Network Structure Identification for Medium Transport in a Virtual Reality Environment

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Abstract: Building Information Modelling (BIM) in the Architecture, Engineering, and Construction(AEC) sector allows for significant improvements in working efficiency throughout the entire life cycle of a building and has become mandatory in many countries. This process necessitates a greater understanding of the entire system from engineers, technicians, and facility managers, resulting in a greater demand for appropriate educational methods involving system simulation. The simulation of building energy services includes determining the network structure for medium transport, which is often not included in the BIM-model. This paper describes a workflow for determining the structure of a component-based geometrical model of a building energy service involving medium transport automatically. The workflow can be divided into three stages: identifying connected components, determining valid connection paths from a starting point to an end point, and determining the initialized flow direction of the transport medium within the system as well as the network structure. The depicted solution includes the workflow's implementation and integration into a virtual reality environment for educational purposes. This approach has been validated through various exemplary generated test systems and allows for the realization of flexible educational use cases.

1 INTRODUCTION

1.1 Simulation as Tool for a Better Understanding of Building Energy Services

Building energy services (BES) include technical systems in a building, such as shading, heating, cooling, ventilation, and air conditioning (HVAC), and are responsible for creating a suitable living and working environment for its residents (Hall and Greeno, 2017). BES are an important component of any modern building, contributing significantly to the fulfillment of requirements for user comfort and the overall energy efficiency of the structure.

Different building usages necessitate different BES, ranging from simple BES in an apartment building to much more complex BES in functional buildings. The number of components (e.g., radiators, pumps, pipes, air ducts) as well as the dimension and specific component types vary between BES. The behaviors of different BES differ accordingly, resulting in increased demand for experts (technicians, engineers, and facility managers) in this domain with extensive system knowledge.

The widespread use of Building Information Modelling (BIM) in the Architecture, Engineering, and Construction (AEC) sector (Milyutina, 2018) enables the availability of a building model, including its BES, that is created and improved throughout the building's life cycle. This opens the door to the use of building simulations, which improves the quality of digital twins of building systems (Lydon et al., 2019). The ability to simulate various system behaviors during runtime or even before the building exists leads to a wide range of important applications that significantly improve a building's sustainability. Early in the planning process, the design quality can be evaluated and improved. Anomalies caused by runtime degradation can be identified in real time by comparing measured data in the real building to simulated data.

The benefits of system simulation mentioned above also apply to educational use. Students and trainees can use simulation software such as MatLab Simulink to simulate the runtime behavior of techni-

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cal devices and systems. The resulting data indicates how the system functions given the working conditions defined by the users. Despite the low effort required to adapt the system model, the limitation of using traditional simulation software in education is the simplicity of the result presentation, which limits learning cognition.

1.2 Application of Virtual Reality for an Immersive Learning Experience

The development of Extended Reality (XR) (Kaplan et al., 2021) allows for innovative forms of information presentation. XR includes a variety of spatial interface technologies and conceptual propositions that provide varying degrees of immersion. These concepts, which are Augmented reality (AR), Mixed reality (MR), Augmented Virtuality (AV), Virtual reality (VR), are parts of the reality-virtuality continuum (Milgram and Kishino, 1994).

Among these concepts, VR uses head-mounted displays to provide a fully immersive experience in a virtual environment and has a high potential for supporting immersive learning experiences (Lau and Lee, 2021). An application for fault diagnosis in offshore wind turbines (Kapp et al., 2022), or VR-approaches that offer practical and clinical emergency medical education (Behmadi et al., 2022) (Rad et al., 2022), are examples of VR training tools.

XR education applications in the AEC sector primarily aim to improve learners' learning ability regarding complex spatial arrangements. XR training tools are used for operation guidance (for example, drilling operation training) and safety training for hazard identification and accident prevention (Tan et al., 2022).

In terms of comprehensive BES-knowledge, VRLab4BES is the only publicised education research using XR.

VRLab4BES (Mai and Werdin, 2022) is a VR tool for educational purposes that provides immersive and interactive learning experiences. This tool's primary application domain is training programmes for engineers and technicians in the AEC sector. The learning units in VRLab4BES are based on a simple simulated BES system. Each learning unit involves one or more building trades (for example, cooling or heating) (fig. 1).

Every learning unit is designed as a closed system with interactable components. An example of a learning unit is seen in fig. 2, which consists of a simple heating circuit. Using an interactive hand panel, the learner can reconfigure the various components (a pump, a sensor, a PI-controller, and a two-way

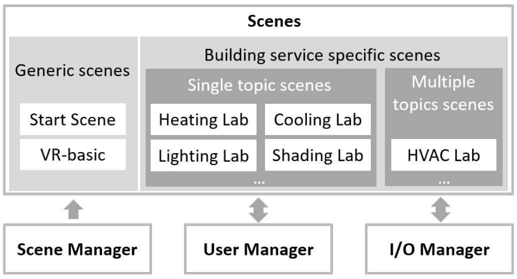

Figure 1: Concept of VRLab4BES (Mai and Werdin, 2022).

valve). The adapted behaviour of individual components and their impact on the overall system are relayed to learners via various diagrams, informational panels, or other visual effects, such as the colours of the pipe's sectors, which depict the temperature of each sector.

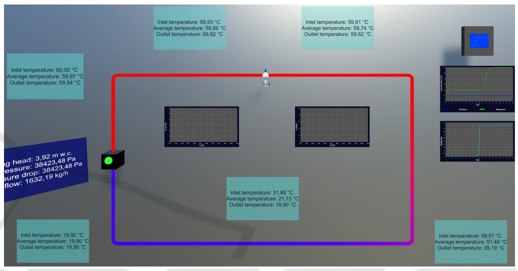

Figure 2: Example of a VR learning unit from VRLab4GST (Mai and Werdin, 2022).

Despite the successful application of the approach in practise (Mai and Werdin, 2022), which shows the advantages in improving learning motivation and cognition over traditional simulation programmes, there is still a lot of potential VRLab4BES. The learners' ability to adapt newly acquired knowledge from a learning unit is limited by the inability to reconstruct or create a BES system from scratch within the learning environment during runtime. Importing and applying the simulation to an existing BIM-Model of a BES is also not possible.

Aside from the difficulties in developing necessary user functions for usability (e.g., a snap function to correctly connect the geometry of different components in a VR-environment), one very important reason for the absence of the aforementioned functions in VRLab4BES is the difficulty in automatically identifying the network structure of a given connected geometry model of a BES. While BIM models can provide information about connectors of various components (for example, air ducts), there is no solution approach that discusses the identification of medium transport systems in general and BES in particular.

1.3 Automated Identification of Network Structure for Medium Transport

This paper introduces a workflow for automatically determining a BES model's network structure as well as the direction of the corresponding medium transport throughout the entire system. This method is the foundation for simulating various building trades such as heating, cooling, air conditioning, and sanitary. The workflow is integrated into the education platform VRLab4BES for validation purposes, and it supports the simulation of heating systems as part of various learning units.

Although the workflow is applicable to other similar usecases and is independent of development environments, the details of its implementation in a VR environment are depicted as a contribution to the research on simulation in XR applications.

2 NETWORK STRUCTURE IDENTIFICATION AS AN ESSENTIAL PART OF BES SIMULATION

2.1 Network Components

A heating system will be used as an example to identify the usage and challenges of network structure identification. A heating system consists of various components of different functions, such as heat source (furnace or heat pump); water circulation system including pipes, bow, T-pieces and crosses; thermostat; heat exchanger; valves as well as other aggregates for safety (e.g. expansion chamber) or the monitoring and system controls (e.g. controller, sensors and operating devices).

Components related to medium transport in a heating system can be classified based on their influence on the medium transport and their number of openings. We use the term *connector* to describe the openings in the scope of this paper. A connector does not only represent a specific geometrical form on the components but also support the parameter exchange between component models as part of the system simulation. Fig. 3 depicts the roles of connectors in terms of medium transport. Each connector can be identified as *input*, *output* or *unidentified*. The *unidentified* status of a connector indicates that the identification process (sec. 3) has not determined this connector's role in the network structure.

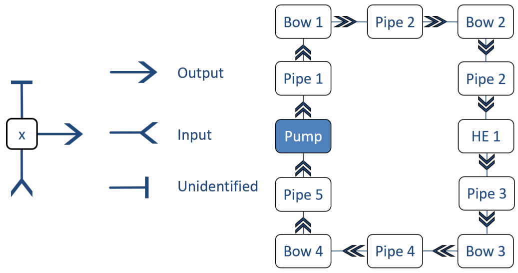

Figure 3: Different roles of component connectors for medium transport.

As a result, the medium transport components can be classified as follows:

- *Pumps* are vital parts of a heating system because they regulate mass flow within the water circulation system. Other building services also have comparable components, such as fans for the air conditioning. Each pump has two connectors, one for water input and the other for water output. Different pumps in a heating system can correspond to different subsystems and functions (e.g. medium transport to heat exchangers or water exchange between the furnace and water tank). Within the scope of this paper, we define a *main pump* as the device in charge of delivering heated water into the system. The main pump is frequently integrated into the heat source. The function of the heat source will be incorporated into the main pump to simplify the description of the workflow in this paper.
- *Circulation components with two connectors* are all non-pump components of the medium transport system with one input and one output. This category includes pipes, bows, heat exchangers, and valves. While valves can have a direct impact on regulating mass flow in the system, they can also be included in this category due to their roles in the yet-to-be-identified network structures.
- *Distributors* are made up of more than two connectors. Aside from water distributors with valves for regulating the flow of water in various heating circuits, aggregates such as T-pieces and pipe crosses can be included in this category.

Aside from the previously mentioned components, there are additional components such as water expansion chambers where water can be delivered to or extracted from. They are part of the heating system's safety components. They will not be included further in the analyses in this paper due to their passive role in medium transport in heating circuits.

2.2 Network Structure and System Simulation

In general, medium transport in a heating system can be described as a closed loop in which the medium begins at the *main pump* (which in this paper also includes the heat source as depicted in sec. 2.1), moves through *circulation components with two connectors*, and returns to the main pump. Figure 3-b depicts an example of a simple heating system. The heated water is transported from the pump to the heat exchanger (HE 1) via multiple pipes and bows, and then back to the pump via additional pipes and bows.

In practise, BES is made up of much more complex network structures. Instead of a single loop, a BES can contain *parallel* structures, as illustrated in fig. 4-a. It is possible to distribute the medium to multiple subsystems by using T-pieces (T1 and T2 in this example). T1 in this example has the function of diverting, while T2 has the function of mixing. Figure 4-b depicts a more complex system structure using T-pieces with multiple subsystems and sub-subsystems. Other distributors with more connectors can transport the medium to multiple subsystems.

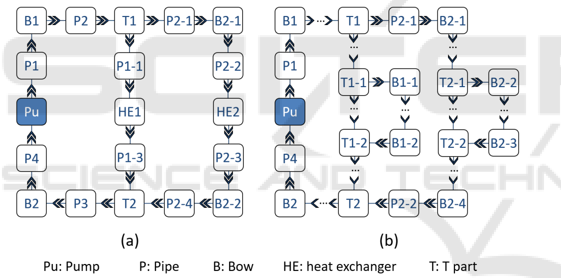

Figure 4: Different network structure in a medium transport system.

A heating system simulation consists of two parts: hydraulic simulation and thermic simulation. All components involved in the medium transport process are simulated. Both simulations are performed in separate loops, beginning with the main pump. The hydraulic simulation determines the hydraulic resistances and other hydraulic parameters. Thermic simulation calculates the temperature in each component or part of a component (e.g. pipe sections) based on the results of the hydraulic simulation and other thermic parameters of the components (e.g. start temperature from the water leaving the main pump, ambient temperature, or the isolation of the components' surface).

The calculation for each component in both simulation loops requires the calculated results from the component(s) before this component in the medium flow direction and delivers data to the calculation for the next components. As a result, the information about the medium flow is critical to the accuracy of the simulation result.

The goal of network structure identification for medium transport in BES is thus to identify all connected components in the system and determine the medium's initialised flow direction through the system given the pump direction. Components such as valves that can be reconfigured during simulation runtime to influence flow direction will be counted as fully opened during the identification process.

BES simulations (for example, in the VR educational environment VRLAb4BES) frequently require this information directly from users. This restricts learning use cases in which learners can import BES' BIM models and simulate them. This limitation also prevents learners from freely modifying the components and structure of a given system and restarting the simulation during a virtual reality learning unit.

3 MODELLING AND IDENTIFICATION OF NETWORK STRUCTURE FOR MEDIUM TRANSPORT SYSTEM

3.1 Modelling of Generic Components in a Medium Transport Network

The modelling of BES components is depicted in fig. 5. Each *BES component* consists of *connectors*, each has one of the three possible *connector types input*, *output* or *unidentified*. Each connector can have a reference of another connector, which this connector is connected to. This concept is used to support the modelling of the network structure consisting of connected components.

Figure 5 depicts the modelling of BES components. Each *BES component* is made up of *connectors*, each with one of three possible *connector types*: *input*, *output*, or *unidentified*. Each connector can have a reference to another connector to which it is connected. This concept is used to aid in the modelling of network structures made up of connected components.

Specific classes describing trade-related properties of a component inherit the generic class *BES component*. To support the ordered execution of the simulation of system components, the concepts *hydraulic component* and *thermic component* are defined for heating system components. The *water connector* in-

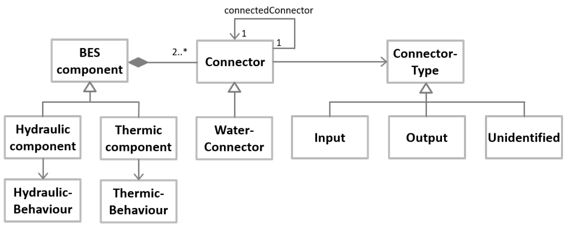

Figure 5: Modeling BES components.

herits the generic *connector* and is used specifically for heating simulation. Also shown in fig. 5 are *hydraulic behaviour* and *thermic behaviour*, where the specific behaviour of each component is calculated based on its own parameters and environment parameters (including the simulation results of its predecessors). The connectors also serve to transfer simulation data between connected components. Because of the focus of this paper, these concepts for behaviour simulation will be described in greater detail in a subsequent publication.

3.2 Generic Workflow to Identify the Network Structure

In terms of network identification, each BES system can be described as a collection of BES components $B = \{b_i\}$. Each component b_i is made up of a series of connectors $C_i = \{c_{i_j}\}$. Each connector $c_{i_j} = (c_{h_k}, t_{i_j})$ contains a reference to its connected connector c_{h_k} belonging to component b_h and a type $t_{i_j} \in T = \{input, output, unidentified\}$

$c_{i_j} = (null, unidentified) \forall i, j$ is the generic starting point for network identification. The goal of the identification workflow is to determine which connectors are connected and whether they are *input* or *output*.

This approach presents a three-steps-workflow, which will be detailed in the following sections.

3.2.1 Identification of Connected Components

The connected connectors will be determined during this step. This information may already be included in a BIM model or must be derived from the BES system's 2D or 3D geometry model. In the case of VRLab4BES, each component has its own 3D model, and a connector is an invisible object positioned in the middle of the 3D model's corresponding opening. *Object colliders* can be added to each connector to determine this *connected*-relationship between connectors. Each collider is a volume centred on the connector object. The collider of one connector can then be compared to the collider of another, resulting in the assignment of connected connectors as references in each connector.

Figure 6 shows a simplified example of this step. The components with their connectors are shown on the left side at the start of this step. The existing connections between connectors of all components are determined at the end of this step. With the exception of the main pump b_0, all connectors have *unidentified* as connector type.

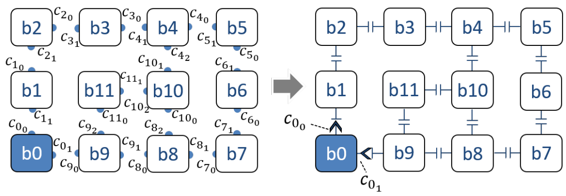

Figure 6: Identification of connected components.

3.2.2 Determine Valid Medium Transport Paths

Given that b_0 is the main component generating mass flow in the system (e.g., the main pump in the heating system), the second step of the workflow will determine all possible valid paths between the output connector c_{0_0} and the input connector c_{0_1} of b_0. Each *path* p_i between two connectors is defined as an ordered list of connectors, with the first and last objects of the list being these two connectors. A valid path is defined as one that has (i) no duplication of its elements and (ii) does not return to the same component after leaving it, with the exception of the main pump. The second condition is met when fewer than three connectors of the same component are found next to each other in a specified path and no other connector of the same component is found else where on the same path.

Algorithm 1 describes the algorithm for determining all possible valid paths within the system. The procedure is carried out using a recursive function *GETPATHS* which takes as parameters any start connector c_{i_j}, any end connector $c_{h_k} \neq c_{i_j}$, the current tracked path p_{cu}, the list $B' \in B$ of components discovered on the current path and the set of paths P.

When the function is executed, it moves along the network through the connected connectors ($c.next$ represents the connected connector of connector c), updates the current path p_{cu} and the list B'. The function distinguishes between (i) the start of the process (L4-L7), (ii) moving from a connector to another within the same component (L9-L11), (iii) moving from one connector to its connected connector (L16-19) and (iv) registering a complete path as an element of P when the algorithm reaches the end connector c_{h_k} (L13-L14).

This step's procedure (L20-L25) includes calling

Algorithm 1: Determine available medium transport paths.

Inputs:
 $(i)\, B$: a set of BES components b_i
 $(ii)\, b_0$: main component generating mass flow
Result:
 P: a set of valid paths p_k from output connector c_{0_0} to input connector c_{0_1} of b_0
function GETPATHS($c_{i_j}, c_{h_k}, p_{cu}, B', P_{result}$)
 if $c_{i_j} = c_{0_0}$ **then**
  $c_{m_n} = c_{i_j}.next$
  $B' \leftarrow B' \cup \{b_m\}$
  GETPATHS($c_{m_n}, c_{h_k}, p_{cu}, B', P_{result}$)
 else
  if $c_{start}.next = p_{current}[p_{cu}.length - 2]$ **then**
   for all $c_{i_x} != c_{i_j}$ **do**
    GETPATHS($c_{i_x}, c_{h_k}, p_{cu}, B' P_{result}$)
  else
   if $c_{i_j}.next = c_{h_k}$ **then**
    $P_{result} \leftarrow P_{result} \cup p_{cu}$
   else
    $c_{m_n} = c_{i_j}.next$
    if $b_m \notin B'$ **then**
     $B' \leftarrow B' \cup \{b_m\}$
     GETPATHS($c_{m_n}, c_{h_k}, p_{cu}, B', P_{result}$)
procedure DETERMINE SET P OF VALID PATHS
 Initialize:
 $P \leftarrow \varnothing$
 $B' \leftarrow \{b_0\}$
 $p_{cu} \leftarrow \{c_{0_0}\}$
 GETPATHS($c_{0_0}, c_{0_1}, p_{cu}, B', P$)
 return P

GETPATHS with c_{0_0} and c_{0_1} as the start and end connector, respectively. The resulting set P is made up of valid network paths.

Four valid paths can be identified and illustrated in fig. 7 for the example in fig. 6. The number for each connector represents the calculated value for the shortest distance to the start connector, which is part of the following step.

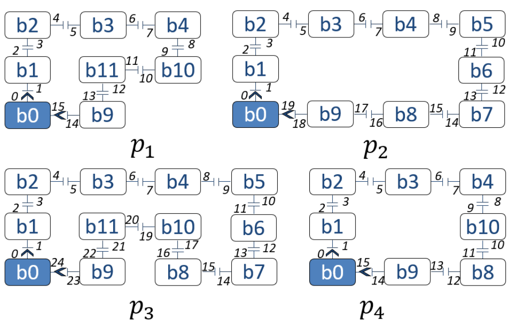

Figure 7: Determine available medium transport paths.

3.2.3 Determining Correct Initialized Medium Transport Direction

Each path identified in the second step represents a potential route for the medium through the system. However, there are paths that contradict each other. In the example in fig. 7, p_3 requires the medium to be transported from b_8 to b_{10} whereas p_4 requires the medium to be transported in the opposite direction.

To address this issue, a function $f(c_{i_j})$ is introduced to calculate the *minimal distance* from any connector c_{i_j} in the system to c_{0_0}. While the distance between connected connectors is defined as zero, the flow distance between connectors of each specific component must be defined or calculated in the 3D model beforehand. Another approach to determining distance is to count the fewest number of connectors between any connector and the c_{0_0} in any path.

During the final step, f will be applied to all connectors in every identified valid path in both cases. The calculated values for the simplified example are shown in Fig. 7. The outcome will be saved as a connector's temporal attribute. If a new value of $f(c_{i_j})$ is found that is less than the current stored value, the stored value will be replaced.

Following this, the stored values of connectors from each *component with two connectors* will be compared (fig. 8-a). The lower-valued connector will be input, while the other will be output. Afterwards, the types of distributors' connectors will be determined based on the type of the connectors connected to them. If a connector connects to an input connector, it will be an output connector, and vice versa (fig. 8-b). Because there are no direct connections between distributors in BES, a distributor's connector always connects to another connector that is not *unidentified*.

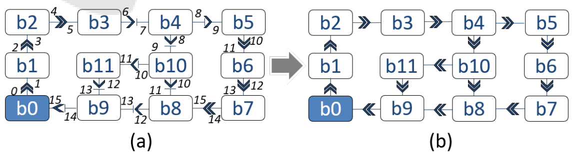

Figure 8: Determining correct initialized medium transport direction.

4 PROTOTYPE IMPLEMENTATION AND VALIDATION

The object model from sec. 3.1 and the workflow from sec. 3.2 to identify the network structure were implemented as part of the VR environment VRLab4BES using the Unity 2020.3.28f1 game engine.

Existing VR learning units for heating have been modified for validation purposes, so that no manual definition of the execution order for the hydraulic and thermic scripts, manual definition of connector type for each connector, or manual assignment of the connected connectors is required.

The approach was evaluated on exemplary systems used in VRLab4BES's various educational units. A test system with a primary pump, one heat exchanger, many valves, and various medium circulation components is depicted in fig. 9. The tests confirmed that the steps in the workflow provided in sec. 3.2 were completed in the right order.

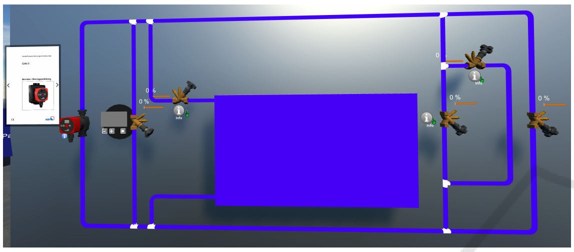

Figure 9: Examplary system for validation test.

The new method produces correct results in systems with parallel subsystems. Systems with other network structures, such as *bridges* between parallel systems, were built for the testing, despite the fact that these structures in BES are not typical. The network identification validation results are correct, reaffirming the approach's applicability in BES simulation and medium transport systems in other domains.

Various test systems were developed to determine the scalability of the approach, varying in: (a) the number of components with two connectors, (b) the number of distributors, and (c) the number of alternative paths from the pump's output to the pump's input. While the number of distributors influences the number of viable paths, the latter aspect is heavily influenced by network topology. As a result, these two aspects should be examined individually. Because the trade-specific duties of each component (e.g., valve, pipe, or heat exchangers) have no effect on the approach's performance, we restricted the components used for the scalability test to a pump, pipes, bows, and T-pieces.

Figure 10-a depicts component blocks made up of several system components that are used to build test systems. Figures 10-b and 10-c show examples of test systems developed for the evaluation.

The method for identifying network structure was run 100 times for each test system. The time it took to complete each loop's various steps was measured and documented. The mean value of the time measured

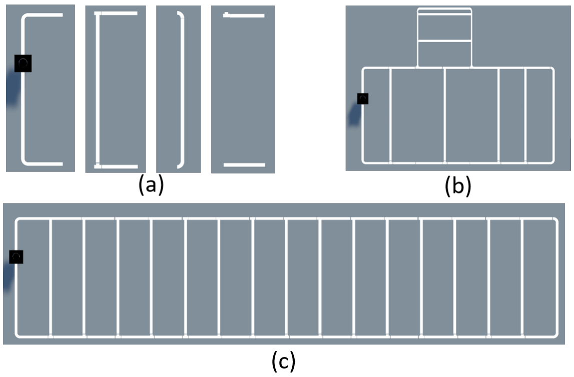

Figure 10: Creating evaluation tests.

for each step is used in the evaluation.

The analysis reveals a linear relationship between the time required to identify connected elements (sec. 3.2.1) and the total number of connectors, which is a combined factor of the number of components with 2 connectors and number of distributors.

The time required to determine the valid medium transport paths (sec. 3.2.2) and the correct initialised medium transport direction (sec. 3.2.3) is affected by a variety of factors. We build many versions for each of the systems in fig. 10-b and fig. 10-c by adding or removing a number of middle-blocks (the second and fourth blocks from the left in fig. 10-a). The time required for each of the two steps mentioned above is shown in fig 11, which varies depending on the number of valid paths for the two test series.

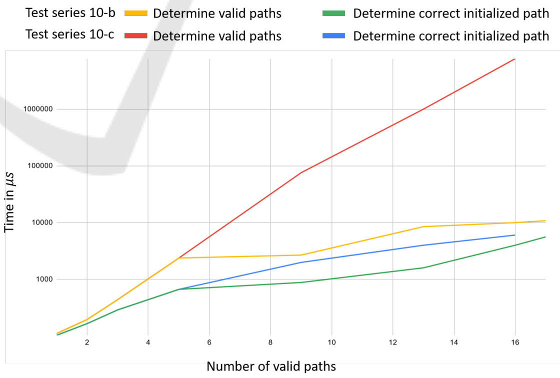

Figure 11: Time measured for the test series.

The variations of both test series with the identical structure and components are shown in the left part of the diagram where the lines overlap. For variations with similar number of valid paths and different number of components, it is demonstrated that the time necessary for the test series 10-b is significantly less than that required for the test series 10-c, particularly for the determination of the valid path.

In general, the workflow duration is related to the number of components, especially the number of distributors that define new branches in the system, as well as the length of the longest feasible valid path. The application of this approach allows a time and effort reduction in configuring learning units in VR-Lab4BES.

5 CONCLUSION

As a groundwork for BES simulation, this paper introduced a workflow for automatically identifying the network structure of medium transport systems as part of BES models. The approach includes a suitable object model with model elements required to describe the network structure and medium flow direction. The workflow is divided into three steps: (i) identifying connected components, (ii) determining valid medium transport paths, and (iii) determining the correct initialised medium transport direction.

For validation, this approach was deployed as a functional extension of the VR educational environment VRLab4BES and evaluated with multiple test heating systems varying in device count and network complexity. The tests show a positive outcome and a significant reduction in effort in developing new virtual reality learning units based on BES simulation.

This approach allows learners to freely create and modify BES systems and apply simulation to each component, rather than dealing with the time-consuming and error-prone manual definition of medium transport direction. For these use cases, research into suitable interacting mechanisms in virtual reality to ensure user-friendliness (e.g. 3D-grid for auto-snap component placement) and the balance between immersiveness and handiness of component placement mechanism during complex system definition is required. Furthermore, due to the scope of this paper, additional details about the hydraulic and thermic simulation of a heating system in VR will be discussed in a subsequent publication.

The procedure of determining medium transport direction based on the shortest distance to the network starting point presented in this paper can be used to other systems using other medium such as air, refrigerant, or electrical energie. Specific implementation and considerations will be required depending on the chosen trade.

REFERENCES

Behmadi, S., Asadi, F., Okhovati, M., and Sarabi, R. (2022). Virtual reality-based medical education versus lecture-based method in teaching start triage lessons in emergency medical students: Virtual reality in medical education. *Journal of Advances in Medical Education and Professionalism, 10(1)*, page 48.

Hall, F. and Greeno, R. (2017). *Building services handbook.* Routledge, 9 edition.

Kaplan, A. D., Cruit, J., Endsley, M., Beers, S. M., Sawyer, B. D., and Hancock, P. A. (2021). The effects of virtual reality, augmented reality, and mixed reality as training enhancement methods: A meta-analysis. *Human factors, 63(4)*, pages 706–726.

Kapp, F., Matthes, N., Kruse, L., Niebeling, M., and Spangenberger, P. (2022). Fehlerdiagnose mit virtual reality trainieren–entwicklung und erprobung einer virtuellen offshore-windenergieanlage. *Zeitschrift für Arbeitswissenschaft*, pages 1–10.

Lau, K. and Lee, P. (2021). Using virtual reality for professional training practices: exploring the factors of applying stereoscopic 3d technologies in knowledge transfer. *Virtual Reality, 25(4)*, pages 985–998.

Lydon, G., Caranovic, S., Hischier, I., and Schlueter, A. (2019). Coupled simulation of thermally active building systems to support a digital twin. *Energy and Buildings 202 (2019).*

Mai, L. T. and Werdin, H. (2022). Vrlab4bes-a virtual reality implementation approach of building service simulation for educational purposes. *2022 8th International Conference on Virtual Reality (ICVR)*, pages 82–89.

Milgram, P. and Kishino, F. (1994). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems, 77(12)*, pages 1321–1329.

Milyutina, M. A. (2018). Introduction of building information modeling (bim) technologies in construction. *Journal of Physics: Conference Series (Vol. 1015, No. 4, p. 042038).* IOP Publishing.

Rad, R., Sadrabad, A., Nouraei, R., Khatony, A., Bashiri, H., Bozorgomid, A., and Rezaeian, S. (2022). Comparative study of virtual and face-to-face training methods on the quality of healthcare services provided by kermanshah pre-hospital emergency staff (ems): randomized educational intervention trial. *Comparative study of virtual and face-to-face training methods on the quality of healthcare services provided by Kermanshah pre-hospital emergency staff (EMS): randomized educational Intervention trial.*, pages 1–7.

Tan, Y., Xu, W., Li, S., and Chen, K. (2022). Augmented and virtual reality (ar/vr) for education and training in the aec industry: A systematic review of research and applications. *Buildings 12, no. 10*, page 1529.