building environment (p.158)

Table 1. The concept of DfAD according to recent publications (Note. This table was made by the Henriques (2022) based on a Literature review).

3.1.1 DfAD in Human Architecture

As humans shape buildings, then the buildings shape humans (Brand, 1994); it is essential to deepen the investigation of Adaptability through the design process. A building is compounded by its shearing layers of change, elements that have different useful lives. Between them, the role of the social layer, "humans in and around the building that interact with and play a role in the life of the building" (Schmidt III & Austin, 2016, p. 55), in shaping buildings to respond to varying requirements across the application of some strategies is crucial. Buildings have distinct internal dynamics, leading to different types of change (Brand, 1994). Buring (2017) defines that there must be a variation in the way buildings are designed. For the author, by considering the accelerated societal changes, spaces are demanded to be transformed on different scales to accommodate them. Moreover, Geraedts *et al.* (2014) point out that the main focus is on future value because looking at future generations is as important as today's users, owners, and society. To comprehend buildings as not static artifact is fundamental to break up with the fallacy of the architect as the only creative protagonist: Design is a complex process, molded by internal and external contingencies (Schmidt III & Dainty, 2015).

The practical guide “Buildings that Last: Design for Adaptability, Deconstruction, and Reuse,” published by The American Institute of Architects (AIA), raises awareness on the subject, mainly in the American context of waste generation. By highlighting the role of architects in the face of the advantages arising from short-term solutions, Melton (2020, p. 7) points out that the first objective of *DfAD* is “to extend the useful life of a building, making it possible to adapt the space with the minimum of interruption,” but draws attention to the fact that, as it is dealing with the future, there is no sure prediction about the extension of the use of the building.
To characterize the design process, it is highlighted twelve design strategies (DS) that the *Adaptable Futures Research Group* synthesized. The Group creation resulted from a pilot project called “Building the Brand,” founded in 2007 by the Loughborough Innovative Manufacturing and Construction Research Center in collaboration with Laing O’Rourke, Buro Happold, and Reid Architecture, and through an interest in research on Adaptability in the built environment. Beadle *et al.* (2008) point out the main objectives in its early years, for instance, identifying future scenarios, understanding success and failure cases, and creating new systems and architectural models. For the research, there is a difference between Design Strategies, Building Characteristics, and Design Tactics:

> *Design strategy:* is an overarching approach towards a way of doing things that can be defined through a set of building characteristics and design tactics.
> *Building characteristics:* prominent features pertaining to the building and/or its constituting parts.
> *Design tactics*: a specific method to achieve a design strategy (embodied in the building) (Schmidt III & Austin, 2016, p. 90).

Thus, DSs link to building characteristics and underlying design tactics *(See Figure 2)*. Schmidt III and Austin (2016) point out that the DSs are not particular to DfAD but represent the core of the adaptable design. They represent a high-level approach to Adaptability, a menu of options named the *DfAD model*, that provides the architect with a way of thinking. The DSs decompose into four areas:

(**1**) Physical Elements, DS1 to DS4;
(**2**) Spatial Aspects, DS05 to DS10;
(**3**) Building character, DS11;
(**4**) Contextual, DS12.

Moreover, the DSs are connected: DS5 loose fit is the most connected strategy, while DS2 Design ‘In’ Time is the least (Schmidt III & Austin, 2016).

> *DS1: Modularity* – separation of the physical parts of the building into defined functional entities;
> *DS2: Design ‘In’ Time* – capacity of the physical parts to provide options for the users (‘in time’);
> *DS3: Long Life* – consideration of the physical parts to last a long time;

DS4 Simplicity and Legibility – use of simplicity and legibility with regards to components and construction methods to enable change to occur more readily;
DS5 Loose Fit – spatial considerations beyond a minimal standard or that defined by the brief;
DS6 Spatial Planning – spatial consideration for the way spaces are laid out; their boundaries, dimensions and relationships to one another;
DS7 Passive Techniques – the building's shape, materiality and orientation provide additional options for heating, cooling and ventilating the building;
DS8 Unfinished Design – capacity to add to or 'complete' an aspect or layer of the building;
DS9 Maximize Building Use – increase the timeframe in which the building is used throughout the day, week and year;
DS10 Increase Interactivity – use of physical and visual connections to increase a sense of awareness creating a more legible place;
DS11 Aesthetics – use of the building's image, form and narrative as a way to appealing to the user's and society's appreciation;
DS12 Multiple Scales – consideration beyond the building to include aspects of the site and surrounding area;
(Schmidt III & Austin, 2016, pp. 91-108).

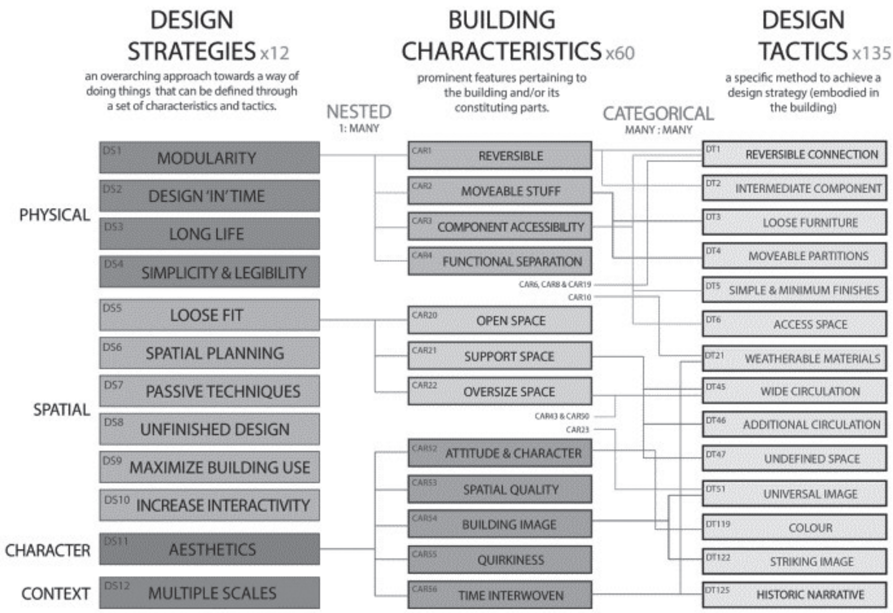

Figure 2. DfAD model: Design Strategies, Building Characteristics and Design Tactics (Note: Diagram reused with permission from Schmidt III and Austin, 2016, p.90) (original not in b&w).

3.1.2. DfAD in Animal Architecture

In Nature, the term Adaptability generally represents a natural mechanism intrinsic to living beings: a characteristic of response and survival to the environment (Tributsch, 1982) that increases the chances of reproduction. Species are not immutable, adjusting in morphology, physiology, and behavior to the habitat (Ridley, 2007). In humans and non-humans, the concept of Adaptability extrapolates the organism (by biological or physiological changes) and meets Architecture: adaptable buildings can adjust to distinct contexts through their lifecycle as much as organisms can adjust to changes in environments. The focus of this section lies in highlighting adaptable strategies that can extend the life of their built environment in animals architectures (DSN), with no deeper consideration to the behavior of the builders – although knowing that its understanding can provide a more holistic view of animals' design, in both physical features or more technical attributes (Sugasawa & Pritchard, 2022).

Animals are, in general, builders and inventors beings. Their builder behavior respects physical forces and the economy. Ecological functionalism generally through a lower expenditure of energy and time by checking the availability of materials in their surroundings and transportation – many even considering prolonged use and recycling (Pallasmaa, 2020), which reflects in the design of thriving habitats for future generations (Arndt, 2013). In short, Animal Architecture objectives for reproduction and the life extension of species (Salvat, 1987). Characteristics such as control and complexity are predominantly noted at the beginning of the animal builder behavior (Hansell, 2007).

Ten design strategies of Animal Architecture (DSN1 to DSN10) were summarized here to characterize *DfAD* in Nature. The authors defined the terms used to name them based on a literature review (Henriques, 2022) –often arising from adjectives (e.g., convertible housing– Convertibility strategy). It is essential to point out that these highlighted strategies do not end the relationships between Adaptability and Animal Architecture but serve as a kick to emphasize the adaptive capacity of their dwellings.

- *DSN1: Expandability* – capacity for size variations, often growth followed by a return to the initial situation. In animal constructions, it is possible to observe this strategy both in dwellings in the body of the species (as the marsupials of female kangaroos) and those built externally.

  (a) The dwellings of the Caddis fly larva (*Lepidostoma hirtum)* are constructed for protection in aquatic environments and using various materials (depending on the habitat). These are usually glued by a secretion of the larva themselves, which ensures their expansion as the animal grows (Arndt, 2013) *(See Figure 3)*.

- *DSN2: Multifunctionality* – the ability to accommodate different functions/uses in the same structure, thus allowing multiple activities (shelter, procreation, or work), which increases usability without the need for new construction or demolition.

  (b) The oven-bird (*Furnarius rufus*) uses clay as its primary material and a double security system for the spatial layout of its bunker. There is a separation between the entrance and the nest camera. This attribute attracts other species when unoccupied (Salvat, 1987), demonstrating how multifunctionality can allow structures to be reused *(See Figure 4)*.

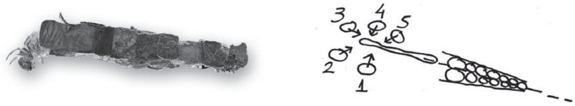

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Figure 3. Expandability in the Caddis fly larva dwellings (Note: a. Lepidostoma hirtum larva by Hallvard Elven (Naturhistorisk museum, Universitetet i Oslo). Source: Wikimedia Commons licensed by CC BY-SA 4.0 (original not in b&w); b. sketch by the authors). **Figure 4.** Multifuncionality in the Furnarius rufus bunker (Note: a. Furnarius rufus by Charles James Sharp. Source: Wikimedia Commons. Licensed by CC BY-SA 4.0 (original not in b&w); b. sketch by the authors)

- *DSN3: Climate Control* – the ability to increase indoor comfort mainly through temperature regulation, in addition to controlling insolation and ventilation through passive techniques, maximizing the possibilities of use for a more extended period and with less energy expenditure.

    (c) Termites create dwellings that vary according to the species (e.g., *Amitermes meridionalis* and *Macrotermes bellicosus*), but in general, flee intense exposure to the sun. Thus, they position their buildings, which can reach four meters in height, in a north-south direction (Pallasmaa, 2020). In these termite mounds, the temperature is constant: hot air rises through the peripheral channels and is cooled by the proximity to the external environment (Salvat, 1987) *(See Figure 5).*

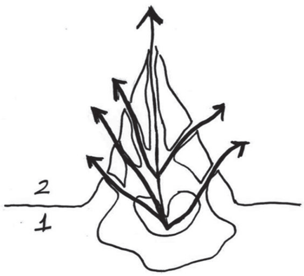

Figure 5. Climate control in Amitermes meridionalis mounds (Note: a. Amitermes meridionalis mounds by Ianperegian. Source: Wikimedia Commons. Licensed by CC BY-SA 4.0 (original not in b&w); b. sketch by the authors).

- *DSN4: Convertibility* – capacity to transform from one situation or state to another in the face of varying demands. It also increases usability without the need for new construction or demolition.

  (d) The underground burrows of badgers (e.g., Meles meles) are passed down from generation to generation: "it is not just any construction or improvised: its distribution adapts to the needs of each family and the characteristics of the place it occupies" (Salvat, 1987, p. 60). Therefore, several entrances and galleries of various sizes form these homes, and, in times of breeding, one of these chambers converts into a birthing place (See Figure 6).
- *DSN5: Personalization* – the ability to create an individual or even collective aesthetic for reproduction and attraction to females, adding meaning. In humans, this characteristic is usually related to the notion of identification and belonging; in animals –especially birds– this characteristic is, in most cases, related to procreation.

  (e) Male pergola birds (*Ptilonorhynchidae*) choose objects, materials, flowers, or fruit pulp, most often in a single color, to capture the female's attention for mating in their nests (Pallasmaa, 2020). Other bird species follow a very similar logic, such as the arboreal birds (*Chlamydera nuchalis*) and the gardener Vogelpok (*Amblyornis inornata*) *(See Figure 7).*
- *DSN6: Rationality* – ability given the economy of construction by a simple method that reduces energy and time expenditure. It facilitates future maintenance and repairs.

  (f) Bees are social insects with a great organization in the hives. These are structured with wax, a resistant material produced by themselves. The hexagonal choice of cells demonstrates the economy, speed, and most effective possible use of space, places that serve both for breeding and storing honey *(See Figure 8).*