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# Analysis of how a complex systems perspective is applied in studies on socioeconomic inequalities in health and health behaviour—a call for reporting guidelines

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## Abstract

**Background** A complex systems perspective is gaining popularity in research on socioeconomic inequalities in health and health behaviour, though there may be a gap between its popularity and the way it is implemented. Building on our recent systematic scoping review, we aim to analyse the application of and reporting on complex systems methods in the literature on socioeconomic inequalities in health and health behaviour.

**Methods** Selected methods and results from the review are presented as a basis for in-depth critical reflection. A traffic light-based instrument was used to assess the extent to which eight key concepts of a complex systems perspective (e.g. feedback loops) were applied. Study characteristics related to the applied value of the models were also extracted, including the model evidence base, the depiction of the model structure, and which characteristics of model relationships (e.g. polarity) were reported on.

**Results** Studies that applied more key concepts of a complex systems perspective were also more likely to report the direction and polarity of relationships. The system paradigm, its deepest held beliefs, is seldom identified but may be key to recognize when designing interventions. A clear, complete depiction of the full model structure is also needed to convey the functioning of a complex system. We recommend that authors include these characteristics and level of detail in their reporting.

**Conclusions** Above all, we call for the development of reporting guidelines to increase the transparency and applied value of complex systems models on socioeconomic inequalities in health, health behaviour and beyond.

**Keywords** Complex systems, Methodology, Reporting standards, Simulation models, Conceptual models, Socioeconomic inequalities, Health, Health behaviour

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## Rationale

In the past 20 years, interest in applying a complex systems perspective to understanding the dynamics underlying socioeconomic inequalities in health and health behaviour has grown (e.g. [1–4]). A complex systems perspective combines systems theory and complexity science, in which health outcomes are considered to be an emergent property of the system as a whole [5]. Complex systems models include factors at multiple levels of influence and specify feedback loops between these factors. This sets complex systems models apart from most traditional approaches to studying socioeconomic inequalities in health, which often focus on linear relationships between single factors (e.g. quality of neighbourhood infrastructure) and lead to policy recommendations centring around single factors and outcomes (e.g. physical activity) [5]. For example, in an approach grounded in a complex systems perspective, the ways in which the quality of neighbourhood infrastructure is intertwined with other resources neighbourhood residents have access to (e.g. money, time or social support), prevailing cultural norms in the neighbourhood and how residents use the available infrastructure (for physical activity and other behaviours, e.g. socializing or consuming alcohol) may be viewed as just one part of what drives socioeconomic inequalities in health in that community. The parts or mechanisms in a complex system come together as more than the sum of their parts, in nonlinear and sometimes unexpected ways to influence the system's behaviour (here, socioeconomic inequalities in health). Adopting a complex systems perspective may more effectively depict the complexity of real life processes, supporting public health policymakers and other stakeholders in meeting the challenges posed by systematic socioeconomic inequalities in health and health behaviour [6].

A complex systems perspective also introduces new analytical and conceptual challenges to understanding and modelling real-life processes, creating a potential gap between awareness about the usefulness of a complex systems approach and its implementation in research [7]. Taking stock of how existing studies on socioeconomic inequalities in health have applied a complex systems perspective may reveal opportunities for this important field of research to continue developing.

In our recent systematic scoping review [8], we provided an overview of 42 studies that modelled socioeconomic inequalities in health and health behaviour from a complex systems perspective using conceptual models, simulation models or both. Conceptual methods to modelling a complex system entail representing the system's causal structure, and simulation methods entail formalizing and quantifying the system's causal structure (e.g. agent-based models or systems dynamics models) [1].

The main focus of the systematic scoping review was to summarize and analyse the content of the identified models. In the content-focused review, we assessed the quality of included studies by evaluating the evidence each complex systems model was based on and the extent to which key concepts of a complex systems perspective were applied. During this quality assessment process, we found that key concepts of a complex systems approach were applied to varying degrees. During the review process, we also noticed that certain reporting styles aided our ability to understand the model structures in the studies we identified, while other reporting styles hindered our understanding. Clear reporting styles, in our view, are crucial for the interpretability and applied value of complex systems models, both for researchers and in practice (e.g. to inform the selection of policies). Given these preliminary observations, additional critical reflection on how complex systems methods have been applied on the subject of socioeconomic inequalities in health and health behaviour and how these methods have been reported on in publications is warranted [4]. This critical reflection on the application of and reporting on complex systems methods is the focus of this manuscript.

In this short manuscript, we aim to analyse how the studies identified in our systematic scoping review applied complex systems methodologies and how these studies reported on the methods applied. In this analysis, we [1] assess and critically discuss current applications of a complex systems perspective in the literature on socioeconomic inequalities in health and health behaviour and [2] provide recommendations for the development of comprehensive reporting guidelines, aimed at improving the transparency and applied value of future complex systems models. This short manuscript is based on data extracted in the process of conducting our systematic scoping review [8]. In order for this manuscript to function as a stand-alone piece, selected methods and results related to the application of a complex systems approach that are published elsewhere are briefly repeated here. What this manuscript adds to existing literature is an in-depth analysis and critical reflection on how complex systems methods were applied and reported on.

## Methods

The complete methodology for the systematic scoping review, which adhered to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) checklist, can be found in the main manuscript [8]. In short, we searched SCOPUS, Web of Science and PubMed from database start dates to April 2023 for studies that: [1] concern the adult general population in high-income countries belonging to the OECD [2, 9], contain an original or adapted conceptual or simulation model,

[3], self-identify as having applied a complex systems perspective [4], include a measure of socioeconomic position and [5] include a health or health behaviour outcome relevant for the adult general population.

A traffic light-based instrument was used to assess the extent to which key concepts of a complex systems perspective were incorporated into the studies identified in our scoping review. Key concepts of a complex systems perspective were selected from prominent literature about complex systems in the context of socioeconomic inequalities in health [1, 10] along with literature about complex systems more generally [11, 12]. The format of our instrument was based on an existing traffic light-based instrument developed to assess the application of a complex systems perspective in public health-related process evaluations [13]. The eight key concepts included in our instrument are presented in Table 1.

For each included study, the application of each key concept was assessed using green, yellow and red traffic lights. Green was used when a concept was explicitly incorporated into the model, meaning that the authors described that the concept was applied and how they applied it. Yellow was used when a concept seemed to have been incorporated into the model, but this was not clearly described in the publication. Red was used when a concept was not incorporated into the model.

In addition to the key concepts of a complex systems perspective, several extracted study characteristics related to the applied value of the complex systems models identified in the literature are especially relevant for this analysis. These include the evidence the model (including the model structure and, if relevant, model operationalization) was based on, how the model was presented in the manuscript (i.e. diagram, text or table) and characteristics of the relationships in the model. Relationship characteristics included the direction (going to and from certain model elements),

polarity (positive or negative) and magnitude (strength) of the relationships.

Data extraction, including the assessment of the application of key concepts of a complex systems approach, was performed by one reviewer (A.M.). Two reviewers (S.V. and M.P.) validated the data extraction on a total of 20% of the included studies. Any discrepancies were discussed between reviewers (and, if needed, the full research team) until agreement was reached, and insights from these discussions were applied to the data extracted from all studies included in the review.

### Complex systems methods-related results from the systematic scoping review

Table 2 provides an overview of the extent to which the 42 studies included in the systematic scoping review [14–18, 25–61] applied key concepts of a complex systems perspective and characteristics related to the studies' applied value. As presented in the systematic scoping review [8], key concepts of a complex systems perspective included in our traffic light assessment were applied to varying degrees, and only five studies explicitly applied all key concepts [14–18].

About half ( $N=23$ ) of the included studies clearly described how the modelled relationships were based on literature, empirical study, iterative model building processes or a combination of these; for the other half, the model evidence base was less clear (Table 2). All studies containing a conceptual model were explicit about the model structure in the sense that they included a diagram of the model structure (e.g. a causal loop diagram), whereas about half of studies containing a simulation model included a diagram. A total of 86% of studies reported the direction of relationships between model elements, 62% reported on polarity and only 24% of studies reported on magnitude. Simulation models contained more detail about the modelled

**Table 1** Key concepts of a complex systems perspective included in the traffic light-based instrument

Concept	Definition
(1) Heterogeneous elements	Distinct system elements that characterize the agents in the system
(2) Levels	A description of the system structure and the level(s) within that structure
(3) Relationships between elements	Connections or interactions between system elements
(4) Presence of feedback loops between elements	Responses between elements that may alter the intervention and its impacts. Can be reinforcing, positive, negative or balancing
(5) Interactions between system levels	Elements at one system level influence elements at other system levels
(6) Adaptation	Adjustments in system behaviour in response to internal and external change
(7) Emergence	Patterns that emerge from the interplay between factors, and system-level behaviour cannot be attributed to its individual parts
(8) Nonlinear dynamics	Inputs into the system do not necessarily result in correspondingly sized effects in the system, and the state of the system changes over time

**Table 2** Overview of study characteristics related to complex systems methods

Studies containing a simulation model															
Application of key concepts of a complex systems approach			Characteristics related to the applied value of studies included in the systematic scoping review												
First author last name	Publication year	Type of model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Model evidence base	Presentation of the model	Model relationship reporting		
													Direction	Polarity	Magnitude
Mooney [14]	2022	Agent-based model									Model structure basis not stated, model parameterized using empirical data	Diagram and text	Yes	No	No
Salvo [15]	2022	Agent-based model									Model structure and parametrization based on empirical data, theory, and team expertise	Text	Yes	Yes	No
Broomhead [16]	2021	Agent-based model									Model structure based on literature and theory, model parameterized using empirical data	Diagram, text, and table	Yes	Yes	Yes
Occhipinti [17]	2021	System dynamics model									Model structure based on iterative participatory modelling, model parameterized using empirical data	Diagram	Yes	No	No
Yang [18]	2019	Agent-based model									Model structure adapted from existing models, model parameterized using empirical data	Diagram and text	Yes	Yes	No
Blok [19]	2018	Agent-based model									Literature and author expertise	Text	Yes	Yes	Yes
Chen [20]	2018	System dynamics model									Model structure basis not stated, simulation model parameterized using empirical data	Diagram	Yes	Yes	Yes
Li [21]	2018	Agent-based model									Model structure basis not stated, model parameterized using empirical data	Text	Yes	Yes	Yes
Zhang [22]	2018	Agent-based model									Model structure based on existing models, model parameterized using empirical data	Diagram and text	No	No	No
Orr [23]	2016	Agent-based model									Model structure basis not stated, model parameterized using literature	Diagram	Yes	Yes	No
Blok [24]	2015	Agent-based model									Literature and author expertise	Text	Yes	Yes	Yes
Brittin [25]	2015	System dynamics model									Literature review	Diagram	Yes	Yes	Yes
Homa [26]	2015	Agent-based model									Group model-building sessions	Text	Yes	No	No
Yang [27]	2015	Agent-based model									Literature and an existing model (not explicitly stated)	Diagram and text	Yes	Yes	No
Orr [28]	2014	Agent-based model									Model structure basis not stated, model parameterized using literature (not explicitly stated)	Diagram	Yes	Yes	No
Zhang [29]	2014	Agent-based model									Model structure based on theory (a multilevel theory of population health), model parameterized using literature and empirical data	Diagram and text	Yes	Yes	Yes
Lymer [30]	2012	Dynamic microsimulation									Model structure basis not stated, model parameterized using empirical data	Text	Yes	No	No
Mahamoud [31]	2013	System dynamics model									Model structure based on a participatory and iterative modelling approach, model parameterized using empirical data	Diagram	Yes	Yes	Yes
Auchincloss [32]	2011	Agent-based model									Hypothetical relationships with some basis in theory	Text	Yes	Yes	Yes
Yang [33]	2011	Agent-based model									Model structure basis not stated, model parameterized using population data	Text	Yes	Yes	No
Milstein [34]	2010	System dynamics model									Insights from previous research and stakeholder review	Diagram	Yes	Yes	No
Holder [35]	1987	System dynamics model									Literature and empirical data	Diagram	Yes	Yes	Yes
Studies containing only a conceptual framework or model															
Application of key concepts of a complex systems approach			Characteristics related to the applied value of studies included in the systematic scoping review												
First author last name	Publication year	Type of model	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	Model evidence base	Presentation of the model	Model relationship reporting		
													Direction	Polarity	Magnitude
Mills [36]	2023	Causal loop diagram									Literature and stakeholder consultation	Diagram and text	Yes	Yes	No
Reumers [37]	2022	Causal loop diagram									Literature, group model building sessions with stakeholders	Diagram	Yes	Yes	No
Crielaard [38]	2021	Causal loop diagram									Literature, author expertise, and stakeholder consultations	Diagram and table	Yes	Yes	No
Rahmani [39]	2021	Conceptual framework									Literature review and expert consultation	Diagram and table	Yes	Yes	No
Sawyer [40]	2021	Causal loop diagram									Systematic umbrella review, expert panel, and iterative model building process	Diagram	Yes	Yes	No

**Table 2** (continued)

Cavill [41]	2020	Causal loop diagram								Literature, author expertise, and stakeholder consultations	Diagram	Yes	Yes	No
Friel [42]	2017	Causal loop diagram								Collaborative conceptual modelling	Diagram	Yes	Yes	No
Sturmberg [43]	2017	Multi-level complex adaptive systems framework								Literature and author expertise (not explicitly stated)	Diagram	Yes	No	No
Zukeran [44]	2017	Conceptual framework								Literature (not always explicitly stated)	Diagram and table	No	No	No
Chastin [45]	2016	Conceptual framework								Literature review	Diagram	No	No	No
Dover [46]	2016	Choice set/choice transition conceptual diagram								Literature and author expertise (not explicitly stated)	Diagram	Yes	No	No
Majowicz [47]	2016	Conceptual systems map								Modified thematic synthesis (systematic search, inductive thematic analysis, mapping)	Diagram	Yes	No	No
Weiler [48]	2015	Conceptual framework								Literature, intuition, and informal networking	Diagram	Yes	No	No
Wittenborn [49]	2015	Causal loop diagram								Structured umbrella review and expert consultation	Diagram	Yes	Yes	No
Fisher [50]	2014	Complexity framework								Literature review	Diagram	No	No	No
De Viron [51]	2013	Conceptual model								Iterative model building process based on existing models, discussion, and re-examination by the authors	Diagram	No	No	No
Picard [52]	2011	Conceptual framework								Literature	Diagram	No	No	No
Neff [53]	2009	Conceptual model								Literature, author expertise, and snowballing	Diagram	Yes	No	No
Joffe [54]	2007	Conceptual framework								Not stated	Diagram and text	Yes	Yes	No
Ansari [55]	2003	Eco-epidemiological theoretical framework								Literature and author expertise (not explicitly stated)	Diagram	Yes	No	No
<b>Green cells (%) (1) (2) (3) (4) (5) (6) (7) (8)</b>														
All studies 93 60 67 57 55 55 38 50														
Conceptual studies 85 70 45 55 55 25 25 20														
Simulation studies 10 50 86 59 55 82 50 77														

**Legend**

	The concept was explicitly applied in the model
	The concept seems to have been implicitly applied in the model, but this was not clearly described in the publication
	The concept was not applied in the model

(1): Heterogeneous elements, (2): Levels, (3): Relationships between elements, (4): Presence of feedback loops between elements, (5): Interactions between system levels, (6): Adaptation, (7): Emergence, (8): Non-linear dynamics

relationships than conceptual models, though conceptual models were not expected to report the magnitude of relationships (direction 95% versus 75%, polarity 77% versus 45%, magnitude 45% versus 0%).

**Further analysis and critical reflection**

**Critical appraisal of how a complex systems perspective was applied in literature**

One reason that studies containing simulation models may have applied key concepts of a complex systems approach more consistently than studies containing only conceptual models may be the existence of reporting standards for specific types of simulation models. For instance, the overview, design concepts and details

protocol (ODD) for agent-based models is widely cited and includes questions about key concepts of complex systems thinking, such as emergence and adaptation [19, 20]. In our analyses, we observed that adaptation was explicitly addressed in 82% of simulation studies (versus 25% of conceptual studies), and emergence was explicitly addressed in 50% of simulation studies (versus 25% of conceptual studies). Still, 50% of simulation studies explicitly considering emergence is not very high, and in fact, the agent-based models included in our review were less likely to consider emergence than other types of simulation models. It seems that, although guidelines such as the ODD protocol are important for the reproducibility and understandability of models, these guidelines may



not yet be widely used in agent-based models on socioeconomic inequalities in health.

Studies that applied more key concepts of a complex systems perspective were more likely to report the direction and polarity of the modelled relationships. To investigate this more closely, we estimated Spearman correlations between the percentage of key concepts that were explicitly considered in a model and whether relationship direction, polarity and both direction and polarity were reported on. These additional calculations showed that the percentage of key concepts explicitly considered in a model was positively correlated with reporting the direction (Spearman correlation coefficient of 0.43,  $P$  value < 0.001), polarity (Spearman correlation coefficient of 0.58,  $P$  value < 0.001) and combined direction and polarity of relationships (Spearman correlation coefficient of 0.60,  $P$  value < 0.001). Reporting on direction and polarity increases the applied value of complex systems models. Specifically, knowing whether a model element has a positive or negative influence on health is crucial to understanding model relationships, feedback loops and the functioning of the system as a whole. In our scoping review, reported relationship direction and polarity allowed us to meaningfully interpret shared drivers of socioeconomic inequalities in health and health behaviour and to summarize the existing literature in a causal loop diagram. It could be beneficial to include whether studies report on the direction and polarity of model relationships in assessments of the application of a complex systems perspective in future research. This would go a step further than our traffic light-based assessment of whether (but not how) connections or interactions between system elements were specified.

A key concept of a complex systems perspective that we did not include in our traffic light-based instrument but that may be important to consider is the system paradigm. A complex system's paradigm is the mindset out of which the system arises or its deepest held belief [21, 22]. The system's paradigm is the source of its overarching goals, which the system can adapt towards over time [22]. One study included in the scoping review analysed and described the system paradigm: Sawyer and colleagues found that the dynamic system underlying the food environment and its influence on dietary intake in low-income groups was driven by an economic paradigm, with 'the need for economic prosperity as the system's deepest held belief' (15, p.10). This paradigm was elucidated by analysing how the model subsystems were interconnected and related to key dimensions of the food environment. According to the Intervention Level Framework, intervening on the system paradigm has the highest potential for impact on the system, whereas intervening on individual system elements has the lowest potential impact [22]. Despite its purported importance, very few policy recommendations or interventions are

aimed at system paradigms, and neither our assessment or other existing assessments of the application of a complex systems perspective included system paradigm as a key concept of a complex systems perspective. This may be because identifying the system's paradigm is inherently complex. There is no singular strategy for identifying the system's paradigm, as understanding a system's paradigm requires thorough and meaningful engagement with the functioning of a complex system. Indeed, building a model of a complex system compels us to view the system as a whole, bringing the system's goals and paradigm to the surface [21, 22]. As the field develops further, researchers should seek to identify the system paradigm when analysing and assessing complex systems models, as understanding the system paradigm may help bring the most useful and effective policy levers to light.

Finally, including a clear and complete depiction of the model structure was important for assessing the extent to which a complex systems perspective was applied and for being able to extract useful information about the model content. Most diagrams included in simulation studies represented the general model structure, and details about the formalized model were provided in text. Studies containing conceptual models were more likely to include explicit descriptions of the model development process and the evidence the model structure was based on (e.g. literature or stakeholder sessions). On the other hand, studies containing simulation models usually included descriptions of the evidence informing the model parameterization (often empirical data), but the evidence underpinning the chosen model structure itself was often vague or missing. In some cases, text-only descriptions were incomplete, making it challenging to interpret model relationships, and in other cases, diagrams on their own may not be informative enough to understand the model relationships (e.g. if relationship polarity is not indicated in the diagram). Diez Roux emphasized the importance of describing the model structure for conceptual and simulation studies alike: 'Any systems approach must begin with the development of what has been referred to as a mental model' (1, p.1631). In the process of extracting model relationships from the included studies, we experienced that it was easier to understand the model if both a diagram and some text describing important model dynamics was available.

#### **Call for reporting guidelines**

Based on this critical appraisal of how conceptual and simulation-based complex systems approaches were applied in the literature on socioeconomic inequalities in health and health behaviour, we call for the development of reporting guidelines for studies that aim to apply a complex systems perspective. Guidelines on reporting standards for a broad

range of complex systems models would benefit researchers, those developing models and those interpreting (or aiming to build upon) study findings alike. These guidelines could focus on making the authors' approach and the model structure understood by readers. In this way, the guidelines would complement rather than replace existing guidelines, such as the ODD protocol [19, 20] or the recently published guidance on the use of complex systems models for economic evaluations of public health interventions [23]. These existing guidelines are more focused on technical aspects of simulation modelling or the development of simulation models for specific purposes (e.g. economic evaluation). In Box 1, we propose some initial recommendations for researchers aiming to apply a complex systems perspective to understanding socioeconomic inequalities in health and beyond, informed by the analysis presented in this manuscript. These suggestions are far from exhaustive and should be expanded on and formalized as comprehensive reporting guidelines. Adherence to such guidelines would likely improve the quality, understandability and applied value of future complex systems models for understanding and tackling socioeconomic inequalities in health.

**Box 1: recommendations for researchers aiming to apply a complex systems perspective**

1. Explicitly describe how a complex systems perspective was incorporated in the model

Explicitly describing which concepts of a complex systems perspective were incorporated into the presented model and which ones were not applied and why, will make the alignment between the study aim and the applied method clearer. Below is a list of characteristics of a complex systems perspective that could be described:

- Heterogeneous elements
- Levels
- Relationships between elements, including the direction and polarity of the relationships
- Presence of feedback loops between elements
- Interactions between system levels
- Adaptation
- Emergence
- Nonlinear dynamics
- System paradigm

2. Describe the process of developing the conceptual model and the evidence base underlying the model relationships

Many different approaches exist for developing conceptual complex systems models, including group model building sessions, literature review, expert knowledge or any combination of these [24]. Knowing more about the development process is essential for the reader to be able to understand the context the model was built in (i.e. what are the perspectives and positionalities of the model developers?) and to assess the validity of the model. This recommendation applies to conceptual and simulation studies alike, as, ideally, the structure of a simulation model is based on a conceptual model

3. Include a diagram depicting the model structure in its entirety

The inclusion of a complete and informative diagram, such as a causal loop diagram, ensures that readers are able to understand the full model structure. Text-only descriptions can leave gaps in understanding, making it challenging to interpret model relationships and making model outcomes less reliable to the reader. Textual descriptions of the model structure can, however, complement a diagram, especially when authors wish to provide information on the relative importance or magnitude of certain model elements or relationships

## Conclusions

In this short manuscript, we analysed how complex systems methods were used and reported on in existing studies on socioeconomic inequalities in health and health behaviour, in which authors reported applying a complex systems perspective. While key concepts of a complex systems perspective were applied to varying degrees, we found that more thorough reporting on how a complex systems perspective was applied increased the understandability and applied value of models. Specifically, describing how key concepts of a complex systems perspective were applied, providing details about model relationships and presenting a clear justification for and depiction of the full model structure all increased the ability to understand the functioning of complex systems models. While we present reporting-related recommendations for researchers based on our analysis, we emphasize the need for the development of comprehensive reporting guidelines to increase the transparency and applied value of complex systems models on topics related to socioeconomic inequalities in health, health behaviour and beyond.

## Abbreviations

OECD	Organization for Economic Co-operation and Development
ODD protocol	Overview, Design concepts, Details protocol

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### Author contributions

A.L.M., C.B.M.K., M.P.P. and M.B. developed the study conceptualization and design. A.L.M., C.B.M.K., M.B. and S.E.V. acquired the data. A.L.M. analysed and interpreted the data. A.L.M. and C.B.M.K. drafted the manuscript. All authors critically revised the manuscript. All authors read and approved the final manuscript. Each author agrees to be personally accountable for their own contributions and to ensure that questions related to the accuracy or integrity of any part of the work, even ones in which the author was not personally involved, are appropriately investigated, resolved, and the resolution documented in the literature.

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### Availability of data and materials

The full search strings and key study and model characteristics are available in the manuscript reporting the content-related findings of the systematic scoping review. Findings from the assessment of the application of a complex systems perspective and from the assessment of the evidence base are available in Table 2.

### Declarations

#### Ethics approval and consent to participate

Not applicable.

#### Consent for publication

Not applicable.

#### Competing interests

The authors declare no competing interests.

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