The Case for Design Affordances

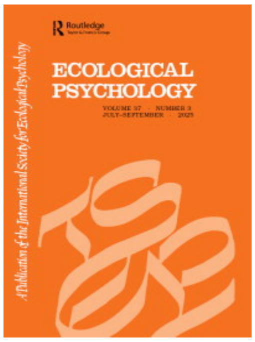
Koutamanis, Alexander

DOI
10.1080/10407413.2025.2559356

Publication date
2025

Document Version
Final published version

Published in
Ecological Psychology



Ecological Psychology

ISSN: 1040-7413 (Print) 1532-6969 (Online) Journal homepage: www.tandfonline.com/journals/heco20

The Case for Design Affordances

Alexander Koutamanis

To cite this article: Alexander Koutamanis (11 Sep 2025): The Case for Design Affordances, Ecological Psychology, DOI: 10.1080/10407413.2025.2559356

To link to this article: https://doi.org/10.1080/10407413.2025.2559356

ECOLOGICAL PSYCHOLOGY
https://doi.org/10.1080/10407413.2025.2559356

Routledge
Taylor & Francis Group

REVIEW ARTICLE

The Case for Design Affordances

Alexander Koutamanis

Faculty of Architecture and the Built Environment, Delft University of Technology

ABSTRACT

The recurring interest in affordances in design studies has produced a disparate body of knowledge and opinion that equally inspires and frustrates. Based on the belief that the concept does hold significance promise for understanding and analyzing interaction, the present paper is an attempt to clarify existing concepts, draw new connections between existing concepts and fill in some missing pieces with new concepts for the deployment of affordances in design. The key contribution of the paper is the distinction between probable user affordances designers intuitively perceive in their designs and affordances they perceive in external and internal representations they use in designing. The former are common to most people, while the latter require some training in or acquaintance with design and its representations. Foundational to the above are the notion of the inbetweenness of technologies and the levels of analysis in activity theory and action identification theory, as well as graph-based design representations for describing both environments and user actions/interactions.

Introduction: definitions and objectives

For several decades now, certainly since Norman (2013) and Gaver (1991) connected the concept to designing and its products, affordances have remained an area of promise for a range of applications: from going beyond stereotypical views of function, use, and users to explaining what designers perceive and act upon in designing. The subject attracts sporadic and intermittent attention in research and has yet to reach practice. There are several reasons for that, including the lack of a universally accepted definition and theory of affordances.

The original definition of affordances as the actionable properties an environment presents to a specific animal, for example, that a frozen lake affords walking to a wolf but not to an elephant (Gibson, 1979, 1983), remains the starting point for most, although it has been criticized for being rather too efficacious (Chemero, 2003; Stoffregen, 2003). Not surprisingly, Gibson's rather compact and often abstract theory of affordances has invited extensions, elaborations, and interpretations. Turvey (1992) defined affordances as dispositional properties of an environment, which are complemented by 'effectivities': dispositional properties of an animal (Shaw et al., 1982).

CONTACT Alexander Koutamanis a.koutamanis@tudelft.nl Faculty of Architecture and the Built Environment, Delft University of Technology, Julianalaan 134, NL-2628 BL, Delft, The Netherlands.

Stoffregen (2003) and Stoffregen and Mantel (2015) viewed affordances as emergent (or relational) properties of animal-environment systems rather than properties of environments alone. Chemero (2003) defined affordances as relations between the abilities of animals and features of an environment, both real and perceivable, but not properties of either the environment or the animal. Fajen et al. (2009) saw affordances as opportunities for action, which describe an environment in terms of behaviors possible at a given time under certain conditions. Osiurak et al. (2017) defined affordances as not tool-centered but body-centered, animal-relative properties that describe mechanical action possibilities at a physical, not neuro-cognitive level, and therefore goal and action-independent.

The above are but a selection that is nevertheless representative of the spectrum of definitions one encounters in affordance studies. To these we could add variations coming from application areas, such as human-computer interaction (Kaptelinin & Nardi, 2012), learning (Lippman & Matthews, 2020) or robotics (Krüger et al., 2011; Moldovan et al., 2012, 2018; Stoytchev, 2008; Sun et al., 2014), as well as revisions that focus on questions of embedded value (Klenk, 2021; Tollon, 2022), relative strength (Davis, 2020; Davis & Chouinard, 2016; Withagen, 2023; Withagen & Costall, 2022) or isolated artefacts (Cosentino, 2021).

The resulting picture has been considered less than coherent or consistent, with too much variation in the use of terms and inadequate definitions (Evans et al., 2017), often incompatible with Gibson's theory (Kaptelinin & Nardi, 2012). Studies are often restricted to laboratory experiments rather than real-world analyses and limited views of affordances, frequently restricted by disciplinary foci (St-Jean et al., 2022), while confusion of affordances with design features is not uncommon (Norman, 1999).

Indicative of such inconsistencies and inadequacies is the frequent omission of the concept of effectivities: the specific combination of an animal's functions of its tissues and organs with reference to an environment (Shaw et al., 1982; Turvey, 1992) or an animal's capacities for action at a given moment (Chemero, 2003). Effectivities are absent in several recent publications, for example, in Cosentino (2021), or substituted by less specific near-synonyms, such as 'dexterity' (Davis & Chouinard, 2016) or 'characteristics of the user' (Tollon, 2022). This use of abstract or generic terms arguably weakens the theory of affordances in a critical way: one of the main arguments for deploying the concept in design is to support a better understanding of users, beyond stereotypes and basic ergonomics (Galvao & Sato, 2005; Tweed, 2001). Giving user capacities a comprehensive and specific formulation is of particular importance in domains such as architecture, where many activities by multiple users combine in the same environments, as well as in situations where effectivities evolve quite rapidly to match environmental opportunities, as with typing with the thumbs rather than fingers on mobile phones.

The objective of the present paper is to clarify existing concepts, draw new connections between existing concepts and fill in some missing pieces with new concepts concerning affordances in design, so as to be able to address the complexities of the real world and bridge gaps, such as the one between the perception of affordances by architects and users of buildings (Hussein, 2012; Koutamanis, 2006; Young et al., 2020). Based on the relational approach to affordances (Chemero, 2003; Gibson, 1979, 1983), the paper examines possible meanings of affordances in design, toward clear, practical formulations that can be used in synthesis and analysis to explain how an environment affords specific actions and interactions, as well as relevant design actions and decisions.

This encompasses all kinds of affordances:

1. Physical: the fundamental action possibilities provided by the physical environment, such as the sittability of a chair that has a surface of appropriate size and a suitable (knee) height. The relations between the chair and its physical context are also included: a chair floating upside-down in a pool or stacked with books loses its sitting affordances.
2. Social: other animals also afford, for example, nurturing or mating (Gibson, 1983), and enrich the environment with complex, bidirectional relations (van Dijk, 2021a, 2021b) and activities that evoke the affordances of the situation (Borghi, 2021). Social affordances can be categorized as opportunities available to others, actions of the observer that are invited or made permissible, and opportunities for joint action (Fajen et al., 2009). If a chair is occupied by another person, it is no longer sittable but if that person is a parent, then the sittability for their small children is enhanced by the combination of chair and parental lap.
3. Cultural: constraints on physical and social affordances enhance or remove possibilities for action (Norman, 2002; Ramstead et al., 2016). A chair in a museum is cordoned off to indicate that it is an exhibit and therefore not sittable for visitors. Interestingly, the rope used for that purpose derives from the physical affordances of fences that impede access. Cultural affordances are frequently designed in this way, by adding regulating technologies which should not be separated from their direct context: a traffic light by itself is meaningless but in conjunction with a road determines when a road may be used for safe passage from different directions.

The following sections focus on two main issues: user affordances, that is, the predicted or actual interactions of users with a (designed) environment, and design affordances, that is, interactions between designers and a design. Section "User, observer, modifier, designer" discusses the transition from user to designer of environments, which underlies how designers perceive user affordances in their work. Section "Design affordances and dispositions" deals with the thorny subject of design affordances and explains that they refer to a different environment, that of design information and its representations. Interaction with design representations is the subject of Section "Affordances in design representations", which focuses on the differences between symbols and implementation mechanisms. Finally, Sections ""Conclusions" and "Discussion" summarize and discuss the conclusions of the paper.

User, observer, modifier, designer

One of the main attractions of affordances is the connection to direct perception: we perceive what we can do with something without mediation of a representation. We do not need to know what something is or what it is called to know that we can sit on it. This intuitive understanding of action possibilities agrees with the equally intuitive way designers claim to know how users will interact with their designs and the resulting performance (Koutamanis, 2006; Young et al., 2020). Personal experience with various interactions apparently forms a foundation for anticipating how others could interact with envisaged environments (Koutamanis, 2024b).

The transition from user to designer is a natural one. As Gibson (1979) pointed out, animals are not passive users of environments but constantly adapt them to improve affordances. A confrontation with harmful or limiting affordances can cause us either to adapt our own effectivities or modify the environment. A low-hanging tree branch that obstructs our path may make us stoop to go under it. Alternatively, we can brush the branch aside. Both actions are often automatic, without conscious thinking, and related to gradedness: affordances are not binary (possible/impossible), separated by a critical threshold but continuous probabilistic functions that represent an individual's likelihood of successful performance (Franchak & Adolph, 2014). The action possibilities offered by an environment may range from comfortable and effortless to cumbersome and demanding. They may require additional effectivities, such as the use of hands and arms to clear the branches above an otherwise walkable path, or some adaptation of body shape or preferred action within one's effectivities, such as crawling rather than walking under low-hanging branches.

This relates to one of the key problems in design: users are adaptable and capable of negotiating uncomfortable chairs, doorways, stairs, etc. without much complaining or even conscious thinking. Still, an unbiased designer viewing their designs from the perspective of their users should be able to identify the difficulties users may have to brave and consider possible improvements, including by making easier the perception and negotiation of hazardous affordances (Foster et al., 2014, 2015; Raveendranath et al., 2024). This supports creativity as an incremental process, where novel solutions emerge from the inadequacies of previous ones (Weisberg, 2010; Weisberg et al., 2021). Such creative thinking is not exceptional but within the capacities of most people and their ordinary cognitive processes. Therefore, interaction with an existing situation is a powerful way of adding the information necessary for nudging toward new directions.

Temporary modifications can easily become permanent: rather than having to brush a branch aside every time, we can simply cut it. Moreover, an impromptu decision to do that can become part of a plan to clear a more walkable path. Fundamentally, this is a design action, in which the activities of users are mapped onto the environment and trigger creative solutions, as when children develop alternative, unofficial paths because the design of a schoolyard does not meet their needs or to escape supervision (Aminpour & Bishop, 2021). Moreover, adaptation often involves the addition of new technologies: we can adapt our effectivities by attaching enhancing technologies to our bodies, such as sunglasses that protect us from sunlight. Modifying the environment also frequently involves adding new technologies to it, for example, building a pergola that affords shelter from the sun (Floridi, 2013, 2014; Koutamanis, 2023).

In addition to our own user experiences, observing others is a familiar way of learning affordances and a starting point for modifications. How others behave in a particular situation teaches us not only cultural affordances but also the complex mixture of social and physical affordances in our environments (Kiverstein, 2024), which is particularly evident in heavily constrained situations, such as sports (Fajen et al., 2009). The brain parts that control movement are used to simulate mentally what others do, as if we were the ones performing these actions. Through that we understand what we are seeing and anticipate what others do. In addition to motor resonance, there is also emotional resonance: observing someone do something in a sad way generates a sad emotion in the brain, even though the observer may be unaware of their own sadness (Calvo-Merino et al., 2005, 2006; Thill et al., 2013).

Perceiving what an environment affords to others means that we can modify the environment also for others, for example, clear higher branches to accommodate someone taller than ourselves. It is also a foundation for generalization: comparisons of different interactions by various users and the outcomes of these interactions allows us to discern general patterns and types of environments, features, users, and effectivities. These can guide the addition and arrangement of technologies in an environment in relation to a wide range of expected users and uses. We can therefore expect that a designer looks at an existing environment from the perspective of prospective users, identifies beneficial or harmful affordances, and determines the features that should be added, removed, or altered to improve affordances. This includes social affordances: the interactions between multiple users in the same environment, which are of particular importance in crowded or precarious places (Templer, 1992). Cultural affordances are also significant, for example, walking on the right side of stairs. Making social and cultural affordances explicit is essential for avoiding design stereotypes and attaining the better understanding of a design situation that underlies both good design and innovation. Moreover, designs often include elements that relate directly to cultural constraints, from traffic lights to lines on the pavement that delineate where bicycle parking is afforded (Figure 1).

The transition from user to designer is also based on the way we anticipate affordances in the course of our actions and activities. Affordance perception concerns features available in the peripersponal space (reachable space from both a metric and a functional viewpoint), which activate relevant brain areas more than targets beyond one's reach, even when one is passively viewing the environment (Gallivan et al., 2009).

Figure 1. Lines on a pavement delineate where bicycle parking is afforded.

These features are perceived in terms of manipulation and use (including through contextual dependencies). Effective possibility for interaction is more significant than visual salience (Costantini et al., 2010, 2011).

Beyond the peripersonal space, perception of affordances is based on the projection of our effectivities and actions to extra-personal space and mapping onto features there, for example, mapping of our effectivities to a door at the other end of a room and getting ready to use an elbow to open it because we are carrying something with both hands. This form of feedforward is fundamentally similar to envisaging how someone else, with different effectivities, would be able to negotiate a doorway. It is also related to the affordances of distorted realities, such as pretend play: using a tennis racket as a guitar involves mental transformation of the environment, as well as of our effectivities (Costall, 2014).

Parsing an environment into parts that could become a future peripersonal space and connecting these parts through mental simulations of sequences of forthcoming events allows for scalability of affordances up to an urban scale in a manner that arguably satisfies critical reviewers (Kelty-Stephen, 2024; Raymond et al., 2017). It also avoids the dangers of easy generalization and oversimplification, as environments retain their complexity. For example, it does not suffice to state that a relatively smooth and flat surface affords ball games such as soccer (Heft, 1989; Kyttä, 2002, 2004). We also take into account the size of the surface and its relations to the rest of the environment to perceive that a particular surface affords only five-a-side games or just ball practice against a wall. Therefore, parsing an environment into fundamental parts and relations with different characteristics (Andersen et al., 2015, 2019; Aradi et al., 2016; Fjørtoft et al., 2010), and making the technologies in each part explicit is essential if we are to perceive affordances with specificity and reliability (Koutamanis, 2023).

It is also important that we make no distinction between what might be construed as natural or human-made in the environment. For Gibson (1979) there is continuity between what humans encounter and what they change or add to it: the environment encompasses both. Heft (2021) argues that the differences between the two are not merely visual but also in their affordances: natural environments such as a forest tend to be irregular and therefore present, for instance, more varied sitting affordances than the standardized sitting layouts in the built environment. On the other hand, he claims, in the built environment affordances are denser and more pronounced but also rather limited by the intentions behind the designs. He also suggests that the potential for self-efficacy makes natural environments attractive and more powerful. Other studies claim that natural environments have potential quality that act as a catalyst for physical activity (Bjørgen, 2016).

However, this is a rather limited view of both natural and human-made environments. Firstly, not all natural environments are varied. A sandy beach can be monotonous but at the same time very popular and inviting of playfulness. To a large degree, this is due to cultural affordances: beaches, forests, and other 'natural' environments have become places of recreation. On the other hand, cultural norms and constraints that limit behavior and physical affordances are more pronounced in the built environment. Once we relax these norms and constraints, we can find a greater variation of sitting affordances: not only chairs and similar furniture but also floors, desks, fences, etc. There are examples of designed environments with limited use of materials and only a few general-purpose features but sufficient irregularity and layout versatility that have been acknowledged as stimulating physical activity and skill development (Lynn van der Schaaf et al., 2021; Withagen & Caljouw, 2017).

To unify our view of the environment, we must apply the right frame (Kahneman, 2013). A frame that focuses too narrowly on the technologies and artefacts of a design, ignoring their immediate context, fails to take into account the chains of technologies that comprise an environment (Federico & Brandimonte, 2019; Floridi, 2013, 2014; Humphreys et al., 2010; Osiurak et al., 2017). For example, a door or sunshade should not be seen separately from the rooms they respectively provide access to or protect from the sun. Isolating artefacts (Borghi, 2021; Cosentino, 2021; Davis, 2020; Tollon, 2022) is therefore inexcusable, except perhaps when studying specific issues in a laboratory setting (Federico et al., 2023). Ignoring the environment within which something exists or claiming that affordances of environments do not easily apply to artefacts (Heft, 1989) misses the point that affordances are presented by whole environments and not by specific features. We may pay attention to traffic lights and door handles but by themselves these afford little—certainly not priority in road usage or passage through doorways. Moreover, such points of attention should be arranged properly for interaction: traffic lights should be visible from where one uses the road, and door handles should be at the right position for the users to grasp and operate a door.

Consequently, from a design perspective, a narrow focus that reduces or eliminates the context robs designers of the full problem statement and of many of the criteria for the evaluation of a design. A designer should understand in full the chains of technologies that constitute an environment, how these can be added to an existing situation, and how the results will meet the needs and requirements of users. Isolating artefacts also entails the danger of falling back on notions of function and design intent (Cosentino, 2021; Tollon, 2022) or focusing primarily on esthetic and stylistic norms, so perpetuating the gap between what designers think and what users experience (Klenk, 2021; Koutamanis, 2006; Tweed, 2001; Young et al., 2020).

In conclusion, most of us should be able to perceive user affordances for ourselves and others in an environment, as well as possible improvements. On top of that, trained designers should be able to translate this into technologies that could be added to the environment and use this information as guidelines in synthesis and as criteria in analysis to seek, test and improve designs on behalf of users much better than through deterministic and narrow notions of function (Maier et al., 2009; Maier & Fadel, 2009a, 2009b; Pols, 2015) or similarly narrow views of use that for example, exclude exploration (Stoffregen & Mantel, 2015). The main prerequisites are that designers:

1. Consider the environment in a holistic and structured manner
2. Analyze user activities in a compatible manner

A holistic treatment of the environment ensures completeness and inclusiveness: that no relevant features or relations are ignored through inappropriate framing or elliptical abstraction. For example, the graspability of a door handle should be placed in the wider frame of operating a door and passing through a doorway, which involves several other features and affordances, too. Moreover, affordances are always socially situated and therefore subject to cultural constraints (Davis, 2020) that must be included. This calls for well-structured descriptions that make all parts and aspects of the environment transparent and explicit.

The graphs used to describe inbetweenness and chains of technologies (Floridi, 2013, 2014; Koutamanis, 2023) are a promising starting point and moreover compatible with the structure of modern computational design representations such as BIM (Building Information Modelling) and digital twins (Koutamanis, 2024a; Koutamanis et al., 2023). They also agree with wider views of sequences of symbols that underpin the complexity of the environment (Waters, 2021). Each meaningful feature (i.e. discrete technology) is represented by a vertex (symbol) and the edges between vertices represent equally meaningful connections and allow the propagation of constraints between features (and interactions with them).

By making relations between features in an environment explicit and meaningful, we can explain the contribution of each feature and the operation of the whole, as well as our apparent focus on specific features, such as door handles in doorways or step dimensions in stairs (Koutamanis, 2024b). Figure 2 is an example of a graph representation of a door that illustrates why using a door is not merely a matter of turning a handle but also involves the connections between the handle and the rest of the door, as well as the connections between the door, its casing, and hosting wall. For example, absence of hinges renders the operation of the door handle ineffective.

As for users and their effectivities, these should be placed in the frame of complete user activities, who normally do not rattle door handles for the sake of it but use them to operate doors in order to achieve some goal. This calls for going beyond body-scaled measures of affordances, such as the ratio between leg length to stair rise (Warren, 1984), which may be foundational but nevertheless improve little on static ergonomics for design. Action-scaled affordances that relate to action capabilities are more appropriate for complex kinds of interaction (Fajen, 2007; Stoffregen, 2003). A full analysis of effectivities also requires going beyond expectations of correct or canonical use. Even when an artifact is used in a canonical way, there can be significant tolerances, for example, in the way one sits on a chair (Costall, 2014). In this sense, it is more important to explore how affordances work in what we do than try to define what they are (Davis, 2020).

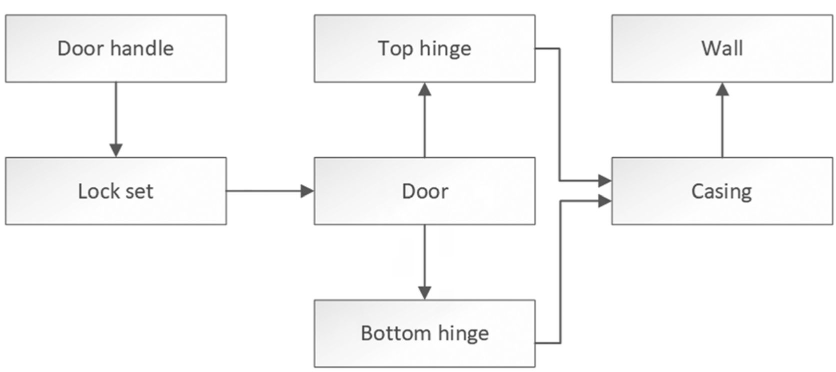


Figure 2. Graph representation of a door. All relations are protocols.

Matching and mapping effectivities onto an environment in a meaningful way for the perception and improvement of affordances in a design, requires analytical descriptions of activities. Rather than developing new formalisms that try to capture interaction aspects and levels (Pols, 2012), we can draw from activity theory (Czerwinski & Kaptelinin, 2007; Kaptelinin et al., 2006; Kuutti, 1996; Leont′ev, 1981), which offers a descriptive framework for parsing human activities into one or more actions, each with its own, conscious goal. For example, going from one room to another may involve going through a number of doorways and rooms or using some stairs. Actions are realized through one or more operations, directed at specific tasks, such as using a door handle or grasping a stair handrail. An action occupies a particular point in the sequence of events that comprise the activity but is also independent from the activity: the composition of actions in an activity is variable. Similarly, operations are determined by the conditions under which the action is carried out (including available resources).

Effectivities and affordances are compatible with operations and actions: they describe the resources available for specific tasks and goals, and the features of the environment that are relevant, including the interplay of goal-directedness and independence from higher-level concerns in the selection of affordances (Thill et al., 2013). Analytical descriptions based on activity theory therefore cover both physical interactions and intentions, either explicit in the conscious formulation of diachronic concerns and goals that determine an activity or implicit in personal values, commitments, self-narratives, etc. behind their resource allocation (Dings, 2021). Consequently, they seem appropriate for parsing the continuous stream of behavior and interactions with the environment in a way that retains its continuity and positions affordances in a reciprocal and cumulative frame (Heft, 1989).

Figure 3 is an example of how an activity can be parsed into sequences of actions that correspond to sequences of peripersonal spaces and operations. As the action sequences are at similar abstraction levels as environment graphs, they can be directly matched to them, as in Figure 2. Each operation relates to specific effectivities, for example, standing up from a chair. It also links effectivities to precedent actions: avoiding collisions with other users in a crowded corridor partly depends on the speed of going through the doorway. Propagating resulting constraints in both directions is essential for capturing the richness of both environments and human behaviors in them (Waters, 2021).

Mapping the effectivities involved in each operation on particular features of the environment allows us to form expectations concerning user affordances, firmly and transparently rooted in the context of the whole environment and the user’s activities. Turning a door handle, for instance, depends not only on the user’s capacities to use their hands for that purpose but also on the availability of the hands, which may be occupied with something sensitive or cumbersome. In such cases, elbows are used to turn door handles without a second thought. Mapping operations on the environment also allows us to identify social and cultural constraints. In an office corridor, one can expect to encounter other users going in the same or opposite direction or just standing still. The corridor parts occupied by them are inaccessible and must be carefully anticipated, especially in the case of moving obstacles. One is also expected to acknowledge and even chat to other users of the office corridor, as well as knock

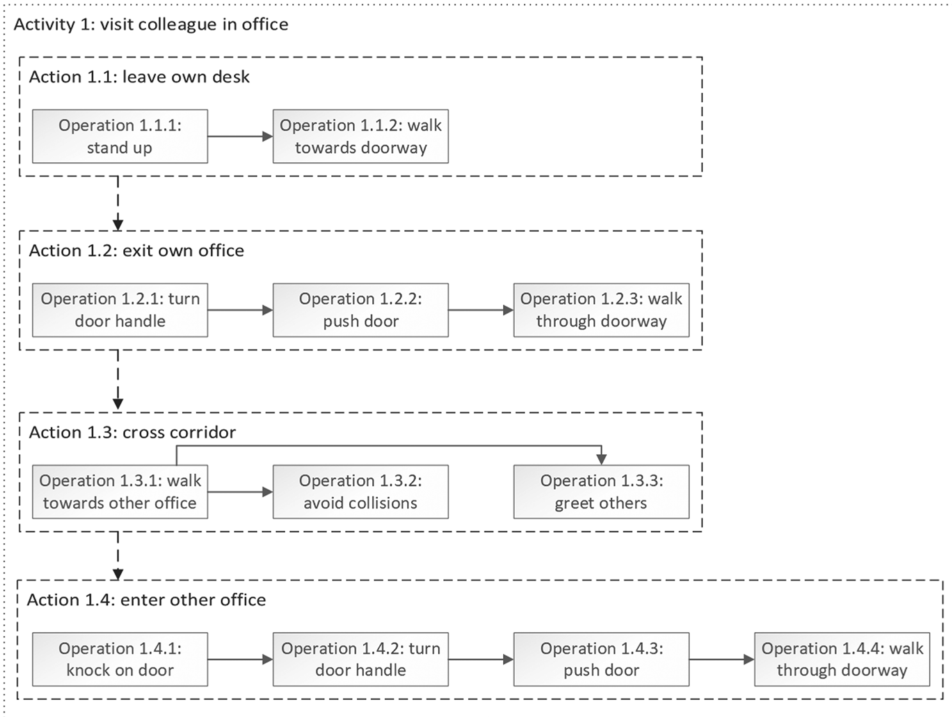


Figure 3. Parsing of an activity into actions and operations.

on the door of someone else's office before entering. Entering one's own office requires no knocking of the door.

Additional support for matching environments to operations and effectivities can be drawn from Action Identification Theory (AIT), which suggests that anything we do has multiple identities at various levels (Vallacher & Wegner, 2012). The higher levels provide an understanding of what we do, its reasons, effects, and implications. The lower ones concern the specifics of what we do and especially how we do it. In crossing a doorway, we may interpret what we do in terms of going somewhere to meet someone (activity), of opening a door (action), or of turning a door handle (operation). When both higher and lower identities are available, the higher ones tend to be prepotent: if all goes well, we operate doors and climb stairs unconsciously, thinking instead about the destination and purpose of the journey. If something cannot be performed with reference to a higher identity, the lower ones take over: we focus on the troublesome operation. To a large extent, focus depends on the fluency supported by beneficial or impeded by harmful affordances: a loose door handle or a door stuck in its frame switch our attention from the activity to the interaction between our body and the chain of technologies that comprises a doorway. AIT, therefore, explains how users have a sense of what is afforded in relation to their activities, from the higher levels of why to the lower levels of how (Dings, 2021). It also explains why we are often misled into isolating an artifact or other feature from each environment, as well as how such narrow frames can be substituted by the right frame that encompasses whole activities and all relevant effectivities. From a design perspective, this also requires quite detailed representations of the environment. For example, the graph in Figure 4 may be necessary (rather than the one in Figure 2) if the door is not rigid enough to transmit the user interaction at the door handle to the hinges.

Design affordances and dispositions

Some design studies expand the application of affordances to the actions of designers. In addition to actions related to user affordances (e.g. improving the height of a door—an 'affordance that invites the architect's response' (van Dijk & Rietveld, 2021)), they also apply affordances to 'large-scale situations,' such as being able to envision an architectural installation, on the strength of the immediacy and apparent clarity of a response that anticipates design actions over larger timescales, taking several months, and relating to nested affordances (van Dijk & Rietveld, 2025, 2021).

Foundational to design affordances are the so-called artifact-to-artifact affordances. The idea of affordances between things was originally proposed in 2009 by Maier, Fadel, and their collaborators in several overlapping publications (Maier et al., 2009; Maier & Fadel, 2009a, 2009b) to explain how designers perceive the relations between parts, for instance, how building components such as beams can rest on top posts. They claimed that these relations are similar to user affordances, such as walking on a floor. Artifact-to-artifact affordances were further expanded by Hu and Fadel (2012), Cormier et al. (2014), and Koutstaal and Binks (2015) to include not only relations within the hierarchical subsystems found in an environment but also between objects of different subsystems at the same overall level. Related work includes the user-artifact-artifact triads proposed by Stoffregen and Mantel (2015).

As an example of artifact-of-artifact affordances we can use loft conversions, which are quite popular in densely populated countries such as the Netherlands. Adding dormers to a sloping roof increases livable space by often more than 20% in a house. A roof unadorned by dormers, as in Figure 5, indicates possibilities for loft conversion, unlike the roof in Figure 6. In terms of artifact-to-artifact affordances, the roof in Figure 5 affords support and accommodation to a dormer or even loft conversion to the house. A designer perceives this affordance and changes the building envelope accordingly.

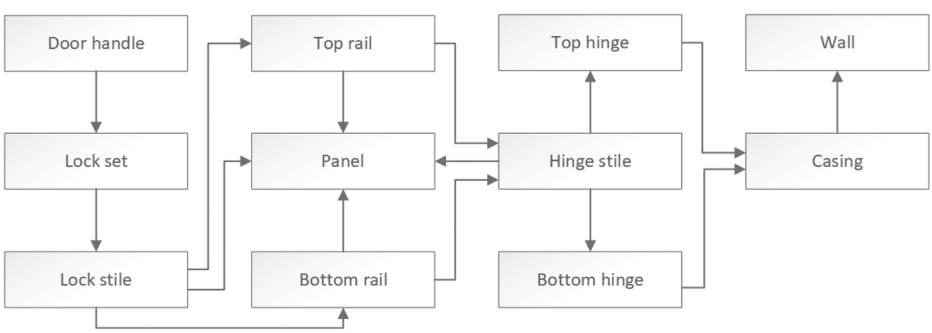


Figure 4. A more detailed version of Figure 2.

Figure 5. Roof without dormers in the Netherlands.

Similarly, one could say that a plot of land affords a building but such truisms are of any value. More interesting are claims that a specific plot of land affords a school building or a vacant lighthouse affords accommodation to a gallery or office (Rietveld & Kiverstein, 2014). This involves knowledge of school building types and sizes, as well as of the context (location relative to pupil catchment area, public transportation, or other facilities). As with user affordances, one could argue that designers select a familiar or ideal building type that answers the design brief, parse it into parts, and then reassemble them mentally on the available land parcel.

The main question is whether this is a metaphorical use of affordances (Heft, 2003). Withagen and Costall (2022) suggest a limit to how far affordances are applied. They argue that affordances are primarily functional and not sufficient to capture everything an environment means to us; not everything in design is affordance-related. An answer to the question can be found in the analysis of inbetweenness of technologies by Floridi (2013, 2014), which underlies design as modification of an environment through the insertion of technologies either between users and environments or between features of environments (Koutamanis, 2023).

In the resulting chains of technologies, the connections between users and technologies are termed interfaces, while those between technologies are called protocols. In using a screwdriver to drive a screw in a piece of wood, the screwdriver handle is an interface, while the connections between screwdriver tip and screwhead, and between wood and screw tip and thread are protocols. The right screw for the wood and the right screwdriver for the screw are chosen on the basis of matching protocols, for

Figure 6. Roof with dormer in the Netherlands.

example, a tip that matches the drives on the screwhead. Protocols tend to be rather strict in many technologies, while interfaces are more flexible and afford user interaction within certain tolerances, provided that this interaction operates the whole chain of technologies satisfactorily, that is, with proper alignment at the protocols and efficient movement of the screw. Similarly, all relations in Figure 2 and Figure 4 are strict protocols. Loose door handles, doors that are falling apart, or hinges that are coming off are unacceptable because inadequate protocols impede the overall operation of the door. Interaction with the interface of the door handle, on the other hand, can take many forms, depending on how users choose to grasp, turn, and push or pull it.

The distinction between interfaces and protocols shows that what an environment affords to an animal is not the same as how parts of the environment connect to each other. The most important difference concerns agency: a user interacts with an interface and causes changes that are propagated along chains of technologies, which just obey the conditions defined by the protocols between them. If we define affordances as resources for agency (Costall, 2014; Davis, 2020), one could argue that connections depending on protocols should be called dispositions (Choi & Fara, 2021): object properties indicating the possibility of a behavior under certain conditions. For example, salt is soluble in water and a floor supports detached things up to a certain weight. These behaviors are usually inevitable when the conditions are met, regardless of the intentions or actions of any agent. Protocols can be very specific, as in screws and screwdrivers, or more generic and fuzzy, as between floors and furniture. The latter should not be confused with interfaces, where the variability of the animal's actions is the main reason for variation in the interaction. Floors always support chairs, only in a tolerant way: in addition to the canonical position for sitting, chairs can be put on their sides, backs, etc. Dispositions in design tend to be more specific than in such generic statements: a post can support a beam but it will not support a beam at any position. The connection between the two must follow the protocols of weight transference in a load-bearing structure.

In any chain of technologies involving agency, dispositions are more often about potential rather than inevitability: a screwdriver placed near a screw does nothing by itself. An animal should actualize the affordances and protocols of both to achieve something. Similarly, one puts chairs on a floor in order to modify the sitting affordances of a room. Merely stacking them or throwing them about does not have the same effect. Designers are aware of both material and dispositional properties in an environment, as well as of interfaces and protocols in technologies, and the propagation of constraints in chains of technologies; they know how a handle operates a door lockset and the swing of a door (in conjunction with hinges) and how to put everything together in a functioning doorway. How well the doorway serves users is a different matter, related to user affordances.

Designers, therefore, use their knowledge of dispositions to arrange technologies in a way that answers user requirements, that is, creates beneficial user affordances, but also ensures good technical performance, such as stability, airtightness, or precise connection between screwdriver tip and screwhead. To do this, they must frame chains of technologies and user activities inclusively and make the connections between technologies explicit. Claiming that a roof affords dormers says very little about all that. The lack of dormers may act as a cue but behind the decision to put one on the roof and change the overall form of the building hide several interconnected design problems, such as the kind of activities to be deployed in the converted loft, structural issues with the roof, the form and position of stairs that connect to the loft, financial and legal considerations, etc. Designers solve these fuzzy, overlapping, and frequently conflicting problems in various ways, prioritizing different issues (sometimes with bias) and learning from rejected solutions.

Designers obviously perceive possibilities for action in any state of a design, for example, improvements in the connection of the dormer to the roof beams, in the ergonomics of a door handle design, or in the construction costs of a screwdriver. Calling all that affordances arguably obfuscates the complexity of designing, the multitude of problem types, the knowledge involved, and the differences between the strategies used, including between Type 1 automatic processes and Type 2 analytical thinking, as defined in dual-process theory (Evans & Frankish, 2009; Kahneman, 2013; Stanovich, 2011).

As for large-scale affordances and nested affordances, these are reminiscent of 'central ideas' and 'basic concepts' from which a design evolves. Unfortunately, such ideas and concepts can also be a posteriori fabrications that justify design choices (Cannon-Brookes, 1984). The variability of processes and unpredictability of outcomes from the same starting point (e.g. design brief) are in sharp contrast with the universality of affordances such as sittability and climbability. Emphasis on the generative potential of initial perceptions also overestimates the capacity of our brain to hold and process complex and detailed representations (Shepard & Cooper, 1982) and underestimates the role of exploration and rejected solutions in creativity (Csikszentmihalyi, 2013; Weisberg et al., 2021).

Distinguishing between affordances and dispositions inevitably brings us back to the debate on the nature of affordances (Wilkinson & Chemero, 2024): are they dispositional properties of an environment (Scarantino, 2003; Turvey, 1992) or relations between specific aspects of an animal and specific aspects of an environment (Chemero, 2003)? From the perspective of the present paper, the similarities between different views on the matter seem greater than their differences. In any case, the proposed ways of parsing environments and user activities, and of mapping the latter on the former are clearly relational. They also indicate that talking about affordances assumes an agent capable of action. As there is no actor in the relation between a chair and a floor, it seems more consistent to state that, thanks to its dispositions, the floor affords *my* putting a chair on it.

In conclusion, we argue that what is presented as design affordances is primarily the designers' understanding of technologies and their layout—not only their material properties but also their dispositional properties and the protocols that characterize these dispositions, as well as known chains of technologies with a relevant behavior and performance. These underlie a fair share of design problems and actions, especially in Type 1 automatic processes. The following section explains where and how they are perceived.

Affordances in design representations

The limitations of human memory mean that designers make heavy use of external representations through which they model and perceive their designs. Such representations are therefore where we should examine how designers perceive design affordances. An existing environment or mental image can always be the starting point in a design process (also for the initial perception of design affordances) but, as the process progresses, dependence on representations becomes unavoidable and intensive.

For a long time, design representations have been predominantly analogue, such as scale models and line drawings, and used geometry to describe and order the form of designs (Cosgrove, 2003). In these pictorial representations, from photorealistic renderings to floor plans, recognition of design entities such as walls and doors, as well as of the graphic primitives that describe them, depends on visual perception by the designer. More recently, computers allowed for digital representations that initially replicated and improved on analogue media. In vector drawing such as CAD (computer-aided drawing), a line segment is an explicit graphic entity rather than a group of ink particles on paper that is recognized by the human user as a single geometric element. This presents new possibilities for interaction: instead of having to erase or add ink particles, one can manipulate such a graphic element as a whole (e.g. move and rotate it) or adapt its shape by moving key points, for example, change its length by moving one of its endpoints.

Even more recent digital representations, such as BIM, go even further and make explicit the symbols of design entities: instead of drawing the lines, surfaces or volumes that describe the form of components such as doors and doorhandles, designers enter and manipulate symbols for these things, in the same way that we enter Unicode characters in a text editor, as opposed to strokes in handwriting. BIM employs pictorial views like floor plans but its primary representations are alphanumeric tables of the database of symbols and graphs that describe the connections between symbols, such as the connection between a door and the wall that hosts it. Symbols in these representations usually also contain non-geometric information, such as material properties, while some dispositional properties are expressed in relations between symbols, for example, in the way a door sticks to the hosting wall (Koutamanis, 2020, 2024a).

Regardless of medium, external design representations can be approached at two levels: symbols and implementation mechanisms. In a line drawing on paper, a designer recognizes what ink particles signify in smaller or larger groups, from line segments on the outline of a screwdriver handle to the form of the whole screwdriver. Interaction with the representation, however, is only at the level of implementation mechanisms, the ink particles. In CAD, interaction is still with implementation mechanisms, only more convenient ones: explicit and adaptable line segments and other geometric primitives, which may be entered or modified either geometrically (e.g. moving an endpoint) or alphanumerically (e.g. typing a rotation angle). Finally in BIM, interaction is directly with symbols, which imposes additional constraints on interaction: in some cases, it may be geometric (e.g. translating a door along a wall) but in others it involves menus and alphanumerical values: to change the width of a door one normally selects the symbol of a different door type, while defining material properties is done by typing values for these properties.

As AIT explains, all interactions have multiple identities: the higher level of symbols mostly relates to design goals, intents, briefs, etc., while the lower level of implementation mechanisms concerns the specifics of the design and the representation, for example, the precise form of a handle for optimal graspability and the geometric primitives that can be used to specify the right shape. Design thinking is normally at the higher level but any difficulty with the implementation mechanisms, for example, due to unfamiliarity with CAD software, switches attention away from symbols and design goals (i.e. the activity and actions of designing) to the use of the software (the operations of CAD).

The same holds for design affordances: designers perceive possibilities for action at the higher level of symbols, for example, where a door should be placed in a wall to ensure smooth pedestrian passage, and modify the design accordingly by translating the door along the axis of the hosting wall in BIM. Similarly, they can perceive the possibility of improving the girth of a handle or the aerodynamic performance of a car bonnet by changing their geometry in CAD. At the same time, they also perceive possibilities for action at the level of implementation mechanisms, for example, that an empty part of a paper affords the drawing of new lines (e.g. an explanatory detail but also to test if a pen is working) or how key points of a line segment in CAD could be dragged to adapt its shape. Here again the higher level tends to prepotent: the affordances of implementation mechanisms are subservient to those of symbols.

So far, we have stressed the symbolic character of design representations. Design thinking can also concern more abstract aspects, such as the overall form of a design, predominantly for esthetic reasons (Rietveld & Brouwers, 2017). This may bypass the level of symbols, that is, of the components of this form, and focus on an abstract, encompassing shape. However, this is also an indirect way of organizing the spatial relations between symbols. Significantly, in such cases, too, interaction with a representation remains at the two levels of design entity and implementation mechanisms, with the difference that the design entity is an aggregate.

Abstract aspects of form and spatial arrangement are also present in informal pictorial representations, such as sketches. Sketches are revered among designers for their capacity to capture 'central ideas' and 'basic concepts' but their appeal arguably lies in the fuzzy way they specify geometry, relations, and composition (Koutamanis, 2001, 2007). In general, we can distinguish between two main kinds of fuzzy representation: geometric form and composition. In the former, a bunch of roughly parallel, roughly overlapping lines are used to indicate what later becomes the geometrically complex, aerodynamic shape of a car bonnet. In the latter, a similar bunch of lines becomes a colonnade (i.e. a group of design entities).

Design affordances also presuppose design effectivities: designers possess capacities that enable them to perceive and utilize design affordances more than lay persons (Rietveld & Brouwers, 2017). At the implementation level one needs acquaintance with and skill in, for example, line drawing or CAD software but more importantly understanding of the technologies involved at the symbolic level. In terms of the dual-process theory, the former are typically Type 1 actions designers undertake automatically, without much conscious effort (so long as things go well), while the latter are predominantly Type 2, analytical and intensive processes requiring domain and case knowledge. Nevertheless, through training and experience (which include familiarization with stereotypes and prototypes) many local choices and arrangements of technologies in a chain can become automatic and effortless, for example, the type and position of a handle in a door, as opposed to the position of the door in a wall with respect to conflicting requirements of easy access to and privacy in the room it provides access to.

In conclusion, we suggest that design affordances are a straightforward extension of the same animal-environment relation. Similarly to perceiving user affordances in a real building or representation of it, designers also perceive affordances for their creative actions in the representations they use. In any state of a design, they perceive possibilities for various kinds of modification in symbols and implementation mechanisms, depending on the goals of the activity and the level of interaction. Moreover, representations are far from equal. Some may support understanding of creative goals better and make some cognitive actions easier. For example, division is easier with decimal rather than Roman numerals (Koutstaal & Binks, 2015). Design representations, too, have different affordances, not only at the level of implementation mechanisms (e.g. 2D versus 3D modeling), but also with regarding the explicitness of symbols and the resulting directness and transparency of interaction.

Conclusions

The key points made in the present paper are:

Perception of affordances

- As users and modifiers of environments, as well as observers of others, designers should have enough capacities to anticipate user affordances in a design.

- User affordances exist in the peripersonal space. Generalization beyond that should be approached through the sequence of peripersonal spaces in a user activity so as to avoid and misleading oversimplifications and abstractions.
- User affordances are distinct from design affordances, which concern interactions with design representations (the symbols these contain, their layouts and implementation mechanisms). What designers perceive in these representations is not necessarily linked to user interactions with the envisaged environment but may primarily concern mechanical interaction with the representation, morphological or typological issues, etc.

Environments

- Design representations may describe physical environments but they should be treated as a different kind of environment, with different affordances.
- Environments should not be opportunistically reduced to particular features or artefacts, even though these may form the design focus at a given moment. Affordances should be framed appropriately, so as to include all relevant parts of the environment.
- Structured, analytical descriptions that make explicit the chains of technologies that comprise an environment support appropriate framing of affordances. Graphs that describe the inbetweenness of technologies are a promising starting point for physical environments. Symbolic design representations are also moving in the same direction.

Effectivities

- Expressing user activities in a similarly analytical manner supports specificity in the matching of effectivities to environment features.
- Activity theory provides means for parsing activities into actions and operations, which make explicit which effectivities are involved and how.
- The combination of activity theory and AIT helps explain shifts in focus and the persistence of overarching goals in interactions with both real environments and design representations.

Discussion

Designers often claim to have an intuitive understanding of user interaction and of the performance of a design with respect to that. Affordances can explain how their own and observed user experiences suffice for most kinds of interaction and many types of users. The direct understanding of affordances in an unfamiliar place is fundamentally similar to predicting affordances in a design. Still, there is considerable room for failure. It is always possible that a designer may fail to perceive user affordances (beneficial or harmful), as any user can, too. Similarly, prioritizing other matters, such as esthetics, or sticking to stereotypes can result in design biases that sacrifice affordances and create unhelpful positions, for example, that users should behave in certain ways only (Raveendranath et al., 2024). Such failures indicate the necessity of sensitizing and educating designers to the needs and capacities of users, using affordances as a vehicle.

User affordances can be both specific and generalizable. Design problems, as specified in design briefs and related documents, can refer to specific, individual users, such as the pupils and teachers at an elementary school, or a vaguer class, such as the visitors of a theater. These share characteristics with other groups and classes, including many that are generic. The design should therefore provide for the specific users as well as for adaptation to other uses and users. Understanding user effectivities at all of these levels is essential for the appropriate formulation of a design problem (Peña & Parshall, 2012) and the evaluation of satisfactory solutions (Simon, 1996).

Affordances do not necessarily reduce the complexity of design problems. They primarily improve transparency concerning use and performance, and therefore also the manageability of design situations. In fact, one could argue that affordances celebrate the complexity of real life by enriching and structuring the information available on a problem, reframe the problem to reveal familiar elements and nudge designers toward new directions and new solutions (Koutamanis, 2024b).

Design affordances refer to a different environment, that of design information, and to the perception of symbols and implementation mechanisms in design representations. This environment is an artificial one, only indirectly connected to the real environment, in the same way that a grapheme is indirectly connected to a phoneme in language. Design affordances are the possibilities for change designers perceive in a state of a design in these representations. These possibilities are informed by user affordances but also other constraints or goals, for example, stylistic ones, as well as knowledge of the technologies involved and the chains these form. The relations between technologies are a key part of any domain knowledge but do not constitute affordances. The lack of agency in the protocols that determines them suggest that they are best considered as dispositions.

Despite the appeal of the notion, we must resist the temptation to consider every design issue as an affordances problem because affordances may not capture everything that an environment means to us (Withagen & Costall, 2022). Design products are often 'things with attitude,' made with a specific end in view, objectifying certain values, expressing identities or denoting status (Attfield, 2020). These ends may distort interaction, even though affordances usually accommodate such interferences in their cultural dimension. In short, there are design affordances (distinct from user affordances) but not all design problems and actions are affordance-related in either sense.

The descriptive mechanisms used in this paper are by no means the only ones suitable for the task of making affordances transparent and operational. For example, an alternative to the combination of activity theory and AIT is the means-end abstraction hierarchy (Dainhoff & Mark, 1995), which is also capable of clarifying real-world complexity and dynamic user activities in a way that supports exploration of action and design alternatives. What matters is that the description of user activities allows us to move between abstract objectives and goals on one hand and specific interactions on the other, so as to connect to what takes place at the peripersonal level, where we encounter specific features of the environment, effectivities, and the matches between them that determine affordances. Equally important is that the sequences of interactions with the environment are explicit, so that constraints can be propagated between them (Waters, 2021).

On the other hand, it is hard to envisage a representation of the environment that does not ultimately amount to a graph. A graph-based representation captures the discrete character of most technologies in the environment, as well as the importance of connections between them for designing, even though many connections can be invisible in use. For that reason, analogue representations that may suffice for the perception of user affordances in a scene are inferior to symbolic representations that also make explicit both relevant features of the environment and connections between them.

Disclosure statement

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

References

Aminpour, F., & Bishop, K. (2021). Children's preferences on the move: Establishing the characteristics of unofficial paths and their benefits for children's physical play in Australian primary school grounds. *Journal of Environmental Psychology*, *75*, 101599. https://doi.org/10.1016/j.jenvp.2021.101599

Andersen, H. B., Christiansen, L. B., Pawlowski, C. S., & Schipperijn, J. (2019). What we build makes a difference—Mapping activating schoolyard features after renewal using GIS, GPS and accelerometers. *Landscape and Urban Planning*, *191*, 103617. https://doi.org/10.1016/j.landurbplan.2019.103617

Andersen, H. B., Klinker, C. D., Toftager, M., Pawlowski, C. S., & Schipperijn, J. (2015). Objectively measured differences in physical activity in five types of schoolyard area. *Landscape and Urban Planning*, *134*, 83–92. https://doi.org/10.1016/j.landurbplan.2014.10.005

Aradi, R., Halvorsen Thorén, K., & Fjørtoft, I. (2016). The urban landscape as affordance for adolescents' everyday physical activity. *Landscape Research*, *41*(5), 569–584. https://doi.org/10.1080/01426397.2015.1077943

Attfield, J. (2020). *Wild things: The material culture of everyday life*. Bloomsbury Visual Arts.

Bjørgen, K. (2016). Physical activity in light of affordances in outdoor environments: Qualitative observation studies of 3–5 years olds in kindergarten. *SpringerPlus*, *5*(1), 950. https://doi.org/10.1186/s40064-016-2565-y

Borghi, A. M. (2021). Affordances, context and sociality. *Synthese*, *199*(5-6), 12485–12515. https://doi.org/10.1007/s11229-018-02044-1

Calvo-Merino, B., Glaser, D. E., Grèzes, J., Passingham, R. E., & Haggard, P. (2005). Action observation and acquired motor skills: An fMRI study with expert dancers. *Cerebral Cortex (New York, N.Y.: 1991)*, *15*(8), 1243–1249. https://doi.org/10.1093/cercor/bhi007

Calvo-Merino, B., Grèzes, J., Glaser, D. E., Passingham, R. E., & Haggard, P. (2006). Seeing or doing? Influence of visual and motor familiarity in action observation. *Current Biology: CB*, *16*(19), 1905–1910. https://doi.org/10.1016/j.cub.2006.07.065

Cannon-Brookes, P. (1984). The post-modern art gallery comes of age: James Stirling and the Neue Staatsgalerie, Stuttgart. *International Journal of Museum Management and Curatorship*, *3*(2), 159–181. https://doi.org/10.1016/0260-4779(84)90041-4

Chemero, A. (2003). An outline of a theory of affordances. *Ecological Psychology*, *15*(2), 181–195. https://doi.org/10.1207/S15326969ECO1502_5

Choi, S., Fara, M. F. (2021). *Dispositions*. https://plato.stanford.edu/archives/spr2021/entries/dispositions/

Cormier, P., Olewnik, A., & Lewis, K. (2014). Toward a formalization of affordance modeling for engineering design. *Research in Engineering Design*, *25*(3), 259–277. https://doi.org/10.1007/s00163-014-0179-3

Cosentino, E. (2021). Artifacts and affordances. *Synthese*, *198*(S17), 4007–4026. https://doi.org/10.1007/s11229-019-02297-4

Cosgrove, D. (2003). Ptolemy and vitruvius: Spatial representation in the sixteenth-century texts and commentaries. In A. Picon & A. Ponte (Eds.), *Architecture and the sciences: Exchanging metaphors* (pp. 20–51) Princeton University Press.

Costall, A. (2014). Canonical affordances and creative agency. In V. P. Glăveanu, A. Gillespie, & J. Valsiner (Eds.), *Rethinking Creativity: Contributions from social and cultural psychology* (pp. 45–57) Routledge. https://doi.org/10.4324/9781315866949

Costantini, M., Ambrosini, E., Scorolli, C., & Borghi, A. (2011). When objects are close to me: Affordances in the peripersonal space. *Psychonomic Bulletin & Review*, *18*(2), 302–308. https://doi.org/10.3758/s13423-011-0054-4

Costantini, M., Ambrosini, E., Tieri, G., Sinigaglia, C., & Committeri, G. (2010). Where does an object trigger an action? An investigation about affordances in space. *Experimental Brain Research*, *207*(1-2), 95–103. https://doi.org/10.1007/s00221-010-2435-8

Csikszentmihalyi, M. (2013). *Creativity: The psychology of discovery and invention* (First Harper Perennial modern classics edition. ed.) Harper Perennial Modern Classics.

Czerwinski, M., & Kaptelinin, V. (2007). *Beyond the desktop metaphor: Designing integrated digital work environments*. MIT Press. http://ebookcentral.proquest.com/lib/delft/detail.action?docID=3338701

Dainhoff, M. J., & Mark, L. S. (1995). Use of a means-end abstraction hierarchy to conceptualize the ergonomic design of workplaces. In J. M. Flach, P. A. Hancock, J. Caird, & K. J. Vicente (Eds.), *Global perspectives on the ecology of human-machine systems* (pp. 273–292). CRC Press. https://doi.org/10.1201/9780203753095

Davis, J. L. (2020). *How artifacts afford: The power and politics of everyday things*. The MIT Press. https://doi.org/10.7551/mitpress/11967.001.0001

Davis, J. L., & Chouinard, J. B. (2016). Theorizing affordances: From request to refuse. *Bulletin of Science, Technology & Society*, *36*(4), 241–248. https://doi.org/10.1177/0270467617714944

Dings, R. (2021). Meaningful affordances. *Synthese*, *199*(1-2), 1855–1875. https://doi.org/10.1007/s11229-020-02864-0

Evans, J. S. B. T., & Frankish, K. (2009). *In two minds: Dual processes and beyond*. Oxford University Press.

Evans, S. K., Pearce, K. E., Vitak, J., & Treem, J. W. (2017). Explicating affordances: A conceptual framework for understanding affordances in communication research. *Journal of Computer-Mediated Communication*, *22*(1), 35–52. https://doi.org/10.1111/jcc4.12180

Fajen, B. R. (2007). Affordance-based control of visually guided action. *Ecological Psychology*, *19*(4), 383–410. https://doi.org/10.1080/10407410701557877

Fajen, B. R., Riley, M. A., & Turvey, M. T. (2009). Information, affordances, and the control of action in sport. *International Journal of Sport Psychology*, *40*(1), 79–107.

Federico, G., & Brandimonte, M. A. (2019). Tool and object affordances: An ecological eye-tracking study. *Brain and Cognition*, *135*, 103582. https://doi.org/10.1016/j.bandc.2019.103582

Federico, G., Osiurak, F., Brandimonte, M. A., Salvatore, M., & Cavaliere, C. (2023). The visual encoding of graspable unfamiliar objects. *Psychological Research*, *87*(2), 452–461. https://doi.org/10.1007/s00426-022-01673-z

Fjørtoft, I., Löfman, O., & Halvorsen Thorén, K. (2010). Schoolyard physical activity in 14-year-old adolescents assessed by mobile GPS and heart rate monitoring analysed by GIS. *Scandinavian Journal of Public Health*, *38*(5 Suppl), 28–37. https://doi.org/10.1177/1403494810384909

Floridi, L. (2013). Technology's in-betweeness. *Philosophy & Technology*, *26*(2), 111–115. https://doi.org/10.1007/s13347-013-0106-y

Floridi, L. (2014). *The 4th revolution: How the infosphere is reshaping human reality* (1st ed.). Oxford University Press.

Foster, R. J., Hotchkiss, J., Buckley, J. G., & Elliott, D. B. (2014). Safety on stairs: Influence of a tread edge highlighter and its position. *Experimental Gerontology*, *55*, 152–158. https://doi.org/10.1016/j.exger.2014.04.009

Foster, R. J., Whitaker, D., Scally, A. J., Buckley, J. G., & Elliott, D. B. (2015). What you see is what you step: The horizontal-vertical illusion increases toe clearance in older adults during stair ascent. *Investigative Ophthalmology & Visual Science*, *56*(5), 2950–2957. https://doi.org/10.1167/iovs.14-16018

Franchak, J., & Adolph, K. (2014). Affordances as probabilistic functions: Implications for development, perception, and decisions for action. *Ecological Psychology: A Publication of the International Society for Ecological Psychology*, *26*(1-2), 109–124. https://doi.org/10.1080/10407413.2014.874923

Gallivan, J. P., Cavina-Pratesi, C., & Culham, J. C. (2009). Is that within reach? fMRI reveals that the human superior parieto-occipital cortex encodes objects reachable by the hand. *The Journal of Neuroscience: The Official Journal of the Society for Neuroscience*, *29*(14), 4381–4391. https://doi.org/10.1523/jneurosci.0377-09.2009

Galvao, A., & Sato, K. (2005, September 24–28). *Affordances in product architecture: Linking technical functions and users' tasks* [Paper presentation]. ASME 2005 17th International Conference on Design Theory and Methodology, Long Beach CA.

Gaver, W. W. (1991). *Technology affordances* [Paper presentation]. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, New Orleans, Louisiana, USA.

Gibson, J. J. (1979). *The ecological approach to visual perception*. Houghton Mifflin.

Gibson, J. J. (1983). *The senses considered as perceptual systems*. Greenwood Press.

Heft, H. (1989). Affordances and the body: An intentional analysis of Gibson's ecological approach to visual perception. *Journal for the Theory of Social Behaviour*, *19*(1), 1–30. https://doi.org/10.1111/j.1468-5914.1989.tb00133.x

Heft, H. (2003). Affordances, dynamic experience, and the challenge of reification. *Ecological Psychology*, *15*(2), 149–180. https://doi.org/10.1207/S15326969ECO1502_4

Heft, H. (2021). Perceiving "natural" environments: an ecological perspective with reflections on the chapters. In A. R. Schutte, J. C. Torquati, & J. R. Stevens (Eds.), *Nature and psychology: biological, cognitive, developmental, and social pathways to well-being* (pp. 235–273). Springer International Publishing. https://doi.org/10.1007/978-3-030-69020-5_8

Hu, J., & Fadel, G. M. (2012). *Categorizing affordances for product design* [Paper presentation]. ASME 2012 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference.

Humphreys, G., Yoon, E. Y., Kumar, S., Lestou, V., Kitadono, K., Roberts, K. L., & Riddoch, M. J. (2010). The interaction of attention and action: From seeing action to acting on perception. *British Journal of Psychology (London, England: 1953)*, *101*(Pt 2), 185–206. https://doi.org/10.1348/000712609X458927

Hussein, H. (2012). The influence of sensory gardens on the behaviour of children with special educational needs. *Procedia - Social and Behavioral Sciences*, *38*, 343–354. https://doi.org/10.1016/j.sbspro.2012.03.356

Kahneman, D. (2013). *Thinking, fast and slow* (1st pbk. ed.). Farrar, Straus and Giroux.

Kaptelinin, V., & Nardi, B. (2012). *Affordances in HCI: Toward a mediated action perspective* [Paper presentation]. Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Austin, Texas, USA. https://doi.org/10.1145/2207676.2208541

Kaptelinin, V., Nardi, B. A., & Foot, K. A. (2006). *Acting with technology: Activity theory and interaction design*. MIT Press. http://ebookcentral.proquest.com/lib/delft/detail.action?docID=3338521

Kelty-Stephen, D. G. (2024). Scaling up: Lawfulness of affordances requires independence from any single "scale of behavior. In M. Mangalam, A. Hajnal, & D. G. Kelty-Stephen (Eds.), *The modern legacy of Gibson's affordances for the sciences of organisms* (pp. 176–195). Routledge. https://doi.org/10.4324/9781003396536-13

Kiverstein, J. D. (2024). The sociomaterial theory of affordances. In M. Mangalam, A. Hajnal, & D. G. Kelty-Stephen (Eds.), *The modern legacy of Gibson's affordances for the sciences of organisms* (pp. 26–41). Routledge. https://doi.org/10.4324/9781003396536-4

Klenk, M. (2021). How do technological artefacts embody moral values? *Philosophy & Technology*, *34*(3), 525–544. https://doi.org/10.1007/s13347-020-00401-y

Koutamanis, A. (2001). Prolegomena to the recognition of floor plan sketches: A typology of architectural and graphic primitives in freehand representation. In H. H. Achten, J. Dijkstra, J. P. Leeuwen (Eds.), *Design research in the Netherlands 2000* (pp. 99–103). TU Eindhoven.

Koutamanis, A. (2006). Buildings and affordances. In J. S. Gero (Ed.), *Design cognition and computation'06* (pp. 345–364). Springer Netherlands.

Koutamanis, A. (2007). Fuzzy modelling for early architectural design. *International Journal of Architectural Computing*, *5*(4), 589–610. https://doi.org/10.1260/147807707783600816

Koutamanis, A. (2020). Building information modeling for construction and demolition waste minimization. In F. Pacheco-Torgal, Y. Ding, F. Colangelo, R. Tuladhar, & A. Koutamanis (Eds.), *Advances in construction and demolition waste recycling* (pp. 101–120). Woodhead Publishing.

Koutamanis, A. (2023). Technologies, inbetweenness and affordances. *Global Philosophy*, *33*(1), 5. https://doi.org/10.1007/s10516-023-09668-0

Koutamanis, A. (2024a). From building information modelling to digital twins: Digital representation for a circular economy. In C. De Wolf, S. Çetin, & N. M. P. Bocken (Eds.), *A circular built environment in the digital age* (pp. 3–20). Springer International Publishing. https://doi.org/10.1007/978-3-031-39675-5_1

Koutamanis, A. (2024b). Stair design and user interaction. *Architecture*, *4*(3), 692–716. https://www.mdpi.com/2673-8945/4/3/36 https://doi.org/10.3390/architecture4030036

Koutamanis, A., Dainty, A., Kvan, T., & Turk, Ž. (2023). The enigma of BIM. *Architecture, Structures and Construction*, *3*(1), 1–9. https://doi.org/10.1007/s44150-021-00017-6

Koutstaal, W., & Binks, J. T. (2015). *Innovating minds: Rethinking creativity to inspire change*. Oxford University Press.

Krüger, N., Geib, C., Piater, J., Petrick, R., Steedman, M., Wörgötter, F., Ude, A., Asfour, T., Kraft, D., Omrčen, D., Agostini, A., & Dillmann, R. (2011). Object–action complexes: Grounded abstractions of sensory–motor processes. *Robotics and Autonomous Systems*, *59*(10), 740–757. https://doi.org/10.1016/j.robot.2011.05.009

Kuutti, K. (1996). Activity theory as a potential framework for human computer interaction research. In B. Nardi (Ed.), *Context and consciousness: Activity theory and human-computer interaction* (pp. 17–44). MIT Press.

Kyttä, M. (2002). Affordances of children's environments in the context of cities, small towns, suburbs and rural villages in Finland and Belarus. *Journal of Environmental Psychology*, *22*(1-2), 109–123. https://doi.org/10.1006/jevp.2001.0249

Kyttä, M. (2004). The extent of children's independent mobility and the number of actualized affordances as criteria for child-friendly environments. *Journal of Environmental Psychology*, *24*(2), 179–198. https://doi.org/10.1016/S0272-4944(03)00073-2

Leont'ev, A. N. (1981). *Problems of the development of the mind*. Progress.

Lippman, P. C., & Matthews, E. (2020). Affordance theory in relationship to the learning environment. In M. A. Peters & R. Heraud (Eds.), *Encyclopedia of educational innovation* (pp. 1–6). Springer Singapore. https://doi.org/10.1007/978-981-13-2262-4_190-1

Lynn van der Schaaf, A., Jeschke, A. M., Caljouw, S. R., & Withagen, R. (2021). The degree to which traditional play equipment, parkour play elements, and Aldo van Eyck's play sculptures have an open function. *European Early Childhood Education Research Journal*, *29*(2), 293–302. https://doi.org/10.1080/1350293X.2021.1895268

Maier, J. R. A., & Fadel, G. M. (2009a). Affordance-based design methods for innovative design, redesign and reverse engineering. *Research in Engineering Design*, *20*(4), 225–239. https://doi.org/10.1007/s00163-009-0064-7

Maier, J. R. A., & Fadel, G. M. (2009b). Affordance based design: A relational theory for design. *Research in Engineering Design*, *20*(1), 13–27. https://doi.org/10.1007/s00163-008-0060-3

Maier, J. R. A., Fadel, G. M., & Battisto, D. G. (2009). An affordance-based approach to architectural theory, design, and practice. *Design Studies*, *30*(4), 393–414. https://doi.org/10.1016/j.destud.2009.01.002

Moldovan, B., Moreno, P., Nitti, D., Santos-Victor, J., & De Raedt, L. (2018). Relational affordances for multiple-object manipulation. *Autonomous Robots*, *42*(1), 19–44. https://doi.org/10.1007/s10514-017-9637-x

Moldovan, B., Moreno, P., van Otterlo, M., Santos-Victor, J., & De Raedt, L. (2012). *Learning relational affordance models for robots in multi-object manipulation tasks* [Paper presentation]. 2012 IEEE International Conference on Robotics and Automation, 14-18 May 2012.

Norman, D. A. (1999). Affordance, conventions, and design. *Interactions*, *6*(3), 38–43. https://doi.org/10.1145/301153.301168

Norman, D. A. (2013). *Design of everyday things (revised and expanded ed.).* Basic Books.

Norman, J. (2002). Two visual systems and two theories of perception: An attempt to reconcile the constructivist and ecological approaches. *The Behavioral and Brain Sciences*, *25*(1), 73–96. https://doi.org/10.1017/S0140525X0200002X

Osiurak, F., Rossetti, Y., & Badets, A. (2017). What is an affordance? 40 years later. *Neuroscience and Biobehavioral Reviews*, *77*, 403–417. https://doi.org/10.1016/j.neubiorev.2017.04.014

Peña, W. M., & Parshall, S. A. (2012). *Problem seeking: An architectural programming primer* (5th ed.). Wiley.

Pols, A. J. K. (2012). Characterising affordances: The descriptions-of-affordances-model. *Design Studies*, *33*(2), 113–125. https://doi.org/10.1016/j.destud.2011.07.007

Pols, A. J. K. (2015). Affordances and use plans: An analysis of two alternatives to function-based design. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, *29*(3), 239–247. https://doi.org/10.1017/S0890060415000268

Ramstead, M. J. D., Veissière, S. P. L., & Kirmayer, L. J. (2016). Cultural affordances: Scaffolding local worlds through shared intentionality and regimes of attention. *Frontiers in Psychology*, *7*, 1090. https://doi.org/10.3389/fpsyg.2016.01090

Raveendranath, B., Rosopa, E., & C. C. Pagano. (2024). "I got all i need to know about affordances from Norman". What engineers, designers, and architects need to know about affordances. In M. Mangalam, A. Hajnal, & D. G. Kelty-Stephen (Eds.), *The modern legacy of Gibson's affordances for the sciences of organisms* (pp. 328–347). Routledge. https://doi.org/10.4324/9781003396536-22

Raymond, C. M., Kyttä, M., & Stedman, R. (2017). Sense of place, fast and slow: The potential contributions of affordance theory to sense of place [conceptual analysis]. *Frontiers in Psychology*, *8*, 1674. https://doi.org/10.3389/fpsyg.2017.01674

Rietveld, E., & Brouwers, A. A. (2017). Optimal grip on affordances in architectural design practices: An ethnography. *Phenomenology and the Cognitive Sciences*, *16*(3), 545–564. https://doi.org/10.1007/s11097-016-9475-x

Rietveld, E., & Kiverstein, J. (2014). A rich landscape of affordances. *Ecological Psychology*, *26*(4), 325–352. https://doi.org/10.1080/10407413.2014.958035

Scarantino, A. (2003). Affordances explained. *Philosophy of Science*, *70*(5), 949–961. https://doi.org/10.1086/377380

Shaw, R. E., Turvey, M. T., & Mace, W. M. (1982). Ecological psychology. The consequence of a commitment to realism. In W. Weimer & D. Palermo (Eds.), *Cognition and the symbolic processes* (Vol. 2, pp. 159–226). Lawrence Erlbaum Associates.

Shepard, R. N., & Cooper, L. A. (1982). *Mental images and their transformations*. MIT Press.

Simon, H. A. (1996). *The sciences of the artificial* (3rd ed.) MIT Press.

Stanovich, K. E. (2011). *Rationality and the reflective mind*. Oxford University Press.

St-Jean, P., Clark, O. G., & Jemtrud, M. (2022). A review of the effects of architectural stimuli on human psychology and physiology. *Building and Environment*, *219*, 109182. https://doi.org/10.1016/j.buildenv.2022.109182

Stoffregen, T. A. (2003). Affordances as properties of the animal-environment system. *Ecological Psychology*, *15*(2), 115–134. https://doi.org/10.1207/S15326969ECO1502_2

Stoffregen, T. A., & Mantel, B. (2015). Exploratory movement and affordances in design. *Artificial Intelligence for Engineering Design, Analysis and Manufacturing*, *29*(3), 257–265. https://doi.org/10.1017/S0890060415000190

Stoytchev, A. (2008). Learning the affordances of tools using a behavior-grounded approach. In E. Rome, J. Hertzberg, & G. Dorffner (Eds.), *Towards affordance-based robot control*. Springer Berlin Heidelberg.

Sun, Y., Ren, S., & Lin, Y. (2014). Object–object interaction affordance learning. *Robotics and Autonomous Systems*, *62*(4), 487–496. https://doi.org/10.1016/j.robot.2013.12.005

Templer, J. A. (1992). *The staircase: Studies of hazards, falls, and safer design*. MIT Press.

Thill, S., Caligiore, D., Borghi, A. M., Ziemke, T., & Baldassarre, G. (2013). Theories and computational models of affordance and mirror systems: An integrative review. *Neuroscience and Biobehavioral Reviews*, *37*(3), 491–521. https://doi.org/10.1016/j.neubiorev.2013.01.012

Tollon, F. (2022). Artifacts and affordances: From designed properties to possibilities for action. *AI & Society*, *37*(1), 239–248. https://doi.org/10.1007/s00146-021-01155-7

Turvey, M. T. (1992). Affordances and prospective control: An outline of the ontology. *Ecological Psychology*, *4*(3), 173–187. https://doi.org/10.1207/s15326969eco0403_3

Tweed, C. (2001). Highlighting the affordances of designs. In B. de Vries, J. van Leeuwen, & H. Achten (Eds.), *Computer aided architectural design futures 2001* (pp. 681–696). Kluwer.

Vallacher, R. R., & Wegner, D. M. (2012). Action Identification Theory. In P. A. Van Lange, A. W. Kruglanski, & E. T. Higgins (Eds.), *Handbook of theories of social psychology: Volume 1* (pp. 327–348). SAGE Publications Ltd. https://doi.org/10.4135/9781446249215

van Dijk, L. (2021a). Affordances in a multispecies entanglement. *Ecological Psychology*, *33*(2), 73–89. https://doi.org/10.1080/10407413.2021.1885978

van Dijk, L. (2021b). Psychology in an indeterminate world. *Perspectives on Psychological Science: A Journal of the Association for Psychological Science*, *16*(3), 577–589. https://doi.org/10.1177/1745691620958005

van Dijk, L., & Rietveld, E. (2021). Situated anticipation. *Synthese*, *198*(1), 349–371. https://doi.org/10.1007/s11229-018-02013-8

van Dijk, L., & Rietveld, E. (2025). Situated imagination. *Phenomenology and the Cognitive Sciences*, *24*(2), 455–477. https://doi.org/10.1007/s11097-020-09701-2

Warren, W. H. (1984). Perceiving affordances: Visual guidance of stair climbing. *Journal of Experimental Psychology. Human Perception and Performance*, *10*(5), 683–703. https://doi.org/10.1037/0096-1523.10.5.683

Waters, D. (2021). *Behavior and culture in one dimension*. Routledge. https://doi.org/10.4324/9781003148210

Weisberg, R. (2010). The study of creativity: From genius to cognitive science. *International Journal of Cultural Policy*, *16*(3), 235–253. https://doi.org/10.1080/10286630903111639

Weisberg, R., Pichot, N., Bonetto, E., Pavani, J.-B., Arciszewski, T., & Bonnardel, N. (2021). From explicit to implicit theories of creativity and back: The relevance of naive criteria in defining creativity. *The Journal of Creative Behavior*, *55*(3), 839–856. https://doi.org/10.1002/jocb.492

Wilkinson, T., & Chemero, A. (2024). Why it matters that affordances are relations. In M. Mangalam, A. Hajnal, & D. G. Kelty-Stephen (Eds.), *The modern legacy of Gibson's affordances for the sciences of organisms* (pp. 12–25). Routledge. https://doi.org/10.4324/9781003396536-3

Withagen, R. (2023). The field of invitations. *Ecological Psychology*, *35*(3), 102–115. https://doi.org/10.1080/10407413.2023.2230192

Withagen, R., & Caljouw, S. R. (2017). Aldo van Eyck's playgrounds: aesthetics, affordances, and creativity. *Frontiers in Psychology*, *8*, 1130. https://doi.org/10.3389/fpsyg.2017.01130

Withagen, R., & Costall, A. (2022). What does the concept of affordances afford? *Adaptive Behavior*, *30*(6), 505–507. https://doi.org/10.1177/1059712320982683

Young, F., Cleveland, B., & Imms, W. (2020). The affordances of innovative learning environments for deep learning: Educators' and architects' perceptions. *The Australian Educational Researcher*, *47*(4), 693–720. https://doi.org/10.1007/s13384-019-00354-y