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Supporting integrated approaches to the design of buildings and their technical systems

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Abstract

The optimal operation of buildings' environmental control systems may be hampered by insufficient coordination of processes in one domain (e.g. thermal control system) with other domains (e.g. visual control system). To address this challenge, in-depth communication and collaboration between architects and building service engineers in the design process is critical. Given this background, the present contribution includes three elements: First we briefly present a schema for control logic distribution of building systems (heating, cooling, lighting, and ventilation) that could both support the building systems design process and enhance the communication between architects and engineers. Second, we provide a summary report on an experiment for testing the usability of the proposed method. Third, we present the results of in-depth interviews with experienced professionals in both architecture and engineering fields, not only to obtain specific feedback concerning the scope and potential of the method for the automated generation of building control schemas, but also to tap on their knowledge concerning integrated building and systems design. The results facilitate the understanding of the state and improvement possibilities of the collaborative and integrated design of buildings' technical systems as well as the related potential of the aforementioned building systems control logic distribution schema.

Keywords: architects, engineers, building systems, building controls

1. Introduction

Efficient operation of environmental control systems in buildings is not a trivial task. Insufficient coordination of processes in one domain (e.g. thermal control system) with other domains (e.g. visual control system) may result in inefficiencies. Moreover, the communication and collaboration between architects and building service engineers in the design process is rarely optimal. Primary building designers' knowledge of building systems is frequently wanting. On the other hand, building service engineers often work without explicitly reasoned procedures in determination of the type, number, configuration, and placement of technical devices. This can result in arbitrary solutions devoid of a traceable reasoning. Given this background, the present contribution includes three elements: First we briefly describe a previously proposed schema ([1], [2], [3]) for control logic distribution of building systems (heating, cooling, lighting, and ventilation). Second, we provide a summary report on an experiment for testing the usability of this schema. Third, we present the results of in-depth interviews with experienced professionals in both architecture and engineering fields. Thereby, we not only solicit specific feedback concerning the scope and potential of the method for the automated generation of building control schemas, but also query their views concerning integrated building and systems design. The results facilitate the understanding of the state and improvement possibilities of the collaborative and integrated design of buildings' technical systems as well as the related potential of the aforementioned building systems control logic distribution schema.

2. The control logic distribution schema

The schema serves the explicit and multi-domain representation of the environmental control zones and devices in a building, their relationships, and the respective framework for the distribution of the required control algorithms. It is generated based on two basic layers of information pertaining to an architectural space. It can be generated for an entire building or any part of a building that may be regarded as closed (well bounded) in terms of control actions and their implications.

As the first step, the positions and numbers of devices and sensors must be established. In the illustrative case of a simple office space depicted in Figure 1, devices are: one blind (B), two windows (W1 and W2), two radiators (R1 and R2) and two luminaires (L1 and L2). In this room five sensors represent the spatial impact zones of the devices: two illuminance sensors (E1 and E2), one indoor temperature sensor (θ), one relative humidity sensor (RH) and one carbon dioxide concentration sensor (C). If more than one device share the same sensor, the impact areas of these devices will represented as a single zone. Hence, the zones of the two windows are merged to one as well as the zones of the two radiators.

The generation of the hierarchical control schema (Figure 2), involves the following six steps:

- Arrange distinct control zones as the basis layer of the schema. The state of these zones is captured via respective zone sensors.
- Arrange device controllers (DCs) in the next layer. Every individually controllable device is assumed to have a DC.
- Connect device controllers (DCs) to the zones, whose states are appreciably influenced by the operation of DCs.
- Generate the zone controllers' layer as follows: If more than one DC influences the same zone, a respective zone controller is required to coordinate their operation. This layer accounts thus for the need for zone-specific coordination across multiple devices.
- Generate the high-level controllers (HC) layer as needed: If a DC receives request from more than one zone controller, a high-level controller (HC) is generated. This layer accounts thus for the need for device-specific coordination across multiple zones (high-level controllers, which control an identical group of zone controllers can be unified).
- If high-level controllers overlap in terms of device involved, merge them into one meta-controller.

The distributed multi-layered control schema contains in this example four layers. Layer 1 (zones) and 2 (devices) result from steps 1 to 3. If more than one device affect the same zone and there is only one sensor for each zone, the devices can be combined in the second layer. In this example, the two windows are merged in layer two, because they influence together only one zone and sensor, just as the two radiators. Furthermore, it is assumed that they are operated in tandem and share one actuator. Layer 3 (zone controllers) and 4 (high-level controllers) result from steps 4 and 5. In projects which are more complex, also a fifth layer (meta-controller) may be necessary.

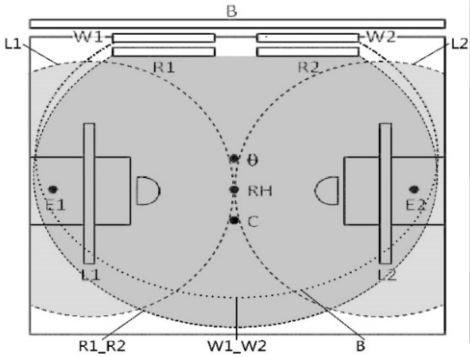

Fig. 1 An office space with seven devices, five sensors and the spatial impact zones of the devices

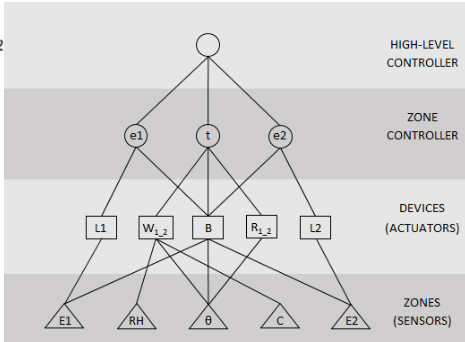

Fig. 2 A control logic distribution schema for the office space from Figure 1

3. Usability experiments for the proposed schema

To improve the control schema generation method and test its usability, an experiment was conducted with 24 architecture and 5 engineering students ([4], [5]). More than half of the students had no experience in designing building systems and only a few of the architecture students did have experience working with engineers. All of the students found it important that architects must know more about buildings' technical systems. The students were introduced to the schema generation method and were asked to apply it to an existing space. Afterwards the participants filled out a questionnaire providing feedback concerning the method's usability, problems faced while generating the schema, and improvement suggestions.

The students' evaluation of the proposed schema was encouraging. The schema and its generation method was found useful in improving the communication between architects and engineers and supporting the understanding of the buildings' technical systems. More than half of the students think that the method helps to identify design problems of the buildings' technical systems and supporting the improvement of buildings' energy performance. The students were also asked about the application and the intelligibility of the method for the automated generation of building control schema. Many students had difficulties in defining zones and finding the correct placement of the sensors, but the frequently mentioned problems concerning the schema were defining zone controllers and high-level controllers.

The projects' evaluation also gave insight into the difficulties applying the method. The first task contained the identification of the devices, terminals and actuators. This was correctly performed by all students. The next task involved the estimation of the spatial impact zones and assigning proper positions for sensors. In many projects, the students defined too many zones and sensors. The participants had also problems with the schema generation process. In many cases, devices were represented separately, even if they are jointly controlled (i.e., share the same actuator). If such devices are not combined in the schema, the next layer becomes too large and the entire schema becomes too complicate. Also in the layer of high-level controllers, there were difficulties. It was often generated in a wrong fashion, for example, the zone controllers were simply connected with a high-level controller. The feedback gained through the experiments with students provided important hints toward improving the structure and the generation process of the proposed schema as wells as its user interface.

4. Interviews with experienced professionals

Ongoing interviews with experienced professionals in both architecture and engineering fields provided insights regarding their educational and professional background. The interviewed professionals shared their understanding and views on building systems and their role in the overall planning of energy-efficient buildings. Specifically, their attitudes regarding the feasibility and usefulness of the proposed scheme was explored. Up to now, 14 architects and 8 building service engineers have been interviewed. Basic information about the interviews and a number of respective results are summarized in Table 1.

Educational background. To be successful, the planning of energy-efficient buildings must not only optimise the primary building design (geometry, fabric, envelope, construction) but also integrate the conception and configuration of the necessary environmental control systems. Hence, the latter activity cannot be exclusively left to specialised engineers, but should also involve primary building designers. This implies the importance of building systems as an essential part of the professionals' education.

The educational background of the interviewed architects and engineers are diverse. 93% of the architects attended a university as compared to only 12.5% of the building service engineers. In Austria – as in many other countries – there is a paucity of educational opportunities (specialised professional degrees) for building service engineers. Hence, only a quarter of the interviewed engineers graduated from a "higher technical school" (HTL) for building services. 50% of the interviewed engineers completed a vocational training as a plumber or draftsman. According to one of the architects interviewed, plumbing companies frequently extend their services to include those of building service engineers. 93% of the architects interviewed suggested that they had been exposed, in their education, to some material on building systems. However, the majority stated that the building systems content of their university curricula had been overtly compressed and insufficient for professional life. On the other side, only one of the interviewed building service engineers, who had started as a draftsman, was introduced to the professional responsibilities and work habits of architects.

Architects and engineers agree that it is important for architects to learn in their education about building systems. They suggested that basic building systems knowledge is essential for the architects' work. Specifically, architects should be aware of the extent and differences of existing building systems solutions and how different systems could be appropriate for different situations (building type, available primary energy types). It is also highly important that architects correctly estimate the required space for building systems terminals, distribution network (for pipes, ducts, shafts, etc.), and technical rooms.

Architects' knowledge about building systems. We asked architects to evaluate the profession's knowledge about building systems and their planning. 38% suggested that it considerably varies (due to experience and personal interest), whereas 31% characterised it as mediocre. Colleagues' knowledge is rarely attributed as poor (8%) but it is not considered to be very good either. While evaluating their own building systems knowledge, the architects appear to be somewhat more forgiving: half of the interviewed architects classify their knowledge as good and 36% as mediocre. Most service engineers see significant variation in architects' knowledge of building systems.

The design process. For a smooth operation of building systems, the technical elements have to be considered from the onset of the architectural design process. Given the interview results, this does not appear to correspond to reality, at least not according to engineers' judgment, 87.5% of whom reported that the primary building design is already completed when the collaboration with architects starts. The percentage was lower (46%) in case of the architects. This discrepancy may be attributable in part to differences in the personal experiences of the professionals interviewed.

All building service engineers we interviewed are convinced that building systems should influence the architectural design process. But only 64% of the architect stated the same. Some architects argue that strict technical specifications and requirements for building systems would limit their degrees of freedom in the design process. Computational tools can provide support in detailed calculations regarding building systems. However, decisions pertaining to the placement of technical systems' terminals are made preferably based on the professionals' experience and not computational tools. Professionals argue that most computational tools and applications are expensive, time-intensive, and complicated. This specifically represents a challenge for smaller companies.

Table 1. Summarised results of professionals' interviews

		Architects	Building service engineers
Educational background	University	93%	12.5%
	Higher technical school	7%	12.5%
	Vocational training	0%	50%
	Others	0%	25%
Was building systems introduced in your education?	Yes	93%	
	No	7%	
Were professional responsibilities and working habits of architects addressed in your education?	Yes		12%
	No		88%
Should architects' education include building systems courses?	Yes	100%	100%
	No	0%	0%
How do you generally rate architects' knowledge about building systems?	Very good	0%	11%
	Good	23%	11%
	Mediocre	31%	11%
	Poor	8%	0%
	Varied	38%	67%
How do you rate your own knowledge of building systems?	Very good	0%	
	Good	50%	
	Mediocre	36%	
	Poor	7%	
	Varied	7%	
Is primary design completed before the start of collaboration between architects and engineers?	Yes	46%	88%
	No	23%	12%
	Partially	31%	0%
Should building systems influence the architectural design process?	Yes	64%	100%
	No	7%	0%
	Partially	29%	0%
On what basis are technical devices placed?	Experience	93%	100%
	simulation/ others	7%	0%

Working experiences amongst architects and engineers. Asked about their experiences with service engineers, architects stated that collaboration generally works well if the engineers participate from the beginning of the planning phase. Some architects criticized that engineers often concentrate only on their own concerns and neglect the consideration of the whole building. They also complained that some engineers focus purely on specific brands of products, which may lead to suboptimal selections.

A further problem in collaboration with service engineers results from the relatively small number of sufficiently experienced building service engineers in Austria. Service engineers the collaboration with architects depends on the individuals involved. Some architects deal intensively with building systems whereas others do not. They also criticized the frequently late onset of the collaboration process. It was also noted that primary building designers frequently underestimate the spatial requirements of technical rooms, building systems terminals, and the distribution system. Both professional groups agree, that a basic understanding of building systems and operation of environmental control systems facilitates the working process of the architects and their collaboration with building service engineers.

Professionals' impression of the proposed schema. The results of in-depth interviews with architects and engineers underline the importance of measures and tools that could effectively support the working process of these professionals and their collaboration. As mentioned earlier, in interviews with professionals, we specifically confronted them with the proposed for the control logic distribution schema to obtain specific feedback concerning the scope and potential of the method and the associated computational support. The architects' impression of the method was largely positive. The bulk of the interviewed architects think that in case of smaller projects such a tool could compensate – to a certain degree – the absence of input from the building service engineers in the very early stages of the design process. Moreover, they could imagine using the method and the respective tool for design support purposes. Toward this end, it would be critical that certain steps in schema generation would be taken in a semi-automated fashion. Likewise, the tool would need routines that would support the automated detection of conflicts and shortcomings in generated schemas. The professionals also suggest that a user-friendly and graphically supported realisation of the tool could facilitate the optimal configuration and placement of indoor environmental control devices.

5. Conclusion

The Interview results suggest that architects receive in their education insufficient instruction regarding building systems. On the other side, nearly none of the interviewed engineers had gained in their education any explicit knowledge of architects' working style and design attitudes. Moreover, inefficiencies in the collaboration between architects and engineers is recognized by both groups. The bulk of thinking regarding the nature and configuration of the technical systems begins only after the primary building design is already finished. Moreover, building service engineers typically operate based on heuristic and experience, rather than formulating an explicit – computationally verified – rationale for the determination the type, number, configuration, and placement of technical devices.

The experts' input not only sheds light on the state and improvement possibilities of the collaborative and integrated design of buildings' technical systems, but can also support the refinement and further development of the aforementioned schema. The usability of the aforementioned method is currently under a test phase.

Professional architects' impression of the method was largely positive, however building service engineers emphasized the importance of timely and close collaboration between architects and engineers.

The students' evaluation of the proposed schema was encouraging. The schema and its generation method was found useful in improving the communication between architects and engineers, supporting the understanding of the buildings' technical systems and help to improve the buildings' energy performance.

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