Student Graduation Projects in the Context of Framework for AI-Based Support of Early Conceptual Phases in Architecture *

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Abstract In this paper, current, past, and planned student graduation projects in the context of MetisCBR, the distributed AI framework for intelligent support of the early room configuration process in architectural design, will be presented. During the last years, a number of such projects were initiated to achieve a master's or bachelor's degree. All these projects have in common that they intend to extend the currently available functionalities of the framework with new features using the modern AI techniques and trends, such as explainable AI or generative adversarial nets, in order to keep up with the recent AI developments. For each project, a summary of the concept(s), results of the experiments (if any), and the current status (e.g., defended or ongoing) will be presented. The main goal of this paper is to reward the student contributions to the MetisCBR framework by making them visible to the research community.

1 Introduction

MetisCBR[1] is a framework for AI-based support of early conceptual phases in architectural design and was initially created 2015 as a master thesis project (during the research project Metis[2]) in the form of a retrieval engine for similar building designs based on established artificial intelligence technologies *case-based reasoning* (CBR) and multi-agent systems (MAS). In the next years, the framework was gradually extended with additional functionalities, and possesses currently (2020), the following features to support the conceptual creation of building designs in the form of *abstract graph-based room configurations*:

[1] http://veisen.de/metiscbr

[2] https://www.ar.tum.de/en/ai/research/ksd-research-group/funded-projects/

1. *Retrieval* – The system looks for similar room configurations for the given query using attribute-value-based or graph-matching-based search strategies. The former is used for a broad general search for inspiring designs, the latter to find exact or almost identical structure of the query within other graphs, for example to examine how the current structure is used in another context. For each search process, a group of agents, placed in a container, is responsible.
2. *Suggestion* – This functionality was developed to recommend the possible next design steps to the designer based on her previous design steps. A step is an action, e.g. *Add*, *Delete*, or *Change type* of the room. Using recurrent neural networks (RNN) and the design steps record (the *process chain*), the system suggests the next step using the most similar previous process chains.
3. *Adaptation* – The framework applies convolutional neural networks (CNN) in the form of the currently popular GAN structure (generative adversarial nets), to produce a number of possible evolutions of the current room configuration to show the designer how it might look in the future merging its feature matrix with the matrices of the most similar previously saved designs and letting the system decide which evolution can be considered real.
4. *Explanation* – Using the methods of explainable AI (XAI) with explanation patterns *Transparency*, *Justification*, and *Relevance*, the system can enrich the results of the previous three modules with *explanations* that contain the contextual insights into the currently executed process. For example, such explanations can provide information on search patterns used for retrieval or which steps of the current session were used to produce a step suggestion.

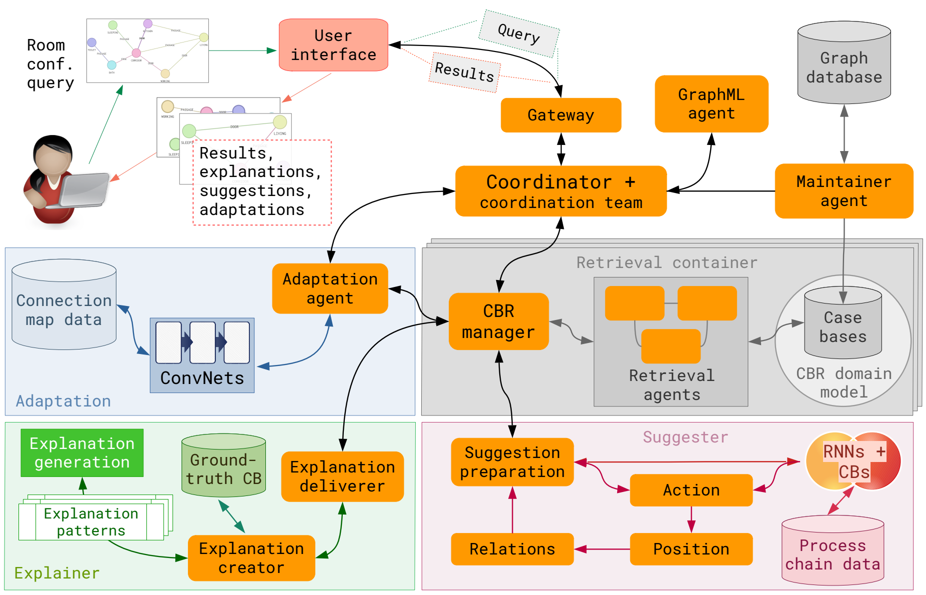

Figure 1. Overview of the current system architecture of MetisCBR.

Being now part of a PhD thesis, MetisCBR was specifically conceptualized for use in student graduation projects in order to conceptualize new functionalities based on the already existing ones and test and implement them if they prove or seem promising. In the next sections, a selection of the most notable graduation projects that had influence on the further development of the framework will be presented. Subsequently, we provide a summary of other relevant projects that relate to the framework but do not directly extend or evaluate it (e.g., surveys).

2 BDI-Based Explainable AI Component

The first graduation projects that will be described in this paper extend MetisCBR with an additional explanation module, the *BDI-Explainer*, that is based on the established multi-agent systems paradigm **B**elief, **D**esire, **I**ntention. This new explainer was inspired by the research work by Broekens et al. [1] and based on its complexity it was divided into two separate graduation projects: an already defended master thesis [4] dedicated to conceptualization and future-proof of the concept by comprehensive evaluation among the targeted user group of MetisCBR (architects), and the currently ongoing bachelor thesis that ains at implementation and quantitative evaluation of this BDI-based explanation module.

The BDI-based explainer (see Figure 2) makes use of different types of knowledge in the form of Beliefs (architectural knowledge of the system), Desires (explanation goals), and Intentions (current action to generate an explanation). The architectural knoweldge is represented by the commonly used architectural techncial terms and vocabularies in the form of typologies or taxonomnies. Identically to the other explainers [2], the BDI-Explainer makes use of explanation patterns described in Section 1. The patterns are used as the current explanation goals (e.g., *justify the suitability of the suggested design step*). The *explanation generation* component provides the user with the explanation expression.

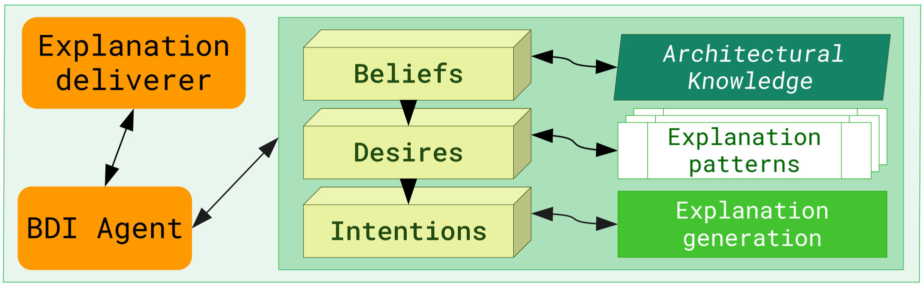

Figure 2. The planned implementation of the BDI-Explainer (figure adapted from [4]).

The evaluation of the concept of the BDI-Explainer revealed that 75% of the participated architects find the explanations in architecture modeling software useful and helpful for understanding of its functionality, however, this does not stimulate the creativity. Currently, the BDI-Explainer is being implemented using the multi-agent systems framework JADE and its BDI extension BDI4JADE [5].

3 Construction of Spatial Layouts with Game Theory

In this currently ongoing master thesis, it is planned to apply game theory, the well-known business negotiation technique, to construct an optimal room configuration (an early representation of a floor plan) based on predefined optimum criteria and the negotiation strategy. Game theory is one of the core features of cooperative multi-agent systems, it provides the relevant agents with a means to achieve an optimal agreement for distribution of the currently planned tasks among them. If executed properly as planned, the game-theory based cooperation strategy usually results in an optimal outcome for each of the collaborating agents.

Game theory was already applied for a multitude of domains, architectural design is among them. However, for construction of an optimal spatial layout of a building, to the best of our knoweldge, this technique was not applied before. The task of the master thesis is to explore the possibilities of game theory for early phases of architectural design and create a concept for this application. In general, it is planned to elaborate a number of specific negotiation strategies that the agents can use to find an optimal configuration for the current design task, e.g., an apartment for an elderly married couple or a standalone multi-functional bungalow. Two general agent setups are possible to apply a strategy:

1. *Holistic* – Every agent is able to propose a solution for the configuration of rooms available in the layout, other agents might or might not suggest the improvements and are able to justify their suggestions using utility functions.
2. *Distributed* – In this setup, each agent is responsible for one room (or room type) only and has a task of placing this room in the best possible position in the configuration. For example, the agent responsible for living rooms will claim the central position for them and easy access from other rooms.

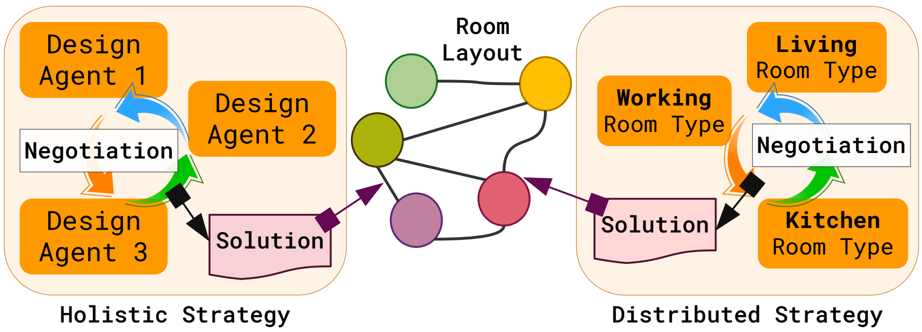

Figure 3. Strategies used for game theory-based spatial layout.

In Figure 3, an overview of both types of the agent setups is shown. After conceptualization, the game-theory-based construction strategies should be prototypically implemented using the aforementioned MAS frameworks JADE and/or BDI4JADE and evaluated by a representative of the architecture domain.

4 Speech UI-Supported Room Configuration Design

Similarly to the BDI-Explainer, this project is also a combination of two graduation projects, where a master thesis contains the research and the detailed concept with implementation instructions, complemented by a practical bachelor thesis which will contain the implementation and quantitative evaluation.

In this combined project a human speech-controlled component for early phases of architectural design should be conceptualized and implemented in MetisCBR and its web-based user interface (UI) RoomConf Editor[3]. Inspired by the modern natural language generation (NLG) assistant systems, such as Apple's Siri and Amazon's Alexa, the collaboration between the system and the architect will be enriched by a human dialog-based module that should listen to the architect's voice commands and questions via the specific web browser API (application programming interface), forward them to the backend of the system for parsing and producing the NLG-based answer that accompanies the achieved results and reproduce it using a human voice imitation in the UI.

In general, all four main functionalities of MetisCBR described in Section 1 should be covered by the speech-based dialog with the system. All functions that can be executed with the non-voice interaction methods, such as requesting the next design action suggestion should be also possible to execute with a voice command. In specific situations, a real dialog with the system should be possible as well, for example to ask for improvement if certain conditions in the layout look doubtful. Another example is providing the step-by-step guidance to the user during a specific design task. Two different methods should cover both situations described above: dialog trees and artificial neural networks (ANN). A gateway selects the most suitable parsing method for the current user expression. In Figure 4, an overview of the voice-controlled design support module is shown.

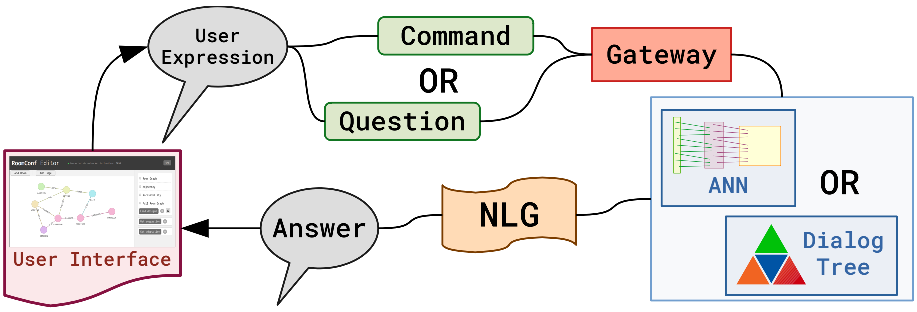

Figure 4. Overview of the voice-controlled design component.

An example of a dialog tree and instructions for implementation of ANNs were already described in the aforementioned defended master thesis [7]. In the bachelor thesis, it is planned to extend them, implement a proof of concept, and comparatively evaluate using different automatically applied design scenarios.

[3] http://veisen.de/metiscbr/roomconf/

5 Surveys and Reviews

Besides the conceptual and practical projects that directly extend the MetisCBR framework, a number of thematically related approach surveys were assigned as graduation projects as well. Their goal is to collect the knowledge available in the research domain and so determine the position of the framework among the related approaches. The following list describes the most notable reviews:

- *MAS in Architecture* [6] – This already defended master thesis examined major monographies, journals, and conference proceedings to identify and classify the existing and past MAS approaches that aim at supporting the design phases in architecture. Using a specific self-defined classification, each approach was assigned into a category and feature-wise compared with the systems from this category. As a quintessence, the work suggests a meta-model for MAS systems in Architecture, including the MetisCBR framework.
- *Data Augmentation and Augmented Reality in Architecture* – In this currently ongoing masther thesis literature review, systems and approaches that enrich architectural design with methods that introduce augmented reality and/or make use of data augmentation for datasets are examined and classified. The goal is to identify the relevant approaches that might provide a benchmark for MetisCBR, as it is planned to extend the framework with augmented reality features, e.g., to map the room layout onto different building contexts.
- *Survey of Open Source CAD Systems* [3] – In this defended master thesis, the currently available open source tools for computer-aided design (CAD), were examined. The goal was to estimate the acceptance of such tools in comparison to proprietary tools and propose a holistic marketing strategy that MetisCBR (if it will be decided to open source it completely) and other approaches can use to find a proper position and user group on the market.

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