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Human interaction with the physical world: a brief review of studies on affordances

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Abstract

Gibson used "affordance" to describe how animals perceive and interact with their environment. Since the term was coined, many studies, both theoretical as well as empirical, have been done. We conducted a review of the 56 most cited works on physical affordances to answer: (1) What methods have been used to study affordances, and how have they changed with time? (2) How has the definition of affordances evolved over time? We went through papers decade-wise and compare their key contributions. Finally, we discuss how the definition and research on affordances has evolved in the last 40 years.

Keywords: affordance, user-centred design, research methodologies and methods

1. Introduction and gap

The concept of affordance originated in the domain of ecological psychology in the context of animal-environment interaction. *"The affordances of the environment are what it offers the animal, what it provides or furnishes, either for good or ill,"* says Gibson. For instance, a flat surface affords locomotion to humans, whereas a water surface affords locomotion to certain species of spiders. Although Gibson briefly discussed the affordances of the man-made world, it is Norman who used the term affordance to convey what a product offers to a user (Norman, 1988). The affordance of a product refers to the action possibilities on it. A switch affords the action of being pressed, just like a chair affords the action of sitting, or a ladder affords the action of climbing. Well-designed objects should convey information to users about how to interact with them, says Norman (Norman, 2013).

Since its inception, the term affordance has taken several meanings and roles. The term has been borrowed by the domains of Information Sciences, Information Technology, Robotics, Virtual Reality, Social Media, Artificial Intelligence, and several others to mean what a physical or a digital artefact offers to a human or an agent. As affordance has taken a broad meaning over time, specific terms are now used to define specific types of affordances. One such classification is by Hartson, who says that affordances in design may lie in one of the four categories (Hartson, 2003): cognitive affordances, physical affordances, sensory affordances, and functional affordances. In this work, we are interested in the physical and cognitive affordances (also known as perceived affordances) of physical artefacts.

Through this paper, we review the literature on affordances to answer the following questions:

1. What research methods have been used to study affordances in the context of human interaction with physical artefacts, and how have they changed with time?
2. How has the definition of affordances evolved over time in the context of human interaction with physical artefacts?

The research on affordances has spanned across domains, and researchers have used a variety of research designs and research methods to study the affordances of objects or environments. Through this paper,

we collate this data from different domains. Further, as affordance in design has to do with the artificial world, the research and meaning of affordance changes as the artificial world changes. Researchers have been studying the affordances of newer physical products and environments. Through this review, we will provide a brief summary of how the research on and the meaning of affordance has changed with time since its introduction more than 40 years back.

To the best of our knowledge, and counterintuitively, nobody has systematically reviewed the literature on affordances of physical artefacts. To justify this gap, we first searched for existing review papers on affordances using a search query of the type: TITLE (("review" OR "reviewing") AND ("affordance" OR "affordances")). We scanned through articles on Google Scholar, Scopus, and ACM Digital Library. The three platforms gave a combined search result of 180 out of which 6 were review papers on affordances of objects or environments. Out of the 6 review papers, 5 were reviews on affordances of specific objects (for example, mirror) or specific environments (for example, environmental affordances for play) and 1 was on affordance-based design to address usability. Hence, we could not find any prior work that reviewed the meaning of and the research on affordances of physical artefacts.

2. Shortlisting method

By now, the word *affordance* has assumed many meanings. In certain contexts, it might refer to a specific action an object offers to an individual. For example, a branch *affords* the action of perching on by a bird. In others, the term may imply allowance, the opposite of constraint. Thus, it is common to find phrases such as “Affordances and constraints of…”. Usage of the term *affordance* to mean general things such as allowance leads to difficulty in using the term to find relevant search results.

Searching for the query of the sort (“Affordance” OR “Affordances”) in the title of the paper gives us 11,600+ results on Google Scholar, 4276 on Scopus, and 200 on ACM DL. Since it was not possible for us to go through 16,000+ articles on affordances, we decided to shortlist further. One way to shortlist is to look for articles in selected journals or conferences. However, we could not find any venue dedicated to publishing work on affordance or a closely related field. Another way is to use a combination of two or more keywords in the search query. Searching for papers having the words "affordance" and "tangible" in the title yields only 6 results in Google Scholar indicating that an addition of a keyword is not a feasible method to shortlist papers (addition of one keyword reduces the result from 11,600+ to a mere 6). The works on affordance span across domains, and it is difficult to find a second common term that binds all of these works together.

As our aim was to understand how the meaning and the research on affordances has changed with time, we decided to select the most influential works of each decade. In doing so, we moved away from the conventional methods used to carry out literature reviews such as PRISMA, Chiarello NLP, clustering, and so on, because they were not well suited to answer the research questions we aimed for. We chose Scopus as our search platform as it has more powerful features for searching, filtering and sorting papers than Google Scholar. On Scopus, we used the search query: TITLE ("Affordance" OR "Affordances"), filtered the articles decade-wise, sorted them from highest to lowest citation count, and went on shortlisting using our inclusion/ exclusion criteria until we had found 14 papers for each decade. In total, we selected 56 articles for reviewing. These articles are by no means an exhaustive list. Selecting articles according to their citation counts may not be the best method, but, as already stated, our focus was on investigating how the definition and research on affordances has changed over time rather than analysing all the work that has happened. Fig 1 illustrates the shortlisting method. Once the papers were shortlisted, they were categorised as either - (i) studies on affordance, or (ii) theoretical contribution to affordances.

2.1. Inclusion criteria:

An article was included for review if it satisfied any one of the following criteria:

- The work is a study or experiment on physical affordances or perceived physical affordances of objects or environments.
- The work is a theoretical contribution to affordance in the context of human interaction with physical objects or environments.

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2.2. Exclusion criteria:

An article was excluded if any one of the following was true:

- The work is on social or cultural affordances rather than physical or perceived affordances.
- The work studies affordances of Information Systems (IS), Information Technology (IT), Robotics, Social Media, Virtual Reality, and so on. [Note: Some researchers have studied the physical affordances of objects using virtual or immersive reality. We have included such papers as they are not on studying the affordances *of* virtual reality but the affordances of objects *in* virtual reality.]
- The work proposes how the affordance theory can be applied to a vastly different field or context.
- The study is on the processes occurring in the brain when a human encounters an object.
- The work studies affordance in the context of human interaction with other humans or animals.

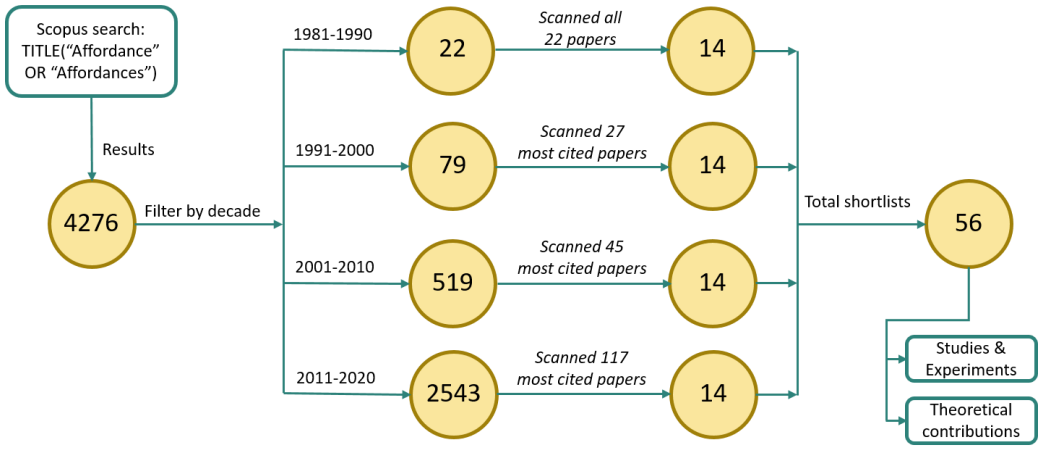

Figure 1. Shortlisting method for selection of papers to review

3. Findings

3.1. Methods employed to study physical affordances of objects/environments

This subsection describes the studies and experiments on physical affordances of objects or environments. Based on the research method around which the study was designed, we have put the shortlisted works into seven categories. These categories are not mutually exclusive, and a work may fall into one or more categories.

3.1.1. Body-scaled metric

"An affordance" says J. J. Gibson *"cannot be measured as we measure in physics."* It has to *"be measured relative to the animal."* (Gibson, 1979) Shortly after Gibson's work was published, researchers started conducting experiments to know if there existed a link between body size and visual preference/ physiological performance. One such famous experiment is Warren's study on staircase climbing (Warren, 1984). He found that when the riser height was about a quarter of the leg length, the energy expenditure to climb a given height was the least. Also, at about a fourth of a participant's leg length, it was perceived to be most climbable by the participant. Thus, at a constant ratio of the leg length – or at around 0.25 of the leg length – a staircase is both visually perceived to be most climbable as well as energetically most optimal to climb. This was true for both tall and short participants. Thus, Warren's study showed that an observer's perceptual judgement was aligned to their actual capabilities, and both could be expressed as a body-scaled metric. After Warren, many researchers have studied affordance by conducting an experiment focused on intrinsic measurements or body-scaled ratios rather than extrinsic measurements or metric units of measurement. For example, (Warren Jr. and Whang, 1987), (Mark, 1987), (Mark et al., 1990), (Konczak et al., 1992), (Stoffregen et al., 1999), (Wraga, 1999).

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3.1.2. Reaction time (RT)

Michaels was interested in knowing if *"Affordances might manifest themselves in the speed at which a response is made"* (Michaels, 1988). To test this, she designed an experiment to study affordance using choice reaction times (also known as choice RTs). In her experiment, participants make a choice between two options based on a rule. Participants have a natural tendency to choose one option over the other based on their intuition. If the rule points to the same option (as a participant would naturally prefer based on their intuition), the reaction times are faster. Else, they are slower. Although Michaels' experiment did not use affordance in its truest sense, her experiment proposed the idea of using RTs to study affordances. Taking the idea forward, Ellis and Tucker's studied the affordances of objects that are gripped (Ellis and Tucker, 2000). Participants are shown objects that elicit the action of gripping (precision grip) or grasping (power grip). Along with the object, they hear a low-pitched or a high-pitched tone sound. The tone dictates the action the participants perform (gripping vs grasping) on a separate instrument they have. As expected, reaction times were faster when there was a compatibility between the affordances of an object shown and the actions performed. In our shortlists, (Tipper et al., 2006) and (Costantini et al., 2010, 2011) also use choice RTs to study affordances.

3.1.3. Haptic perception

Visual perception has been the dominant way to study affordances. However, some researchers have tried to study affordances via haptic perceptual systems. For instance, Fitzpatrick et al. (Fitzpatrick et al., 1994) conducted a study to compare the visual perceptual system with the haptic perceptual system. In their study, the participants had to judge - either visually or blindfolded and with the help of a dowel - if a slanted path could support an upright posture. Although slower, haptic exploration was nearly as accurate and reliable as visual perceptual systems. Turvey and his team used haptic systems to study the physical perception of heaviness (Turvey et al., 1999). Some studies on young children and infants too (mentioned in 3.1.4), have used tactual exploration to study affordances.

3.1.4. Studies on infants and young children

Many well-cited studies on affordances have been conducted on infants or very young children. Such works have been put into a separate category as the study design and the data collection methodology is vastly different from those of other studies. While most other studies rely on data from verbal responses or protocol-based actions, studies on young children use data from their gaze times or their natural actions to make conclusions about what a child might have perceived. The children are often encouraged to (or sometimes, made to) interact with an object they are presented with. In the shortlisted works, the children explore the affordances of an object tactually (Caron et al., 1988; Gibson and Walker, 1984), or through actions such as climbing a surface (Adolph et al., 1993) or reaching out for an object (Yonas and Hartman, 1993), or by trying to use an object as a tool (van Leeuwen et al., 1994).

3.1.5. Other quantitative studies

This category includes studies which use quantitative data to make conclusions about affordances and which do not lie in any of the categories described above. The quantitative data consists of measurements made during an action in the form of, for example, timestamps or data collected from the sensors. Oudejans and his team studied the role of running in perceiving whether or not a ball was catchable (Oudejans et al., 1996). The study revealed that running towards a ball resulted in better judgement than being stationary perceivers, whether one was an expert outfielder or a non-expert. The work by Plumert et al. (Plumert et al., 2004) is on the affordances of a gap while cycling through cities. Timestamps of actions are used to study how children and adults use temporal gaps for crossing. (Sartori et al., 2011) studied how objects are grasped in different conditions by tracking the kinematics of the hand used for grasping.

3.1.6. Qualitative studies

Most of the above studies on affordances are conducted in strict experimental setups where participants perform pre-decided actions. (Kyttä, 2004) and (Sandseter, 2009) chose to investigate the affordances

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of neighbourhoods and preschool playgrounds respectively through interviews, video recordings, field notes, and observation. Qualitative data collection methods in both these cases allowed the researchers to capture actual data on how humans interact with the environment around them. While Kyttä uses the data of eight neighbourhoods to compare the affordances between them, Sandseter discusses the affordances of two preschool playgrounds and the situations of risky play in both of them.

Table 1. Categorisation of studies on physical affordances of objects and environments

Methods \ Paper		(Warren, 1984)	(Gibson and Walker, 1984)	(Warren Jr. and Whang, 1987)	(Mark, 1987)	(Michaels, 1988)	(Caron et al., 1988)	(Mark et al., 1990)	(Konczak et al., 1992)	(Adolph et al., 1993)	(Yonas and Hartman, 1993)	(Fitzpatrick et al., 1994)	(van Leeuwen et al., 1994)	(Oudejans et al., 1996)	(Stoffregen et al., 1999)	(Wraga, 1999)	(Turvey et al., 1999)	(Ellis and Tucker, 2000)	(Kyttä, 2004)	(Plumert et al., 2004)	(Tipper et al., 2006)	(Sandseter, 2009)	(Costantini et al., 2010)	(Costantini et al., 2011)	(Sartori et al., 2011)	(Follmer et al., 2013)	(Lopes et al., 2015)
Quantitative studies	Body-scaled metric	X		X	X			X	X						X	X											
	Reaction time					X												X			X		X	X			
	Haptics											X					X										
	Infants & children		X				X			X	X		X														
	Quantitative (other)													X						X					X		
Qualitative studies																			X			X					
Novel products																										X	X

3.1.7. Affordances of novel products

Instead of studying the affordances of familiar environments or objects (playgrounds, neighbourhoods, staircases, seats, handles, and so on), some researchers have prototyped novel objects and investigated their affordances. For instance, Lopes and his team study affordances of a wearable device that guides a user towards performing specific actions with given objects (Lopes et al., 2015). The researchers reason that not all actions can be communicated by an object. Hence a wearable device may communicate to a user, using electrical muscle stimulation, the actions to be taken. Follmer et al.'s work is on the affordances of shape-changing interfaces (Follmer et al., 2013). The shape-changing interface can assume several forms such that the interface acts as (or provides affordances of) a button, or ramp, or handle, or slot, and so on. The two studies meet our inclusion/ exclusion criteria, however, both studies are focused on the capabilities of technology rather than the human-interaction part.

3.2. How have the research methods used to study physical affordances changed with time?

Table 1 lists the categorisation of studies on physical affordances of objects and environments. As we can see, quantitative methods have been predominantly used to study affordances. In the years following the publication of Gibson's book *The Ecological Approach to Visual Perception* (Gibson, 1979), researchers were interested in finding empirical evidence to test the ideas proposed by Gibson. The studies on body-scaled measurements confirm Gibson's theories: that body size affects actual capabilities, and that by looking at the objects around us, we can perceive the actions and the action boundaries they afford. Early on, many researchers also took an interest in studying whether infants and young children could perceive the affordances of objects they were given. All studies on very young children are also quantitative - in the absence of possibility to talk to infants, the researchers have no choice but to rely on measurable actions performed by infants. A third kind of quantitative study used to measure affordances has been choice reaction times. The study method takes advantage of the

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intuitive response an object evokes. Choice RT as a study method was proposed in 1988, but has remained popular in recent times as well (as opposed to body-scaled metric, which has gradually faded away). A few studies, spread across the last three decades, have relied on haptic exploration or other quantitative methods to measure affordances. Using qualitative data to measure affordances is relatively new. Our shortlisted studies that used qualitative methods worked with real-world data rather than strictly controlled and lab-based ones, thus giving richer insights about affordances of the artefact studied. Our last two shortlisted studies are neither quantitative nor qualitative - their contribution is a novel prototype and/or novel interactions with the prototype. They reflect the interest of the research community in studying affordances of products embodying newer technologies.

3.3. How has the definition of affordances evolved over time in the context of human interaction with physical artefacts?

To answer this question, we look at the research papers that with theoretical contributions. Table 2 lists the shortlisted papers. As categorising theoretical works is not easy and straightforward, we will describe the shortlisted works decade-wise.

3.3.1. 1981-1990

In the decade following the publication of *The Ecological Approach to Visual Perception*, researchers either add to Gibson's ideas or compare them with existing theories about how animals perceive their world. Harry Heft, in his paper *Affordances and the Body* (HEFT, 1989) builds upon Gibson's theory of affordances (Gibson, 1979) by bringing attention to two points - the role of intention in perceiving affordances, and the sociocultural nature of affordances in the human world. Chow views Heft's and Gibson's work in the light of another prevailing viewpoint of the time - information processing approach to object perception, and challenges Heft's ideas (CHOW, 1989). Heft replies back (HEFT, 1990) pointing out that Chow's analysis results *"from a tendency to impose on the position a theoretical framework that is antithetical to its essential structure."* The role of goals in carrying out an activity is proposed independently by Riccio, at around the same time. (Riccio and Stoffregen, 1988).

Jones et al, in their work *Categorisation and affordances* (Jones and Pick, 1981) propose that Gibson's theory of affordances can benefit from Ghiselin's theory on *categories, life and thinking* (Ghiselin, 1981). All objects that offer similar affordances may fall into the same cognitive category. Although the paper proposes a new idea, it is not clear where the idea could be applied. McCabe, too, tries to extend Gibson's ideas (McCabe, 1982). He defines two terms: structural invariant and transformational invariant, and the paper is about how the invariants offer affordances that allow animals to interact with other individuals of the same or a different species.

Loveland's work is on affordances of a reflecting surface (Loveland, 1986). Loveland provides a theoretical reasoning behind how children and animals learn to discover affordances of a mirror.

3.3.2. 1991-2000

In this decade, some researchers view Gibson's work in light of selected theories or paradigms. While Turvey discusses the ontology of affordances and provides a formal definition of affordances (Turvey, 1992), Greeno applies situation theory to Gibson's affordances (Greeno, 1994).

Some researchers interpret Gibson's work, and in the process, they extend his work. For example, Eleanor Gibson (Gibson, 2000) and Costall (Costall, 1995). Eleanor Gibson's paper answers two questions - what do animals perceive, and where does the information exist for what animals perceive. She says that animals perceive their world, and the information lies in the events *"that include the relevant environmental features, the activity of the organism, and the consequences that ensue as well as the relations among these."* Thus, she concludes, one must study events to study affordances. Costall states that Gibsonian theories bridge the gap between the material world and the world of 'agents' (Costall, 1995). However, Gibson fails to acknowledge the social or cultural element in his work. Costall discusses the underlying social-cultural nature of Gibson's theory and argues that socio-cultural nature of things is real and failure to acknowledge it would be a failure to recognise the difference they make.

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Table 2. Shortlisted works that contain a theoretical contribution on affordance in the context of human interaction with physical object or environment

Sl	Decade	Shortlisted works having a theoretical contribution
1	1981-1990	(Jones and Pick, 1981) (McCabe, 1982) (Loveland, 1986) (Riccio and Stoffregen, 1988) (HEFT, 1989) (CHOW, 1989) (HEFT, 1990)
2	1991-2000	(Turvey, 1992) (Greeno, 1994) (Costall, 1995) (Gibson, 2000)
3	2001-2010	(Chemero, 2003) (Stoffregen, 2003) (Scarantino, 2003) (Michaels, 2003) (Fajen, 2007) (Fajen et al., 2009) (Maier and Fadel, 2009) (Osiurak et al., 2010) (Bloomfield et al., 2010)
4	2011-2020	(Withagen et al., 2012) (Costall, 2012) (Rietveld and Kiverstein, 2014) (Zhu et al., 2014) (Fayard and Weeks, 2014) (Pezzulo and Cisek, 2016) (Davis and Chouinard, 2016) (Osiurak and Badets, 2016) (van Dijk and Rietveld, 2017) (Osiurak et al., 2017)

3.3.3. 2001-2010

By 2000, many researches have either interpreted or built upon or challenged the original theory of affordances. They have explained when and where does affordance come into play. They've viewed the theory of affordances through different lenses. Consequently, a lot of researchers in this decade try to summarise the previous viewpoints while also discussing their strengths and limitations, and propose their own definition or approaches about affordances. These researchers are: (Chemero, 2003), (Fajen et al., 2009), (Scarantino, 2003), (Fajen, 2007), and (Michaels, 2003). Chemero (Chemero, 2003) and Fajen (Fajen et al., 2009) summarise the post-Gibson definitions on affordances, point out a few problems in those definitions, and proposes a new definition. According to Chemero, "affordances are relations between animals and features of situations," while as per Fajen, "affordances are properties of the animal–environment system, and they exist only at the level of the animal–environment system." Scarantino (Scarantino, 2003) discusses Gibson's theory of perception and the controversial claims of the Gibsonian movement. He argues that affordances are dispositional properties. Fajen (Fajen, 2007) compares two main approaches to explain visually guided action - model-based approach, and information-based approach. Since both approaches have limitations, Fajen introduces a new approach, affordance-based control. Michaels (Michaels, 2003) discusses four points about affordance theory that are often discussed and debated: do affordances have to be perceived to exist, are affordances dependent on actions, relation between affordance and animal effectiveness, and nesting of affordances. She then proposes a tentative definition of affordances and her opinions on the four points of debate.

Some researchers discuss the theory of affordances with respect to technology or design. The paper by Bloomfield et al. (Bloomfield et al., 2010) is on how the concept of affordances applies and does not apply to technological objects. While doing so, the authors comment on the relationship between technological artefacts and humans. Maier and Fadel (Maier and Fadel, 2009) urge the design and engineering design community to bring out a change in design thinking by focussing on affordance-based approach rather than function-based approach for designing products. Osiurak et al. discuss affordance in case of human tool use (Osiurak et al., 2010) while Fajen et al's paper discusses affordances and control of action is sports (Fajen et al., 2009).

3.3.4. 2011-2020

Except for Osiurak et al's work (Osiurak et al., 2017), none of the papers in our shortlist summarize the previous viewpoints on affordances or propose their own definition. Most researchers in this decade focus on only a few aspects of affordance, and they do not look for a general definition that addresses the limitations of the previous definitions. Withagen et al argue that product affordances are not merely action possibilities but they invite behaviour (Withagen et al., 2012). Davis et al, writing four years later, make a similar point (Davis and Chouinard, 2016): affordances are non-binary and artefacts *"request, demand, allow, encourage, discourage, and refuse"*. Costall differentiates between affordances in general and affordances connected to artefacts; the latter, he terms as *Canonical affordances* (Costall, 2012). Osiurak compares manipulation-based approach and reasoning-based approach in explaining tool usage (Osiurak et al., 2017). Rietveld proposes extending the idea of affordances to a broader context, such as higher cognitive functions of language understanding and logical problem solving (Rietveld and

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Kiverstein, 2014). Fayard and Weeks discuss affordance for practice (Fayard and Weeks, 2014), while Zhu et al. use knowledge based representations to classify affordances (Zhu et al., 2014).

4. Conclusion

In this paper, we review the most cited articles on affordances published in the 40-year span between 1981 and 2020. We analysed the research methods, and we found that quantitative approaches for investigating affordances dominated in the initial years. Key among them was studying affordances through body-scaled metrics. Other popular quantitative approaches have been: choice Reaction Times, haptic perception, and studies on young children. However, in recent years, the research methods have diversified, and there has been an inclusion of qualitative approaches as well as studies on affordances of novel products. We also analysed how the definition of affordances has evolved with time. In the early years of affordance research, scholars compared Gibson's definition with the prevailing concepts and research paradigms, leading to the development of many theories that either built upon, complemented or challenged Gibson's views. Over time, researchers identified loopholes in Gibson's definition, and they came up with alternative theories and definitions on affordances. In recent years, there has been a shift in focus from debating on Gibson's definition to examining specific aspects of affordances, and considering the roles of objects and designers in the process.

We acknowledge that our work has a few drawbacks. Since it was not possible to summarise lengthy and well-built arguments, theories, and definitions in a few lines, we might not have done justice while summarising the theoretical contributions in our paper. Second, as we have already stated, selecting papers based on citation count may not have been an ideal method to select papers to review.

Although we reviewed only 56 papers, we hope our review gives the reader a broad overview of the literature on affordances.

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