ADVANTAGES AND DISADVANTAGES OF BUILDING BLOCKS IN SIMULATION STUDIES: A LABORATORY EXPERIMENT WITH SIMULATION EXPERTS

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ABSTRACT

Many logistic problems are solved using simulation, however these studies often take too much time and cost too much. One of the reasons for this is the lack of a clear structure of simulation models. To solve this problem we postulate, based on our research, that simulation building blocks can be used to provide fast and easy construction of simulation models that are easy to maintain and to extend. We defined a set of laboratory experiments to evaluate whether building blocks really provide the benefits we expect. In this paper we describe a laboratory experiment in which simulation experts were asked to perform a simulation study and to provide as much support to the problem owners as possible. The experts were divided into two groups: a group with and a group without building blocks. The outcome was nothing like we expected. None of the experts managed to reach an acceptable level of performance. The experts using building blocks faced a lot of errors due to sloppy user input and the experts using plain simulation constructs were still configuring their models at the end of the time allowed for the experiment. The participants using building blocks mainly complained about documentation and the training material, but felt that they understood the building blocks and could, in future, carry out a high-quality simulation study more quickly.

INTRODUCTION

Simulation is often used as a research methodology for problem solving. Many different books exist that show how this research methodology can be used when dealing with logistic problems (Law and Kelton, 1999; Kelton et al, 2002; Banks, 1999; Harrington and Tumay, 1999). The books explain when simulation is useful and what the different involved actors should do. Yet even though there is extensive literature on how a simulation study should be performed, lots of pitfalls can still be identified and these can cause simulation studies to fail. This results in dissatisfied problem owners, projects that miss their deadlines and overspending of budgets. Keller et al (1991) summarize the pitfalls of failed simulation studies as:

- low salesmanship of the simulation expert to the problem owner, i.e. the problem owner does not understand what the simulation expert wants or is trying to do,
- low skills on behalf of the simulation expert, mainly regarding specific domain knowledge and statistical background,
- lack of time to complete the study, so the study is abandoned before all the necessary experiments and statistical tests have been performed.

Robinson (1999) also describes a set of pitfalls specific to simulation studies that cannot be solved using a clear process for a simulation study. These problems result from the *structure* of a simulation model. Robinson lists reasons for these pitfalls:

- the simulation model development is started from scratch, reuse is not applied,
- the implemented simulation model does not fit with the conceptual model,
- the simulation environment leads to unstructured complex models,
- the simulation model is too inflexible and has a limited set of options for experimentation.

The result of these problems is that it takes too long to construct a simulation model, and the models are difficult to use for experiments. When a simulation model is used for experiments to evaluate different scenarios, the simulation model often needs to be extended or adjusted, and a rigid structure makes it difficult to change the model to incorporate the needed extensions. Another problem that is observed is that the problem owner has difficulties understanding the structure of the model, and relating the structure to the real world system.

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A possible solution to these problems is to use reusable blocks to form a simulation model, because – when designed well – these blocks can represent an element of the system in the way the problem owner expects, both in structure and in behavior. We use the term building blocks (Valentin and Verbraeck, 2002) to describe the concept of designed reusable simulation modeling blocks. The concept of building blocks encompasses the idea of decomposing a prototypical system within a domain and implementing the observed domain elements in a standard simulation environment. The expected benefits of simulation building blocks are a higher recognizability of simulation models, easier construction and adjusting of simulation models and an ability to transfer a simulation model to an environment where there is less experience in simulation and experimentation. These benefits should result in a better support for problem owners, because they will receive more insight into their system in less time.

We have implemented sets of building blocks for problems in different domains, such as modeling passenger flows at airports, luggage handling at airports, information flows in supply chains, transaction management in international banking and traffic flows at container terminals. Then, we performed simulation studies in these different domains using the building blocks to construct our models. These case studies taught us much about the structure of building blocks and pointed to several advantages of using such blocks. In this paper we describe a set of laboratory experiments to assess the added value of building blocks by comparing simulation studies using building blocks with studies using a standard simulation environment. The group of analysts consists of simulation experts, who have an experience of many years using the chosen simulation package. Earlier laboratory experiments looked at the ease of adjusting a simulation model to run simulation experiments, and at the construction of a simulation model using building blocks. Both experiments were performed by novices and showed us that some parts of simulation studies can benefit from using building blocks, but that activities where there where no building blocks used caused the novices more problems than we expected. We therefore wanted to see whether the benefits of using building blocks remain when we study simulation experts instead of novices. The research question for this third laboratory experiment was:

> *Can simulation experts provide better support to a problem owner by using building blocks than by using the standard constructs of a simulation environment?*

We give more background on building blocks and the main lessons we hoped to learn from this laboratory experiment in section two. In section three we describe the set-up of the laboratory experiments, and in section four we discuss the outcome of laboratory experiments. We conclude this paper by relating the laboratory experiment described in this paper to future planned research and experiments.

BACKGROUND

Simulation environments increasingly provide us with constructs, which allow us to later reuse parts of our model. The main arguments provided by the simulation vendors to support these features are faster model construction and an ability to reuse previous work. In our research projects we tried to work with the provided concept. The first simulation study that we performed in a domain by using (reusable) objects was a success, but follow-up simulation studies in the same domain were much harder and did not reuse the objects as much as we expected (Verbraeck et al, 1998; Hooghiemstra and Teunisse, 1998). We also had problems with transferring the objects to other modelers, who did not understand the objects or tended to 'misuse' them, or use them in a different way than we had intended.

The experiences we had with these cases caused us to come up with the idea of building blocks. Our research is based on the on-going research of the BETADE research program (Verbraeck et al, 2002). BETADE defines the concept of building block as:

> *A building block is a self-contained, interoperable, reusable and replaceable unit that encapsulates its internal structure and provides useful services to its environment through precisely defined interfaces*

In the software engineering the similar definitions are used for software components. Within the BETADE research program is argued that a BuildingBlock applies in many more domains than only software. Therefore a software component is an implementation of a building block in software. Based on the knowledge of the BETADE research program and our experience drawn from the above mentioned cases, we filled in the concept of simulation building blocks using a structure consisting of different levels of abstraction and different types of blocks (Valentin and Verbraeck, 2002). When we used these new building blocks in a set of case studies the expected benefits of faster model construction, structured models and a reduced need for experienced simulation experts seemed to be achieved; however, we had nothing with which to compare our results. The main questions were: Was it *really* faster? And: did it *really* reduce the need for experienced simulation experts to successfully carry out a study? Because we could not answer these questions we also could not say whether building blocks really provide improved support for problem owners.

From the literature on software engineering research we learned that expert and novice software developers use software components in a different way. The experts are more hesitant to use components and prefer to construct models or components themselves, because they are not sure whether they can trust a component made by others. Novices are glad the components are available and see them as their best option. We expected the same kind of outcome in simulation studies, and we wanted to evaluate whether experts and novices used the simulation building blocks in accordance with our conceptual definitions. The planned set of laboratory experiments was designed to show us the difference between building blocks and constructs of standard simulation environments and whether we needed to improve the conceptual model of building blocks in some way.

LABORATORY EXPERIMENT

General Information

Our goal for the whole range of laboratory experiments was to identify whether simulation studies are carried out more effectively when building blocks are used, rather than constructing the model from the elements of a standard simulation environment. Figure 1 is a simple representation of the expected effects of building blocks on the outcome of a simulation study, the '+' and '–' signs in the figure denote the expected relationships, which we have evaluated in different laboratory experiments. Process descriptions of simulation studies (Law and Kelton, 1999; Kelton et al, 2002; Banks, 1999; Harrington and Tumay, 1999) show that the number of actions a simulation expert has to perform varies with the phase of the project. Thus we needed different kinds of experiments to evaluate the sub-processes to permit conclusions to be drawn for all the '+' and '–' relationships. We describe in this paper the third laboratory experiment in the range of evaluating building blocks in predefined settings.

We used two sets of building blocks with different levels of "domain specificity" in the different laboratory experiments. More precisely, we used one set of building blocks and constructs taken from the simulation environment Arena (Kelton et al, 2002). Arena is one of the most popular commercial simulation environments at the moment, and it was one of the first simulation environments that allowed for the development of building blocks by simulation experts. We use this environment to teach simulation to our students at the faculty of Technology Policy and Management of Delft University of Technology. This in turn has helped us to get a reasonable set of novices who are willing to participate in the experiments. Finally the vendors of the simulation environment were willing to participate in laboratory experiments and to provide experienced simulation experts for experiments to test the effectiveness of simulation building blocks. Experts from Rockwell Software were studied in this laboratory experiment. These experts are developers of the simulation software Arena and internal consultants with several years of experience.

We required a case study for the laboratory experiments aimed at measuring the relationships shown in figure 1. It was also necessary that the case could be modeled within a limited time, that it showed repetition to provide a trigger for the use of building blocks, and that it was suitable to be modeled using the simulation environment Arena. We ended up with a design problem for an advanced automatic public transportation system. This system, based on a simulation project performed by Brandt (1999), has been proposed to provide public transport between the cities of The Hague and Ypenburgh in the Netherlands. We judged that we could reuse all the data from this study to provide input and output, and a good (verified and validated) set of performance indicators.

The map of the expected route between the cities of The Hague and Ypenburgh is shown in figure 2. This simulation study was designed to handle a new and advanced automatic transportation system. The route is fixed, but there are still a lot of open design choices that need to be evaluated using simulation.

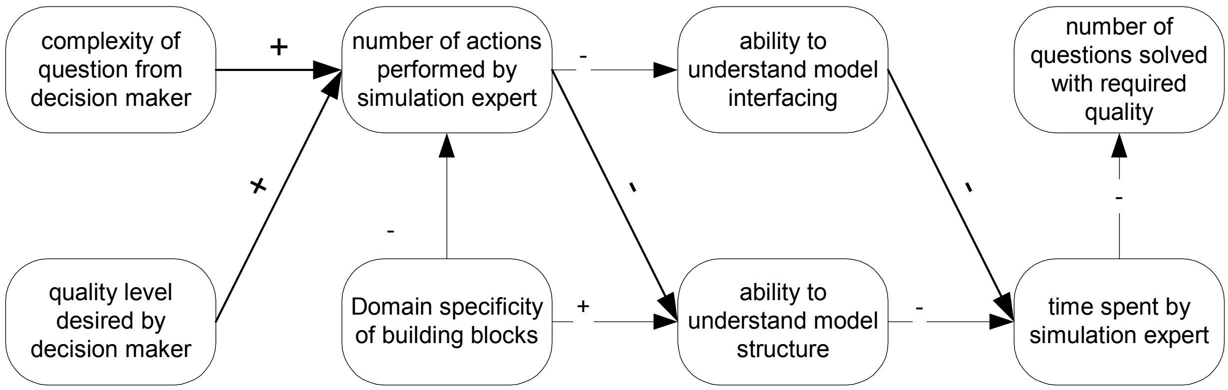

Figure 1: Causal diagram simulation study

Some of the choices are:

- type of vehicle; monorail versus cable mover, large versus small vehicles, fast versus slow
- number of vehicles
- daily pattern of the vehicles
- number of platforms at stations
- number of tracks between stations

These choices need to be evaluated for a large set of scenarios. A small set of variables needed to be varied in the scenarios to test the proposed solution under a wide range of assumptions. The variables are: arrival pattern of passengers, origin-destination relationships of passengers, effects of new offices or leisure activities in the region attracting new passengers, effects of transfers from and to the conventional public transportation (bus, tram, and train).

We developed a set of building blocks that fit the building block concept of Valentin and Verbraeck (2002). The set of building blocks consists of blocks for the physical infrastructure, e.g. *track*, *platform*, *station* and several building blocks for *control* and *generators* for passengers and vehicles. Using the building blocks we were able to develop the same models that Brandt developed using the Arena simulation language without building blocks. We used the same performance indicators and data input and evaluated the outcome. The key values, among them traveled kilometers for vehicle and passengers, utilization of vehicle and wait time were the same, with a 95% confidence interval, as in the original model.

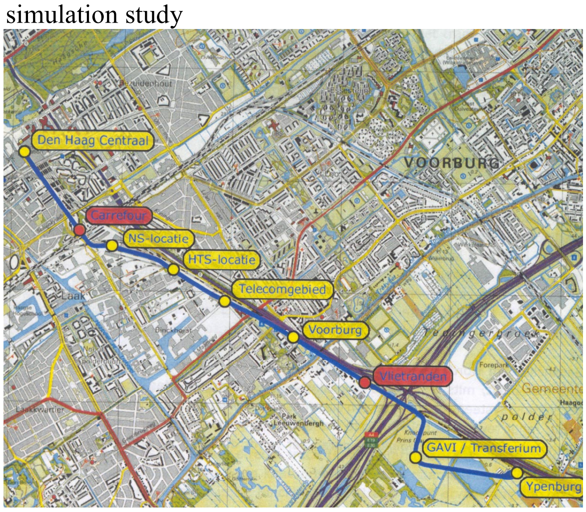

Figure 2: Expected route for the SkyShuttle transportation system

Set-up Laboratory Experiment

In a first simulation experiment, we gave the Delft students a pre-developed simulation model, either with or without building blocks, for the transportation system problem. The students had to perform different simulation experiments using these models. The main outcome of this laboratory experiment was that the novices in simulation using building blocks could adjust the models faster for experiments than the other group, this group thought that their models were easy to understand and maintain, but they completely forgot about the need to validate their models.

In the second laboratory experiment we asked participants with a similar background and knowledge as in the first experiment to develop a full simulation model from scratch for the problem situation, including the preparation of the experiments. The students using building blocks could develop a simulation model quite quickly, but had a lot of problems with the user-input and producing of a good and valid initial set-up. The students using simulation constructs worked hard, but forgot to abstract from their problem working in more detail than the students using building blocks.

Based on both observations we concluded that simulation experts using building blocks is usually faster, because they can quickly set-up their model, but using standard simulation constructs is not so bad, because modelers can reduce and abstract their initial model much better. The second laboratory experiment triggered a third laboratory experiment using simulation experts, which is described in this paper in more detail. We expected that simulation experts would perform better than novices, and we had them work on the complete simulation study where the simulation model had to be built from scratch – with and without building blocks. We limited the participants' time to 8 hours, let them construct a simulation model at the level of detail they preferred and let them perform the experiments that they assumed to be key. Afterwards we evaluated the performance of the simulation experts by showing the outcome of the study to real problem owners.

Eight employees from the company Rockwell Software participated in the experiment. Rockwell Software bought the company Systems Modeling that developed the simulation environments SIMAN and Arena. A sample of 8 persons is small, but given the expertise of these people we were glad they could participate. All of the participants involved had been working for at least 5 years in simulation, some of them even for 20 years. The group consisted of developers of the Arena core code, developers of templates in Arena and consultants that use Arena in commercial projects. Even though the group consisted only of simulation experts, the experts were not comparable, e.g. a junior consultant can not be compared to a developer of the Arena core who has published more than 20 scientific articles about discrete event simulation. The group was divided into four comparable couples:

- two developers of Arena software with more than 15 years of experience and a PhD in computer science,
- two expert Arena user with ± 10 years of experience,
- two developer of commercial Arena Templates (Call Centers and High Speed Packaging) with ± 7 years of experience,
- two junior consultant mainly using Arena, including VBA with ± 5 years of experience in simulation projects.

One person of the couple, chosen at random, received building blocks developed in Arena including all documentation (but not the source code). The partner person was expected to work with the Arena basic constructs.

The participants were given a maximum of 8 hours to develop their model and to run any number of experiments they assumed to be necessary. The experiments were meant to demonstrate the validity of the simulation models. If they finished in less than 8 hours, the participants could continue doing other things. None of the participants was able to participate for a straight 8 hours in a row, so they divided the laboratory experiment over a period of three days.

All the participants received documentation about the concepts that could be used for the simulation models. These concepts formed the basis of the building blocks that were given to the experts using building blocks. It was made very clear to all participants that the conceptual model was just an overview and they were not forced to comply with the conceptual models. The group using building blocks received some extra material about the background and technical implementation of the building blocks. The time that participants with building blocks needed to understand this material was included as part of the 8 hour allowed for the complete laboratory experiment.

At the end of the laboratory experiment the participants were required to provide a set of deliverables.

1. A simulation model based on the building blocks or the Arena basic constructs.
2. An extension to the presentation of the SkyShuttle team that could be used to explain the problem solution to the problem owners at the Municipality of The Hague
3. A filled in questionnaire about their satisfaction with using either the building blocks or the Arena constructs and their expectations of the model development assignment
4. A log-file describing their activities of the 8-hour period.

Plans for Evaluation

The evaluation we planned to do using the results of the participants consisted of three steps. The first step dealt with the problem owner of the SkyShuttle project. The problem owner needed to feel supported by the simulation expert, based on model outcome, visualization, experiments and useful model abstractions. The second step was to judge the quality of the simulation model, using simulation experts, on level of detail, completeness, model structure and ease of adjustment. The third step was to evaluate the questionnaire and log files created by the participants.

We did not have real problem owners for this evaluation, because we were working with a slightly adapted case compared to the original study. However, we asked the problem owners of the initial study that triggered this setup for the laboratory experiment to participate, and some other experts drawn from the field of transportation who have used simulation models in their projects. We developed a list of more than 50 items that a problem owner might be interested in. We planned to let the problem owner set the priority of these items and then judge the work of each of the participants to determine how well it dealt with the top 15 items. We planned to do the same thing with the simulation expert, we first showed them a large list of items, then we let them prioritize and score the top 15 items for the final simulation models of each of the participants. The two basic lists were developed together with R. Sadowski, the chair of the annual Arena-modeling contest for undergraduate students.

Based on the material of the problem owner, the simulation experts, the questionnaire and the log-files we expect to see that:

- the problem owner would judge the visualization and performance indicators of the simulation models using building blocks to be more valuable than the visualization and performance indicators of the simulation models based on the basic constructs,
- the simulation models based on the building blocks would contain more details than the models using basic constructs,
- the first simulation model based on the basic simulation constructs of Arena would differ more in detail, quality and animation, from the final simulation model, compared to the differences between the first and final model using building blocks,
- the participants using the building blocks would be more positive about the quality of their simulation models, technically and visually, compared to the model developers using basic constructs,
- the participants using the building blocks would assume they had better met the problem owner's needs regarding visualization, performance indicators and preparation for future experiments compared to the assumptions made by model developers using basic constructs.
- the participants using building blocks would agree more with the statement that they had had enough time compared to the model developers using basic constructs.

OBSERVATIONS LABORATORY EXPERIMENT

Unfortunately we could not apply the evaluation plan as we designed it. The participants in the laboratory experiment did not succeed in finishing the simulation study. None of the participants performed a full range of simulation experiments and none of them provided a good design for the SkyShuttle system. The participants provided different reasons for failure and combined with our observations this lead to some additional conclusions, which we will discuss below. We would have preferred to use the objective problem owners and simulation experts, but because the work was not finished, it did not make sense to bother these volunteers with the unfinished outcomes produced by the participants.

Observations during the laboratory experiment

During the laboratory experiment we made notes of the things we noticed regarding the processes and the models of the participants. We then evaluated these observations with the participants, remarkably similar ideas were identified and registered, this allows us to speak of the participants using building blocks as one composite individual and the participants using the standard Arena concepts as another.

The participants using building blocks started directly, clicking the simulation model together based on the diagrams shown in the documentation. They copied the data from the Excel sheets, unfortunately this copying was done by retyping instead of copying all the text at once, and once they were finished they tested the model to see if it worked. This first attempt to run a full model took two and a half to four hours of work.

The participants using building blocks were convinced their model was correct and as a result they were surprised when they received error messages. The errors ranged from "reserved name" to "linker errors" and "undefined symbol". The participants spent the following hours solving their problems. The participants used different ways to do this. Two of the participants dived into the example models and tried to see what was different, they performed the test assignments and got stuck with the examples, because their results differed by 0.4 % with the mentioned values of the main performance indicators. The other participants constructed the whole model twice before they noticed they had made a typing error in one of the names of one of the elements in their simulation model.

Once the participants using building blocks got the model running, but the model contained deadlocks and produced an odd outcome. Both problems were due to an invalid configuration and should have been solved by applying different parameter settings, e.g. more tracks, different platforms, or a different vehicle frequency. However, the participants doubted the quality of the building blocks and started to debug the simulation model using the SIMAN-command view. As a result they did not succeed in performing experiments. These participants stated that they now understood the working of the building blocks and would be well able to perform the test if they were asked to do it again.

The participants without building block all started with a good walk-through of the problem description and the provided conceptual model. Probably they followed the conceptual model so closely that they did not think to deviate from it, because the provided simulation models were very comparable to the conceptual models provided to act as an example. However, the conceptual models contained a lot of details like the scheduling of vehicles, the behavior of doors and destination schedule of passengers. As a result of not applying reduction to their models, none of the participants using the basic Arena constructs succeeded in developing a complete working model in Arena.

The main reason for the lack of outcome was a lack of reduction, but some additional reasons were individual choices in setting up the of their simulation models as well. One of the participants used VBA-code to automatically construct the simulation model, but getting the VBA-code correct took much more time than he expected. Another participant had been working with the development of new features for Arena for a couple of years, and was not used to the available SIMAN constructs, so he lost a lot of time evaluating different concepts to model his vehicles, in the end he had this working, but did not have time to implement the passengers in his simulation model. The last two participants working with the Arena constructs noticed the long list of desired experiments and made sure their models were very flexible for any kind of layout and vehicle parameter setting. This flexibility lead to concepts that did not allow easy communication with passengers and this made the implementation of passengers in the simulation model very hard, a task they had not completed at the end of the experiment.

Observations based on the Time Logging Form

Most of the important parts of the log-form have already been discussed in the previous sub-section. The participants using building blocks needed a lot of time to get their simulation model working the way they wanted. The participants using the Arena constructs spent almost all their time on model development. One of the participants pointed out in his log-form that he spent 5 minutes on experimentation in the first hour, which he used to think out the different experiments he wanted to perform. In the evaluation with all participants they claimed that they all spent some time to overview the kinds of experiments they needed to perform.

Outcome of the Questionnaire

The questionnaire showed clearly that the participants were short on time and it also showed that all the participants expected they would do much better if they would have had more time. The main difference was that the participants using building blocks thought they needed 2 to 4 more hours, while the participants using Arena constructs thought they would need 10 to 30 more hours to get the simulation study finished.

From the questionnaire it could be seen that the participants using building blocks expected that the problem owners would like their work better. They expected to be able to easily do any possible experiment and to easily visualize the simulation model in such a way the problem owner would understand what was going on. The participants using the Arena constructs were less optimistic. They assumed they could do most of the desired experiments, but had to conclude that they would ignore some of the issues, as they were not prepared for them and could not extend their simulation model in that direction.

Outcome of Evaluation with Participants

After all the participants had handed in their material, we arranged a meeting to discuss the preliminary analysis and what we had expected. During this meeting we discussed the outcomes of the participants, mainly why they did not succeed in finishing on time. The participants using Arena concepts agreed that they followed the conceptual model and the suggested experiments too much. They did not think of doing a quick and more global study first, followed by a more detailed analysis. The participants using the building blocks complained about the documentation. They received error messages, which they could not understand. They complained about a lack of quick explanations, something like a Frequently-Asked-Question list to help them through their main problems. They also complained they did not have the code, so when they encountered problems, they could not check the source code of the building blocks to see whether the developers of the building blocks had made any mistakes.

CONCLUSIONS OF THIS LABORATORY EXPERIMENT

Our overall observations are that the experts using building blocks had a high conceptual mismatch and hesitation before fully trusting the building blocks using them. When we compare this with the novices in the first two laboratory experiments (adjusting a simulation model and develop a simulation model) the novices did not have an opinion of their own how to model such a system, they just did what they were asked to do. They did not have any conceptual idea about how a transportation system should work, so they did not want to understand the building blocks. Based on the desire for additional technical information, we can conclude that simulation experts need to be fully convinced of the technical superiority of building blocks before they use them, this will allow them to conclude that they are wrong when errors are reported, instead of the building blocks. This process of producing conviction should be performed using hands-on training, additional explanations or Frequently-Asked-Question lists.

The participants using the Arena concepts wanted to show off their expertise with Arena and show they could model any conceptual model. They were convinced of the quality of their generic simulation tool so they did not want to abstract too much. However, pragmatic problem solving collided with their drive for high-quality solutions and this resulted in no solution within the time parameters of the experiment.

FUTURE RESEARCH

Even though the outcome was not as convincing as we expected before we started the laboratory experiment, we can still conclude that building blocks show a higher efficiency for the support of problem owners using a simulation study. This laboratory experiment showed that simulation experts using building blocks achieve more results than simulation experts that start with standard simulation constructs, and we expect that the difference may even be larger. An important indicator for this is the expected time the experts would need to successfully complete the study: the building block group mentioned 2-4 hours, compared to 10-30 hours for the basic simulation group.

One of the main outcome was that the documentation and training for the experts using building blocks was not good enough, we need to convince the experts that building blocks are the concept of choice before allowing them to work with building blocks. This might sound harsh, but the main thing that these technical experts wanted, was insight into the building blocks. They experienced the building blocks as black boxes and they did not fully accept what was going on.

Finally, the participants of this laboratory experiment were mainly developers of the simulation environment Arena and not consultants that work daily in a simulation environment. Perhaps the differences between the participants using building blocks and those using Arena constructs would change if simulation consultants performed the laboratory experiment.

Both ideas, using improved technical documentation and different kind of experts, need to be tested to gather additional knowledge about the efficiency of using of building blocks in simulation studies.

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