THE ANATOMY OF AN ARCHITECT’S ARGUMENT: FORMALLY CAPTURING SOCIALLY-ORIENTED DESIGN INTENTIONS IN THE BUILT ENVIRONMENT
Yazan N. H. Zayed, Anna Elisabeth Kristoffersen, Gustaf Lohm, Aliakbar Kamari, and Carl Schultz
Aarhus University, Aarhus, Denmark

Abstract
Sustainability is a large driving factor in today’s society. This work focuses on assessing aspects contributing to the social sustainability of buildings. Social aspects encompass, for example, well-being and the building’s impact on the occupants regarding qualities such as air quality, visual and thermal comfort, and privacy among others. We introduce “ProFormalize”, a formalization framework, for capturing the structure of design arguments regarding social intentions. Moreover, presenting the formalization of design intentions and activities obtained through case-study focused interviews. In addition, the organization and formalization of design arguments are presented as preparation for software implementation.

Introduction
Building designs are often full of intentions and visions for how the building should be experienced and perceived by its users. These intentions are typically tied together with the physical aspects of the building in the form of different design choices. Examples of this can be that building users feel at home and relaxed in specific areas of the building because the area contains lounge furniture of good quality, or the building users feel a sense of ownership towards the building because they feel that the used decorations and artworks represent them. These intentions are introduced by different stakeholders through the design phases, based on the different perspectives added by stakeholders to the project (Entwistle, 2022). Throughout the changing stages of the building design process, the responsibility shifts between stakeholders (Säwén, 2023), which often leads to the risk of losing design intentions due to different stakeholders’ focuses, and that these intentions are often implicit and not explicitly stated in the project documentation.

To effectively address this problem, we present the initial work of developing a formalization framework for design intentions regarding social aspects. The two main research questions in this work are:

RQ1 How can socially-oriented design arguments be captured in the digital representation of buildings?
RQ2 How can socially-oriented design arguments be represented in a way that prepares such kind of data to be implemented in software?

To address these questions, we present the first proof of concept of our framework, and the main contributions are:

C1 Setting up the overall workflow of our formalization framework “ProFormalize” in the form of four activity stages (elicitation, organization, formalization and implementation), and the corresponding output of each stage. This contribution is presented in “The formalization framework - ProFormalize” Section, and it addresses RQ1.

C2 Formalization of a selection of socially-oriented design arguments and presenting them in the form of First-Order-Logic (FOL) formulas and Abstract Syntax Trees (ASTs) in order to be used in further software implementation. This contribution is presented in “Analysis of case studies” Section, and it addresses RQ2.

Background
Sustainability is a large driving force in today’s society and is influencing decisions and practices across numerous industries. One of these industries is building and construction, where sustainability is commonly addressed based on a large range of building certification systems (Jensen et al., 2018). Existing building certification systems consist of varying criteria, which are related to each of the three pillars of sustainability: environmental, economic and social sustainability (Jensen et al., 2018).

Out of these three pillars, the social pillar is the least developed and the most vaguely defined (Bebbington and Dillard (2009); Boström (2012); Kristoffersen et al. (2024)). The existing definitions and approaches towards social sustainability do not offer neither a widely accepted definition nor a universally accepted list of included aspects (Bebbington and Dillard (2009); Boström (2012); Kristoffersen et al. (2024)). However, through our recent extensive survey on social sustainability, we have determined that there exists an agreement that social sustainability is focused on humans, and that definitions often include aspects such as, but not limited to, the forming of social networks, health, safety and justice (Kristoffersen et al. (2024)). This lack of a commonly agreed-upon definition can lead to a hollow shell concept of social sustainability due to its large adaptability to different contexts.

Instead of using the term social sustainability, it has been proposed to use the term social values followed by the specification of which exact value and to whom (Kristoffersen et al. (2024)). The research presented in this paper,
The formalization framework - ProFormalize

In this section we introduce our overall formalization framework “ProFormalize”, and we explain the core purpose of, and activities within, each stage, as well as how the stages connect to each other. We give particular focus to how we formalize socially-oriented design intentions following our so-called “three-level approach”.

Deriving the “anatomy” of architect arguments

A socially-oriented design intention argument represents a design activity that is intended to evoke a certain feeling of the occupants regarding their presence in the building or to improve their experience and perception of a specific social intention in that building.

This shows a causal logical relationship between “building elements” and “social intentions”, that is, the design activity that architects decide to implement, influences socially-oriented design intentions and contributes to the occupants experience in the building. This relationship is illustrated in Figure 1.

For example, “installing artwork in the workplace will increase the sense of belonging to the workplace”. This is a socially-oriented design intention argument. The underlying structure of this argument can be derived as follows:

The argument addresses a specific social intention which is the ultimate goal that the architect is trying to accomplish, that is, evoking a sense of belonging to the workplace among building occupants. The other part of the argument defines a design activity that is implemented in order to achieve the mentioned socially-oriented design intention, that is, installing artwork.

This anatomy of design arguments produces our “three-level argument structure”, which is a core foundation of how we formalize socially-oriented architectural arguments by making them unambiguous, precise, and explicitly integrated into the digital representation of buildings. Through the three-level approach, we define three levels of formalization: the goal level, the domain level and the product level.

This approach is inspired by the work of Lauesen (2002), where the author introduced the goal-design scale that consists of four levels of requirements: the goal level, the domain level, the product level and the design level.

In our work, we focus on social intentions in the context of the built environment, that is among others, the set of emotions, behaviors, functions and experiences that people have in buildings.

The goal of this approach is to formalize the socially-oriented design intention arguments of architects and other early design stakeholders about the impact of different arrangements of objects and building elements on the social aspects experienced by building occupants. Such aspects include sensory aspects (visibility, hearing, etc.), behavioral (movement, functions, etc.), emotional (excitement, privacy, inspiration, etc.).

We define the arguments of interest in our work as the arguments that contain information about both social intentions and the building elements used to affect them.

Consider the following arguments:

1. Installing LED lights in the working area would reduce energy consumption.
2. Organizing regular meetings with the business owners would increase the sense of belonging to the workplace.
3. Installing pieces of art in the workplace would increase the sense of belonging to the workplace.
4. Organizing regular meetings with the owners would improve business performance.

Based on the definition of arguments of interest in our work we can classify the above arguments as follows:

The first argument contains information about a type of building element (the LED lights) but the intended goal is not related to a social aspect but rather environmental and economical, hence this argument does not fit our formalization approach.

The same is true for the second argument as well, where the intended goal is related to social aspects, however the way to achieve this goal is not related to the arrangement of building elements.

The third argument is the one that fits our formalization approach. In this argument, the intended goal is to increase the sense of belonging to the place, which is a social intention, and the proposed way to achieve that, is to install pieces of art, which are building elements.

The fourth argument does not fit our formalization approach, as it does not contain any information about how a certain arrangement of building elements would achieve a social intention.

From the above definition, there are at least two basic levels of formalization that should exist for each design intention argument. These two levels are the social intentions level and the building elements level.

We use these two basic levels to form a reasonable way to initiate the structure of our formalization approach. The social intentions level is called the goal level, and the building elements level is called the product level.

![The Basic Argument Structure](image)

This provides the basic structure of the formalization approach, that is to classify parts of the arguments into these
two levels. The first one includes information about building elements such as walls, doors, slabs, lighting, art, furniture, etc. The second one includes information about the ultimate goal to be achieved which must be a social intention representing the feelings, emotions and behaviors of building occupants.

We argue that there is an implicit reasoning between these two basic levels of formalization, and we should introduce an intermediate level. This would be the smallest number of categories that we can work with in order to introduce a universal formalization approach that can handle a wide range of design intention arguments.

This intermediate level represents the stage between how building elements are arranged and the emotional and the behavioral experience is perceived by building occupants. It explains how changes in the design and in the arrangement of building elements will go through their senses and impact their interaction with their surroundings.

For example, considering the third argument again, “installing pieces of art in the workplace would increase the sense of belonging to the workplace”. It is not enough to install pieces of art for the building occupants to have a sense of belonging to the workplace. Although the argument fits the basic approach criteria, it is important to explain how installing this art would create this experience. Where should the building occupant stand in the room to see the art and be triggered by it? What if the building occupant is visually impaired, does not that limit the area of the room from which the art is visible?

These are valid questions, and they help explain the flow of the design argument. Such questions and more are answered with the addition of the third level, the domain level, which has information about the sensory experience of the occupant and the functional spaces in the building.

To summarize, the goal level contains information about the social intention that is under consideration, and why architects are implementing a certain design activity. The domain level explains how the effect is going to be achieved and the product level explains what building elements are being used and controlled to achieve the goal of the socially-oriented design intention.

The workflow of ProFormalize

Figure 2 shows the four stages of the workflow and the corresponding output of each stage.

The work in this study is data-driven and case-study-based. The cases are selected related to EU funded project (Probono) of buildings located at Aarhus University Campus, and they are:

1. The Library basement.
2. The basement floor of the Molecular Biology Department.
3. Human Resources Department.
4. Center of Education Development.
5. Institute of Advanced Studies.

In the following, the four stages of the framework from Figure 2 are elaborated.

Stage (1) Elicitation of socially-oriented design intentions from existing projects through semi-structured interviews. The elicitation of design intentions was conducted through semi-structured interviews with early-design stakeholders, in this case, an architect who has been involved in the six projects mentioned above. The interview was planned based on the guidelines and insights by Robson and McCartan (2016) as well as Kvale and Brinkmann (2015). The interview was planned to have a narrative and anecdotal approach. This is done to encourage the interviewee to focus on what has actually happened and been done and not on what the interviewee wished for or would like to have done (Blommaert and Jie, 2020).

The interviewer developed an interview guide and updated herself on projects connected to the interviewee before the interview was conducted. A generic excerpt from the interview guide is presented in Table 1.

The approach utilised in practice in the interview has similarities with an unstructured interview since the interviewee was allowed to follow his train of thought and move freely between talking about different building projects and social intentions. In cases where the interviewee strayed away from the focus point of the interview, the interviewer utilised one of the prepared questions from the interview guide to reestablish the focus of the interview.

<table>
<thead>
<tr>
<th>Question type</th>
<th>Question examples</th>
</tr>
</thead>
</table>
| Main Questions | • Which building and design projects have you been involved in?  
• Can you tell me a bit about the thought behind the project? |
| Elaborating Questions | • What was the intention?  
• How was the intention integrated into the project?  
• Has the intention been successful?  
• Is the intention adding the expected value to the building?  
• Have you gotten any response from the users? |

The interview language was selected based on which languages the participants in the interview understand, and which working language the early-design stakeholders use. Whenever possible, the interviews were conducted in the same language as the main working language of the interviewee, to encourage the interviewee to use the phrases which were included in the project during the early design stages. The interview was recorded using a voice recorder on the interviewer’s phone. This was done to let the interviewer and interviewee focus on the dialogue without slowing down or pausing the interview to take notes. The recording was transcribed in the interview language, either Danish or English, by first using Microsoft Word’s
transcribe function, after which the interviewer edited the transcript to remove the errors originating from the transcription’s automation.

**Stage (2) Organization** of the design intention arguments and sorting them out by identifying socially-oriented design intentions and their corresponding design activities to achieve those intentions.

In this stage we categorized the transcription from the elicitation stage into items containing two parts: **the socially-oriented design intentions** and the **design activities**.

This was done by following the four sub-stages: Identification of intents, translation, systematization/input of data and validation.

The identification of intents was performed by reading the transcribed interview, and marking when the interviewee states a socially-oriented design intention or of an architectural or design-oriented decision. The essence or key points of the intent were then translated into English by the interviewer if the interview was conducted in Danish.

After this, the intention was added to the database of the collected intentions, which is managed in an Excel sheet. The database contains information about in which building the intention was implemented, the activity used to implement the intent, in which interview the intent was identified, and a timestamp referring to when in the interview the intent was mentioned. The references to which interview and the timestamps were recorded to make a direct connection between the database entries, the transcription and the interview recording.

The identified and translated intents were sent for approval and review from the interviewee to ensure that the English translation of the intent represents and encompasses what the interviewee meant.

**Stage (3) Formalization** of the itemized design intention arguments.

In this stage, architects design arguments were represented explicitly, including the categories of targeted building occupants, their senses that the design activity is trying to evoke and the surrounding environment or situation.

The core of this level is to systematically identify implicit and ambiguous aspects of each design intention argument and systematically decide how to disambiguate them.

In order to do that, each statement was manually translated into first-order-logic formulas based on the three-level approach presented in “The formalization framework - ProFormalize” Section. This makes particular aspects of the argument explicit such as occupant sense-experience, the surrounding environmental conditions, etc.), moreover, natural language concepts are expressed as predicates and terms, and combined into formal logical statements.

In addition, qualitative spatial prepositions are grounded with definite interpretations that at the same time allow architects to adjust them based on their reasoning.

Hence, this approach provides architects with a structured form of building blocks to present their arguments in a valid way and shows them what different terms they can use in each level.

The three levels of formalization are defined as follows:

**The goal level** contains predicates about **social intentions**. Those predicates refer to the aspects that affect the experiences and the feelings of building occupants. The goal level is the only level that can take such predicates, as it is the level that represents the objective of the design activity and describes the accurate intention behind that activity.

**The domain level** contains predicates about **building occupants and their senses**, this level takes predicates from two major categories which are:

1. **Spatial artefacts**, those are regions of empty space that contain important semantic value because they represent the space in which an object can be seen, heard, used, etc. For example, the movement space of a room, which is the space where people can move within a room, or the visibility space and the hearing space of humans, they refer to the region of empty space where humans can see or hear the visual or acoustic effect of a building element, respectively. (Bhatt et al. (2010)), (Bhatt et al. (2012)).

2. **Spatial prepositions**, those are the terms that represent the direction, orientation, or position information of spatial artefacts and building elements, such as in front of, between, near, inside, directed at, etc.
The product level contains predicates about building elements that are going to be used or arranged in a specific way to affect a specific social intention.

Figure 3 demonstrates this structure and presents some examples of each predicate category.

Stage (4) Implementation of the formal design arguments as Abstract Syntax Trees for software development.

In this final stage, we performed a direct one-to-one translation from the formulas into first-order abstract syntax trees to be used in software implementation.

<table>
<thead>
<tr>
<th>The Goal Level</th>
<th>The Domain Level</th>
<th>The Product Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social value</td>
<td>Spatial artefact</td>
<td>Building element</td>
</tr>
<tr>
<td>predicates</td>
<td>predicates</td>
<td>predicates</td>
</tr>
<tr>
<td>privacy()</td>
<td>visible_space()</td>
<td>art()</td>
</tr>
<tr>
<td>curiosity()</td>
<td>hearing_space()</td>
<td>wall()</td>
</tr>
<tr>
<td>belonging()</td>
<td>function_space()</td>
<td>use_art()</td>
</tr>
<tr>
<td></td>
<td>near()</td>
<td></td>
</tr>
<tr>
<td></td>
<td>student()</td>
<td></td>
</tr>
<tr>
<td></td>
<td>elderly()</td>
<td></td>
</tr>
</tbody>
</table>

**Figure 3: Predicate rules of the three-level approach**

**Analysis of the case studies**

In this section, we discuss in more detail the case study that is the focus of this research, which originates from a project conducted at the building housing the Department of Molecular Biology at university campus (institution name removed for blind review). The building houses students, researchers, and other university employees. Most of the collected intents focus on how the students use and feel in the building, since students are the primary users of the areas which the interviewed architect has focused on.

**Elicitation**

The elicitation of socially-oriented design intentions has been conducted through semi-structured interviews in accordance with the description of the Elicitation stage in the Section “The Workflow of ProFormalize”. The intentions were collected through three interviews over 14 months. The interviewee in all the interviews was the same architect, who has been participating in the planning and implementation of the intentions into the building. The first two interviews were conducted in Danish as sit-down interviews with only the architect and the main interviewer participating. The third interview was conducted walking through the Department of Molecular Biology at the university, where the architect showed the building and the activities tied to the socially-oriented design intentions.

The interview was conducted by the same main interviewer as the previous two, with a secondary interviewer joining the interview with the goal of documenting design choices through pictures and indications on a floor plan drawing. The interview was conducted in English to accommodate the secondary interviewer. The result of this stage forms the basis for the identification, organisation and processing through the following steps.

**Organization**

The organization of the data consists of identifying socially-oriented design intentions in the transcribed interview, and presenting the intentions in an organized manner that can serve as a stage towards concertising the intents.

The dark red points on the floor plan shown in Figure 4 represent the locations of socially-oriented design intention items which were collected through the on-site interview and have been transcribed and organised. These points are explained in Table 2 and presented in Figure 5.

The dark blue points on the floor plan represent the locations of socially-oriented design intention items that have not been transcribed or organised yet, this includes wall (a and c), changing wall colours (b), and specific furniture (d and e).

**Formalization**

The three levels are represented as first-order-logic formulas, this is explained through the following example of a design intention argument about the case study of the molecular biology building: “A delimited area of the basement in the building is being equipped with real, one-of-a-kind artworks, the intention with this space is to make an area where the students feel inspired, and actually want to be sitting”.

Based on the three-level approach we can classify the following parts of the argument as follows:

1. The social intention under consideration is “sense of inspiration”, this represents the goal level. And this is the intention behind the architect’s design decision.
2. The way to achieve the goal is to place the artworks in the area to be visible by the students, this represents the domain level.
<table>
<thead>
<tr>
<th>Id</th>
<th>Socially-oriented design intention</th>
<th>Design Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>DI1</td>
<td>The art is growing and developing when you look at it and creating a space where the students feel inspired and actively want to sit.</td>
<td>Installing art consisting of four lamps emitting different light of different temperatures and intensities.</td>
</tr>
<tr>
<td>DI2</td>
<td>Creating an area where the students actively want to sit.</td>
<td>Installing a sofa that is adapted to the room size, taking accessibility into consideration.</td>
</tr>
<tr>
<td>DI3</td>
<td>Creating an area where the students actively want to sit.</td>
<td>Installing sockets on the sofa which are directly integrated through a conscious design choice in the sofa.</td>
</tr>
<tr>
<td>DI4</td>
<td>Creating a subspace within a larger area and providing a feeling of coziness.</td>
<td>Using high contrast colors of the sofa and the wall between the general area and the subspace.</td>
</tr>
<tr>
<td>DI5</td>
<td>Draw attention and encourage mobility and inspiration to explore the building.</td>
<td>Painting a line of color wrapped around the corner.</td>
</tr>
<tr>
<td>DI6</td>
<td>Draw attention and encourage mobility and inspiration to explore the building.</td>
<td>Installing a contrasting color expanding into the hallway.</td>
</tr>
</tbody>
</table>

3. The building elements that are under consideration are the “artworks”, they represent the product level.

The goal level formula: increasing their sense of inspiration of the occupant \( P \) in room \( R \):

\[
\text{sense\_of\_inspiration}(P,R)
\]

The domain level formula: the occupant \( P \) must be inside the visible space of the artwork \( A \) to see it:

\[
\text{occupant}(P) \land \text{inside}(P, \text{visible\_space}(A))
\]

The product level formula: using artwork \( A \) in room \( R \):

\[
\text{art}(A) \land \text{room}(R) \land \text{use\_art}(A, R)
\]

As our approach is based on case studies of actual buildings, this approach is under constant development and there might be a need to add more levels to achieve a different level of detail, but for the current moment, as it is unnecessary to add more levels, we use this three-level approach, and we could represent different design arguments in a reasonable way.

In the previous example, 6 predicates and 1 function have been used, this is explained as follows:

1. A predicate named “art” is used to define an artwork as a building element. It takes 1 argument, which is the variable representing the artwork.
2. A predicate named “room” is used to define a room in the building. It takes 1 argument, which is the variable representing the room.
3. A predicate named “use_art” is used to specify which art piece is used where. It takes 2 arguments, the first is the piece of artwork, and the second is the place where this art is installed.
4. A predicate named “occupant” is used to define a general building occupant. It takes 1 argument, which is the occupant.
5. A predicate named “inside” is used as a spatial preposition to describe that an element is inside a specific space. It takes 2 arguments, the first is the element itself and the second is the space that the element is inside.
6. A function named “visible_space” is used to represent the space from which a specific element is visible. It takes 1 argument, which is the element for which the visible space is needed.
7. A predicate named “sense_of_inspiration” is used to describe that an occupant has a sense of inspiration regarding a specific building element. It takes 2 arguments, the first is the occupant and the second is the building element.

There is also a term named “Var” that takes one argument only and it is used to represent a building element or an occupant as variables.

**Implementation**

In the implementation stage, we transform the formalized first-order-logic formulas into abstract syntax trees as a preparation for the software stage. In the abstract syntax tree representation, there are the following elements:

1. **Logical expressions**, that evaluate to either true or false. This includes logical operators (and, or, not) and predicates (Pred).
2. **Terms**, that includes functions (Func) that is applied to other terms and they evaluate to a new term, and variables (Var) that are used to represent different terms.
The following is an example of the abstract syntax tree of the domain level:

\[
\begin{align*}
\text{And}&(\text{Pred}(\text{"occupant"}, 1, \text{[Var(\text{"P"})]}), \\
\text{And}&(\text{Pred}(\text{"building_element"}, 1, \text{[Var(\text{"A"})]}), \\
\text{Pred}&(\text{"inside"}, 2, \\
\text{[Var(\text{"P"})],} \\
\text{Func}&(\text{"visible_space"}, 1, \text{[Var(\text{"A"})]})))} \\
\end{align*}
\]

**Discussion and conclusions**

In this paper we presented the initial stage of "ProFormalize", a formalization framework to capture socially-oriented design intentions in buildings. The underlying structure behind architects socially-oriented design intention arguments was derived and the three-level structure was presented. In the subsequent phase of this work, the implementation stage of the proposed framework will be further developed. One potential service that this framework provides is to query about socially-oriented design intentionsthat are related to specific building elements, and vice versa.

Figure 6 shows a floor plan of the basement floor of the molecular biology department highlighting a selected path that an occupant might take to reach their working area. Along the shown path, the occupant passes through several locations where architects have implemented certain design activities using various building elements in order to improve or add a specific feeling or experience. For example, in design intention (DI5), the architect argues that painting a line of color around the corner will draw attention and encourage occupants to move around the building and explore it. This location is highlighted with the blue point with coordinates (13,3) in the floor plan.

As an implementation of the framework, the following query example is presented:

```
>>> relation(DI5, building_element).
building_element = wall3265
building_element = paint4873
```

The predicate “relation” is referring to the relationship between building elements and design intentions. The goal of this query is to list the building elements that are used to achieve design intention 5 (DI5), those elements are listed using their unique ids as (wall3265) and (paint4873).

Another query example is to list the design intention items that are affected by a specific building element. The following query lists the design intention items that are affected by the sofa with the unique id (sofa0012).

```
>>> relation(DI, sofa0012).
DI = DI2
DI = DI3
```

In addition, the user can query about the design intentions that will be experienced according to the argument.
For example, the path shown in Figure 6 is defined as the line segments connecting the set of 2D points:

\[ \text{Path} = [(0,0),(10,1),(10,3),(13,3),(13,5)] \]

then the following query can be implemented:

```python
>>> social_intention(Path, Dis).
[(at([13,3]), social_intention(inpiration), id(DIS))]```

The “social_intention” predicate takes two arguments, one is the selected path represented as the set of points and the second argument represents the design intentions that are located along the path.

The output of the predicate will be a list of elements, where each element contains a point, a social intention represented using the “social_intention” predicate, and the design intention represented using the “id” predicate.

This provides architects a way to find out which building elements affect a specific socially-oriented design intention, and reduces the risk of losing some intentions when changing the use or arrangement of the building elements through different phases of the design process.

Additional querying services might also include the visualization of the functional space of certain equipment or service areas such as printing facilities, storage rooms, working stations, among others. This space represents the area from which this equipment or service zone can be used safely, efficiently, privately, etc.

This framework was developed based on case studies of actual buildings that are mainly used by students or employees of an educational institution. Further applicability of this framework include governmental buildings (e.g., offices) and the scale of applications could be expanded to cover multiple buildings located in a close area up to a neighborhood.

The main limitation of this work was the limited amount of collected socially-oriented design arguments. As part of the future work, more locations are planned to be visited and more interviews are planned to be conducted with architects who are working on relevant projects concerning the addition or improvement of social criteria in buildings.

Acknowledgments

We gratefully acknowledge the funding support of the European Union Horizon 2020 research project PROBONO under grant agreement no. 101037075.

References


