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The impact of architecture on collective behaviour

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Despite the obvious influence of space on interactions, constraints imposed by the built environment are seldom considered when examining collective behaviours of animals and humans. We propose an interdisciplinary path towards uncovering the impact of architecture on collective outcomes.

Built structures, such as animal nests, serve two overarching purposes: shelter and providing a space where organisms interact. Shelter has dominated much of the discussion in the literature[1]. But, as the study of collective behaviour expands, it is time to elucidate the role of the built environment in shaping collective outcomes.

Collective behaviour in social animals emerges from interactions[2] and collective cognition in humans emerges from communication and coordination[3]. Despite the obvious influence of space on interactions, because spatial proximity is necessary for an interaction to occur, spatial constraints are rarely considered in studies of collective behaviour or collective cognition. An interdisciplinary exchange between behavioural ecologists, evolutionary biologists, cognitive scientists, social scientists, architects and engineers may facilitate a productive exchange of ideas, methods and theory that could lead us to uncover unifying principles as well as novel research approaches and questions in studies of animal and human collective behaviour. Research collaborations across disciplines allow us to study, for example, the impact of structures on the collective behaviour of animals in ways that can inspire architects to design spaces that facilitate collective movements, interactions, collaboration and innovation of humans. Further, with new technologies (for example, tracking tools), and analytic techniques (for example, network theory), an increased understanding of the effects of structural constraints on interactions and behaviour is now possible (Box 1). Here we suggest an integrated set of research questions made possible through interdisciplinary exchange coupled with recent technological advances.

Collective cognition and efficiency

Work on the impact of architecture on collective outcomes has already provided preliminary accounts of how structures influence the efficiency of collective behaviour in animals and collective cognition in humans. Biologists have found that the speed at which harvester ants recruit to a food source increases with the connectivity of nest chambers[4] and that obstructions near the nest exit of ants facilitate rapid evacuation when in distress[5]. Social scientists have found that the layout of buildings affects scientific collaborations and innovation[6]. Palaeontologists speculate that the development of complicated forms of architecture coincide with the emergence of complex social organizations[7]. Physicists have shown that architectural design can improve the efficiency with which pedestrian crowds move[8]. Despite conceptual similarities among these research communities, there has been little, if any, cross-disciplinary communication. Although the various organisms that occupy built structures differ physiologically, there are functional similarities that motivate our research. These similarities include the need to coordinate activities and collaborate. Conclusions from studies of such functions can be extended from one discipline to inform others.

Box 1 | Quantifying structures and spatial location of social interactions within them.

Although methods for quantifying structures are essential for examining how structures affect collective outcomes, we currently lack a diverse quantitative toolbox. Network representations have proven extremely useful for describing the arrangement of structures in studies of social insects[4,13] and humans[6,14]. However, further development of algorithms that translate structures into networks, and of relevant network measures, are still needed to expand this line of research. Furthermore, when chambers or rooms are difficult to define (for example, in an art gallery), networks may not be suitable. One possible solution is skeletonization[12], which reduces complex 3D structures to emphasize their geometrical and topological properties (Fig. 1). A glaring methodological gap is our inability to combine the quantification of both topology and volume of structures into a single variable. Measuring the volume of structures at different depths[15] may provide information on the amount of space that can be utilized, but it holds no information on structure topology. Likewise, an examination of network representations of structures holds no information on their volume. Finding ways to jointly quantify topology and volume is an interdisciplinary challenge that calls for cross-disciplinary collaborations to develop tools and formulas capable of testing the utility and generalizability of such approaches.

Once we quantify architectural features, we require methods for examining the movements and interactions of the occupants of these spaces. Specifically, there is a need for methods to quantify the relationship between movements and the resulting social interactions and various spatial constraints. The use of sensor technologies, such as tracking devices, provides ample spatial data that can be analysed in similar ways across systems. Advances in materials engineering to create devices that are capable of simultaneously capturing information transfer and movement patterns will allow for studies on both the form and content of information transfer across different spatial scales and in different species.

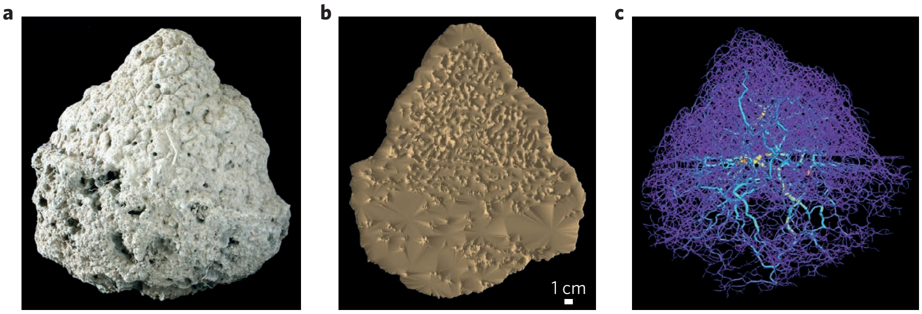

Figure 1 | An example of the skeletonization of a termite nest (*Trinervitermes geminatus*). **a**, A picture of the nest. **b**, A tomographical slice of the nest. **c**, The network of tunnels in the nest in which edges are coloured according to their betweenness centrality value. The technique used to extract this network is based on ref. [12].

Studies on the location of spaces that are used for communication in social insects (for example, the dancing floor in honeybee hives) may inform the positioning of features, such as shared break rooms, which are informal spaces that facilitate the spread of tacit knowledge, in human buildings. Studies of animal behaviour are highly amenable to experimental manipulations that are not feasible with human societies. Thus, testing and manipulating social structures and group interactions in social animals, may provide insights on the causative relationships between certain architectural features and collective outcomes that can then be used to improve the efficiency of human societies.

Information processing

When group members interact to produce collective outcomes there is information exchange and processing. Physical structures can serve an important functional role in this information processing. First, structures can help manage the volume and diffusion of information. Larger spaces afford greater amounts of information to be transmitted. However, being exposed to too much information simultaneously can be overwhelming and cause individuals to shut down and reduce interactions with their surroundings[9]. Thus, structures that segregate individuals (for example, chambers and tunnels), may reduce stimuli and help filter unnecessary information. Second, certain spatial cues, such as the chemical trails of social insects and road signs in human transportation networks, can aid in the interpretation and use of information. Such cues in the environment can help avoid information overload by externalizing knowledge that can then be used as a scaffold for further knowledge building. Despite the economic implications of such structures (furniture, signs, obstacles etc.) on work productivity in humans, there has been little quantitative research on how spatial layouts and physical artefacts can influence collective information processing. By manipulating signals and/or the physical environment to examine their impact on the collective actions of social animals, we can develop new, biologically inspired, means to improve information processing in humans.

Structure and behaviour feedback

Structures are not formed in a vacuum, there is intricate feedback between the architecture of a structure, its residents, and the external environment. Animals constantly renovate their structures, for example, to alter gas exchange dynamics[10] and respond to changes in colony size[11]. Thus, there is constant feedback between a structure and the needs of the individuals that reside in it. Engineers and architects of human structures use the physical attributes and age of construction materials and the amount of people that occupy a building to inform renovation plans. We argue that the social activities taking place in these structures may also shape them and should be considered when designing human structures. Currently, we know very little about how the functional needs of a group influence their built structures and changes to them over time. Testing the bi-directional relationship between built structures and collective behaviours in social animals can be as simple as examining the architecture of structures animals build when subjected to different environmental constraints to facilitate the most effective collective outcomes. Research on social animals can rapidly explore a wide array of environments and outcomes, thus expediting our improvement of human architectural designs.

Conclusions

Interdisciplinary work on architecture and collective behaviour may uncover new biomimicry concepts that will create synergies among biologists, social scientists, physicists, engineers, and architects. Uncovering general principles that describe the impact of architecture on collective behaviours has far reaching implications. Most basically, understanding the effect of structures on the collective behaviour of social animals may reveal important fitness consequences. Furthermore, the scientific understanding of how building architecture influences human interactions can be used to scaffold collaborations that drive innovation. But there is a greater opportunity for scientific advances when considering interdisciplinary research that enables studies across multiple species. Lessons from biology may help formalize the quantification of spaces and thus advance studies of current, historical and pre-historical human architectural features. Furthermore, interdisciplinary exchange has the capacity to enhance innovations that result from teamwork by learning from biological systems that have been selected by millions of years of evolution. By initiating a cross-disciplinary conversation we hope to inspire further research on the relationship between architecture and collective behaviour. ❐

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Competing interests

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