# Configuration of Domotic Systems based on Constraint Solving

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## ABSTRACT

Current crises (such as the war in Ukraine) are confronting end consumers with ever new challenges, for example, in the context of energy management. This paper presents a configurator that enables end-users to make certain functions in their household "smart" and thus, for instance, get a better grip on their energy management. The concept is based on constraint programming, concretely on the open source platform Choco[1]. After emphasizing the algorithmic problems and challenges, a first version of a prototype is presented, which illustrates the possibilities of guiding end-users through the process of making their living environments smart. Related possibilities, potentials and challenges of the proposed approach are discussed at the end of the paper.

## CCS CONCEPTS

• **Human-centered computing** → *Interactive systems and tools*; • **Information systems** → *Search interfaces.*

## KEYWORDS

Configuration, Smart Home, Constraint Solving

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## 1 INTRODUCTION

Recent global developments such as the war in Ukraine have exacerbated the problems related to the climate crisis and the scarcity of fossil fuels. These developments make it increasingly important for private consumers to be able to better manage the infrastructure of their living environment in order to - among other things - observe and control their energy consumption. This is also important on a societal level, because private households are responsible for around 40% of the global energy consumption [2].

In this paper the current status of a platform is presented which aims at supporting the private consumer (in cooperation with local service providers) in the planning and implementation of smart features. The central tool to support this task is a smart home configurator enabling the consumer to configure smartness which optimally meets the individual needs. The back-end is based on the constraint solver platform Choco. Before going into detail on the technical details an example scenario is described in the context of which the presented approach could be applied.

**Example Scenario**

*A homeowner wants to make his heating system "smart" in order to gain better control over his or her energy consumption, to reduce energy waste and in this way to be able to react on continuously increasing energy prices. The house has a state of the art pellet heating system, controlled by a thermostat mounted at a central position in the household. The homeowner wants to be able to control the heating more flexibly, e.g. remotely with a smartphone.*

The - on first sight - easiest solution for the homeowner would be to add a smart gateway to the heating system which many heating suppliers offer. Such a gateway is directly connected to the furnace on the one side and to the household's WiFi on the other. With a few settings (e.g. port forwarding, connection to the cloud system of the supplier), the heating could be controlled on the smartphone with an App.

However, an essential prerequisite for a viable and sustainable smart functionality would be an integration into a higher-order system. There are numerous smart solutions available on the market, but they are typically proprietary, following the scheme: device1 (e.g., smart bulb) → App1, device 2 (smart speaker) → App2, device3 (vacuum robot) → App3, etc. These solutions only shift the *remote control anarchy*, as Jakob Nielsen [8] termed the problem, from the hardware to the software level, because they result in a high number of apps on the smartphone which have to be separately operated (in most cases based on very different interaction mechanisms). An important objective for viable and sustainable smartness would therefore be an integration of different systems into - ideally - one single system. This is, for example, state-of-the art in the automotive sector. Although an actual car is based on around hundred different sensors, microprocessors and computers, a seamless interaction with them can more or less taken for granted.

Following the approach from the automotive sector, a solution to aim at for a smart home would be to integrate the heating in the example scenario either into a smart home infrastructure that

[1] https://choco-solver.org/


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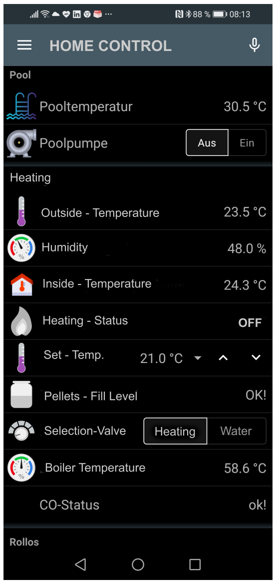


**Figure 1: Integrated Smart Home Interface example (Android App).**

already exists or to envision such an integration in a higher-order system in the future.

How this could look like on the interface level is illustrated in Figure 1 - showing a snippet of a state-of-the-art smart home management platform integrating smart components from different brands / manufacturers. However, the focus of this paper is not on the run-time / usage of such a system, which is, for example, supported by smart home platforms such as OpenHAB (Open-Home-Automation-Bus) (cf. e.g. [10]).

The paper focuses on the basic problems related to the physical features and constraints of the components present in a typical household and how to deal with the challenge to interconnect them, to enhance them with smartness and to integrate them to achieve - in the optimal case - an individual, sustainable and integrated smart home environment.

The scientific problem addressed in this paper has several dimensions. First, we deal with the complex field of smart home, second with configuration. The approach followed to build a bridge between these two dimensions is based on Constraint programming (CP) and/or the solution of Constraint satisfaction problems [12]. Concretely, we utilize the Choco constraint solver environment[11] to cover the constraints that could be relevant in the context of smart home configuration. Choco is a representation of a Constraint Programming (CP) solver, an approach which has proven to be useful in different industrial settings (e.g. [1]). The Choco system provides a number of constraint solving solutions in different domains.

The approach to apply constraint programming in the context of smart home was already followed by other researchers, for example by[7]. However, the majority of related work did not apply constraint solving in the *design time* of smart homes, but on the *run-time*, more concretely on problems related to energy balancing, smart grid aspects. The work of [13] describes the application of constraint solving to enhance the interaction with smart homes. In a similar manner, [3] use Choco for the definition of smart home constraints.The use cases addressed are, for example, adapting lighting conditions for a person watching TV or to deal with high temperature when window state (open/close) and the status of the air condition (on/off) has to be taken into consideration.

## 2 METHOD

As pointed out with the example of heating integration, the focus of our approach is to utilize constraint solving in the context of planning smart functionalities. To be able to achieve the goal of interconnecting devices with others in a higher-order system, it is necessary to take a closer look on technical specifications. The pellets furnace in the example does not have any specific interfaces to connection infrastructures such as WiFi and Bluetooth, it can be controlled by a local thermostat only.The interface to this thermostat is - similar to many other furnaces on the market - a simple electric contact. When the contact is closed, the heating starts. The specification of these kind of contacts differs between manufacturers, but typically they are potential-free or operate in the low DC-voltage segment (12V). By utilizing this contact in a higher-order system, the furnace could be flexibly and sustainably made smart.

On the other, the operation side, there is the smartphone which is planned to be used to switch the furnace, but in the optimal case also allows for other related tasks, such as the observation of the furnace's status, the current temperature in the household or the fill level of the pellet tank (as shown in Figure 1). As WiFi systems can be assumed to be present in almost every household nowadays, controlling the whole system over WiFi would be an appropriate approach.

The actual solution for the described problem is the following: A binary (on/off) actuator which can operate potential-free is attached to the furnace's thermostat input. The actuator is connected to a wireless thermostat and both components are parts of a state-of-the-art smart home platform which manages interconnection and control. This solution has the following advantages. The wireless thermostat exchanges the conventional one that was attached to the furnace before. In this way, the basic functionality (temperature falls below a threshold $\longrightarrow$ thermostat is activated $\longrightarrow$ heating starts) is still working, but enhanced with the possibility to switch the heating with the Smartphone (by using the smart-home platform in the back-end). The latter is independent of whether the temperature threshold on the thermostat is undershot or not and could be, for instance, useful when the homeowner wants to activate the heating while commuting home, because he or she wants the house to be already warm when returning from the office.

Although the number of involved components seems to be manageable, the basic connection requirements are not trivial. They serve as an example for the challenges that this kind of configuration problems have to deal with when attempting to cover a variety of components to be used to make a system "smart".

To recap we have the following components:

- **Furnace** - operated on 230V AC mains power, potential-free thermostat input.

- **Actuator** - also operated by 230V AC mains power, switchable channel which can be activated either potential-free or with voltages up to 230V (both AC and DC).
- **Thermostat** - battery operated (AA Battery, 1.5V), operating wireless and communicating with the smart home system via 866MHz radio protocol.
- **Smart Home Gateway** - powered by a transformer supply unit (230V AC / 12V DC), controlling components via software.

The first constraint to be dealt with is the voltage, the next is type of current (AC or DC) and if the devices have to be connected to power or battery operated:

$$\forall i \in [1,7],\ \text{voltage}_i = [[0, 6, 12, 24, 110, 230, 380]] \tag{1}$$

$$\forall j \in [1,2],\ \text{type}_j = \{0,1\} \tag{2}$$

$$\forall k \in [1,2],\ \text{connection}_k = \{0,1\} \tag{3}$$

This setting would lead to the following filter (see Formula 4) and incompatibility (see Formula 5 and 6) constraints:

$$fc1 : type = DC \rightarrow voltage \neq 380 \tag{4}$$

$$ic1 : \neg(voltage = voltage_{1-4} \land type = type_0) \tag{5}$$

$$ic1 : \neg(voltage = voltage_{5-7} \land type = type_1) \tag{6}$$

Table 1 shows an overview on possible constraints to deal with in the configuration scenario.

**Table 1: Examples of constraints to be considered in the context of configuration.**

| Category | Subcategory | Variants |
|---|---|---|
| **Power** | | |
| | $Mains(AC)$ | 110, 230, 380V |
| | $DC$ | 0. . . .24V |
| | $Battery$ | 0. . . 60V |
| **Connectivity** | | |
| | $Lan$ | Cat.5. . . .Cat.8 |
| | $Wifi$ | 802.11a..n |
| | $Bluetooth$ | 802.15 |
| | $Zigbee$ | 802.14 |
| | $Radio$ | 433, 866 MHz |
| **Infrastructure** | | |
| | $Wiring$ | NEC(US), IEC(EU). . . |
| | $Sockets$ | Type A. . . Type H |
| **State** | | |
| | $Binary$ | 0,1 |
| | $Discrete$ | 0...10,20 |
| | $Continuous$ | 0...100% |
| **Modality** | | |
| | $Visual$ | Display, Lights,. . . |
| | $Tactile$ | Keyboard, Mouse, Touch, Gesture |
| | $Acoustic$ | Microphone, Speaker |

The overview is meant as example and does not cover all of the possible variations, such as differences in electrical wiring, where there are no global standards (in terms of colours, diameters, etc.). However, speaking of Europe, there are related standards harmonized under DIN EN 60446. Such basic problems related to differences in specifications of components from different manufacturers have to be considered in the context of smart home configuration problems.

## 3 RESULTS

The preliminary result of our activities is the prototype presented in this section. The system already has a basic constraint solver back-end which allows for the simulation of simple smart home related configuration examples, such as how to make a light source in the household smart. The example itself is trivial, however, to guide an end-user appropriately to achieve an adequate solution is not. Based on experiences made in our previous work (e.g. [4, 5]), the approach the end user is guided through to solve his or her actual problem has been changed.

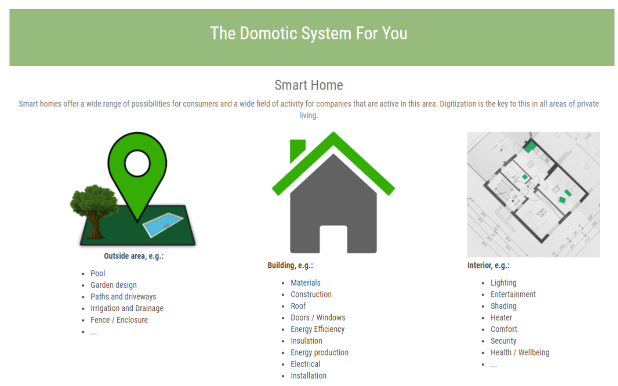


**Figure 2: Smart Home Configurator Overview Page - Different areas and examples of smart devices / functions are shown.**

In our previous work we tried to motivate the user to initially enter a high amount of information on his or her living circumstances (e.g. by sketching a floor plan and placing existing devices on it). This approach is appropriate to support a thorough renovation / a significant enhancement of smartness, but does not pay-off in the case of small enhancements. Therefore, the procedure was changed into a dialogue based approach (see Figure 2) consisting of - in the optimal case - only a few steps.

The concept behind is to ask the user about his or her needs (e.g. making the heating smart) and not about topographic features of the living environment (i.e. where is the heating located). The dialogue starts by guiding the user through the different areas of the living environment (exterior, building structure / hull, interior). In the following steps the user is asked which component or device he or she wants to enhance with smartness (examples are given to increase the understanding).

By choosing a category the user is moved to the next step where the possibilities for smart enhancements are focused on the respective area (in the example the interior) and presented in a higher level


**Figure 3: Smart Home Configurator - Detail page of Interior.**

of detail (Figure 3). In this step the preferred category is selected which leads the user to the more or less last step of the sequence. In this step the concrete possibilities based on the previous selection are shown (Figure 4).


**Figure 4: Concrete possibilities for smartness.**

The list of possibilities is continuously supplemented based on advancement of the constraint solver back-end and the knowledge-base. Figure 5 shows a possible result page. As the user in the example only wanted a quick solution to control his or her lights with the smartphone, the result is not very complex. However, what is taken into account is, for example, that the solution is not a proprietary one, but offers at least the possibility of being integrated in a higher-order system in the future. These aspects are also managed by the constraint solver operating in the back-end.

## 4 DISCUSSION AND CONCLUSIONS

In this paper the current status of a configurator was presented which supports end-users to find appropriate (i.e. individual and customized) solutions to make their living environments smart.

The presented platform is already functioning [2] and utilizes Choco, however with a currently limited functional range which is continuously updated.

[2]http://smarthome.selectionarts.com

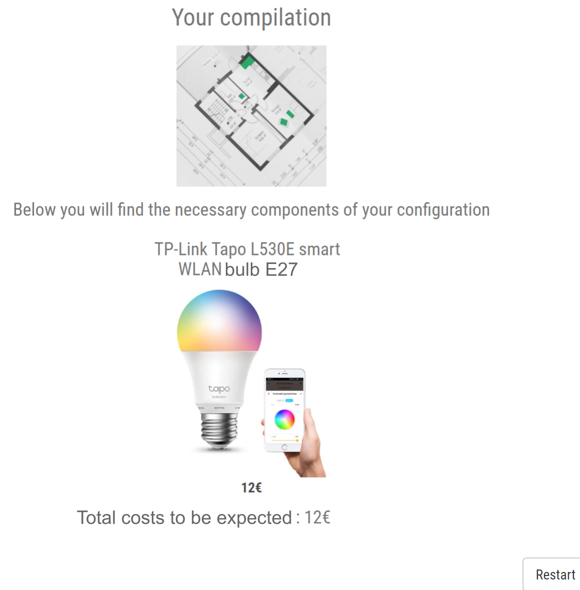


**Figure 5: Smart Home Configurator result page.**

Although the focus of this paper is to emphasize the relevance of the presented approach in the context of energy issues, such a platform can also make sense in the context of other problems. These are, for example, what [14] call the *Big 3* challenges Europe has to face, which are - climate change, aging populations, and digital revolutions. The example emphasized in the paper is mostly related to climate / energy saving and waste reduction aspects. However, such a platform could also contribute to solving other challenges. In regard to the problem of the aging population there are more than one connection points. The first is, that smart homes are seen as one of the potential tools to deal with the problem of aging population, e.g. by giving elderly people the possibility to keep their living standard or even increase it by the support of state-of-the-art technology. The field of AAL (Active and Assisted Living [6]) is booming in this regard. However, due to the shifts in the ratio of retired persons and the working population, shortage of qualified personnel also affects this area. Giving the average consumer the possibility to perform initial steps in the definition / configuration of smart functionality would help in relaxing the related problems. Professionals do not have to be involved throughout the whole process, but at later point of time only, when initial questions are already answered and the first configuration steps are already performed. This aspect is of specific importance in our approach. The goal of the project (Interreg MC 4.0) in the context of which the development of the presented configurator took place is to support small and medium enterprises on their way to digitalization. One competitive advantage of SME compared to globally operating enterprises is their knowledge of the local market and circumstances (e.g. specifications and regulations in regard to electrical installations). Involving them as stakeholders in a smart home configuration scenario results in a win-win situation. If appropriately designed, the outcome of a configuration process provides high quality information on the requirements of a consumer to the professional which has otherwise to be collected during phone calls and personal meetings. This enhances the efficiency on the side of the professional. The consumer on the other hand has the guarantee that the offered solution is appropriate for his or here needs and that their is a local professional available which can manage the installation / maintenance in the consumer's household. This cooperation aspect is discussed in detail in [5]. The presented approach has also connection points to the third challenge - the digital revolution. We in our role as consumers and citizens are continuously forced to use digital instead of human/personal services. Examples thereof are banking and e-government services. Paternò et al. [9] do not only see an increased need of self-services, they even predict the need for users to co-develop their digital systems in the future. When looking back on the development of Web 2.0 this vision might be realistic. However, the authors state that End User Development (EUD) from a socio-technical viewpoint does not only have disadvantages (e.g. being forced to deal with digital interfaces) but also positive aspects. If the digital tools provided are appropriate (in terms of Usability and User Experience) the can support users in achieving solutions that optimally fit their individual needs. In this regard configurators would have high potentials, as we can see on the success of configurators in the automotive sector. However, the big difference to deal with is - in contrast to the automotive sector where the manufacturers can dictate interfaces and specifications to their suppliers - that the variety in the home is almost unlimited.

Besides the advantages of the presented approach it has to be pointed out that there are also limitations, dangers and threads to be considered in the further development. Interconnecting components from different manufacturers raises new questions, for example in connection with warranty. Which manufacturer is held responsible in case of a problem, an accident? Other aspects to take into account are security and safety. Enhancing the usability (by making the operation of components from different manufactures easier) without taking into account potential security problems, which could be the result of exchanging data between different cloud systems could be a disadvantage of the approach.

## 4.1 Future Work

The work described in this paper represents the first version of a new configurator platform as a result from evaluating several design alternatives in the past. The current state is focused on supporting end consumers who are not familiar with the variety of functionality of smart home components or systems and to enable them to find a quick solution for their problems.

One main task for the near future is to enhance the prototype to support scenarios of higher complexity, e.g. a complete renovation of a house or apartment with the goal to make it " completely smart". As was shown in 1, even with a limited set of constraints, the basic problem can already become quite complex. Considering all constraints requires the investment of efforts in the back-end as well as in the front-end, the latter in order to not to overwhelm the user with too many decisions / features.


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