Model-driven Development for User-centric Well-being Support
From Dynamic Well-being Domain Models to Context-aware Applications

Steven Bosems and Marten van Sinderen
Faculty of Electrical Engineering, Mathematics and Computer Science, University of Twente, Enschede, The Netherlands

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Abstract: Applications that can use information obtained through device sensors to alter their behavior are called context-aware. Design and development of such applications is currently done by modeling the application's context or by using novel requirements engineering methods. If the application is to support the user's well-being, these methods fall short due to their technical focus. We propose a model-driven approach that deals with the specifics of the well-being domain by using a DSL that captures the user's personal well-being context. The development method is user-centric, rather than technology focused. Initial user experiments show promising results.

1 INTRODUCTION

Throughout the years, an increase in the amount of available sensors in smartphone devices can be observed. Even low-end models are equipped with a wide array of means to collect data. With this data available, applications that can derive information from it to alter their run-time behavior are growing in popularity. (Dey, 2001) defines such context information as "any information that can be used to characterize the situation of an entity." Applications that can use context information to enhance their services are called *context-aware*. Examples are alterations of the application's behavior when the user's location changes or changes in the use of external services when new services become available.

One domain in particular benefiting from this context-aware nature, is that of *well-being*. Although closely related to health-care, which is defined as "efforts made to maintain or restore health especially by trained and licensed professional" (Merriam-Webster, 2014), well-being concerns the improvement of one's health and overall state of happiness without a predefined treatment plan or professional guidance.

Developers working on context-aware well-being systems face two challenges: (i) the application has to cope with a continuously changing system environment at run-time, which can not be fully predicted at design time, and (ii) well-being systems are highly personal, so development has to be user centric.

Our contribution to the field of development of context-aware well-being systems consists of three parts. Firstly, we have created a DSL that allows us to capture specifics of the well-being domain. Secondly, we have developed a model-driven approach for application development that leverages this DSL. This method is supported by model transformations and tools. Thirdly, we have applied our method to several cases to demonstrate it works and results in an improved development process. This paper continues work by (Bosems and van Sinderen, 2014a) and (Bosems and van Sinderen, 2014b).

The rest of this paper is structured as follows: section 2 provides a motivating example, and section 3 lists related work. In section 4 we discuss the structure of our DSL for the well-being domain. Section 5 lists the technologies used in our model-driven process, section 6 provides information about the tool support offered, section 7 explains our model transformation process, for which use cases are discussed in section 8. Section 9 provides concluding remarks and directions for future work.

2 MOTIVATING EXAMPLE

Our example is based on the "Activity Coach" (op den Akker, H. et al., 2012). The application runs on a smart-phone and monitors the user during the day. Its goal is to improve the user's physical well-being, which is done by managing the his/her activity. The application coaches him/her to be more active when

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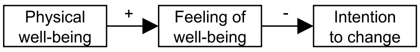


Figure 1: A simple causal path.

s/he is passive, or slowing him/her down if s/he undertakes too much activity early on in the day. The application works unobtrusively. The user's activity progress is evaluated regularly, and feedback is provided to guide the user. Other important factors for the Activity Coach are the user's motivation and intention to change his/her daily behavior. Physical factors such as cardiovascular fitness and body composition should also be taken into account, as well as heart rate and blood pressure. Relations between these factors may not be intuitively clear.

3 RELATED WORK

The development of context-aware applications has widely been recognized as demanding. Several solution directions exist.

Firstly, (Seyff, N. et al., 2008) recognize that continuous changes in the environment around the user will cause changing user requirements: requirements are context dependent. The authors try to solve this problem by incorporating in-situ requirements engineering in the design process: a requirements engineer follows users while they use a prototype version of the application under development, noting down new requirements and the respective context as they arise. This method is labor intensive.

Secondly, runtime models are proposed as a solution (Alferez and Pelechano, 2012), (Salifu, M. et al., 2007), (Sitou and Spanfelner, 2007), (Qureshi and Perini, 2010). Approaches in this direction capture either requirements or context information in models which can be interpreted by the application at runtime. If a situation of context change occurs, these models are reevaluated. The internal models can be adapted to reflect the updated context when needed, or the desired behavior can be derived from the requirements captured in the models. These models, however, expect extensive context knowledge and the ability to predict required information.

Thirdly, authors propose to use model-driven approaches as a tool for development (Maiden, N. A. M. et al., 2004), (Muñoz, J. et al., 2006). These approaches, however, are aimed at solving the technological problems of context-awareness, disregarding the future end-user. We propose a method that is centered around the user, thus being better able to cope with changes in the personal context.

Finally, the modeling of the context of the application is given as a solution direction (Henricksen, K. et al., 2002), (Henricksen and Indulska, 2006). By capturing every aspect of the (technical) context, the development of context-aware applications should become easier. However, while this approach might suffice for applications with a clearly defined context (a tour guide for example), or systems that deal with altering, but predictable contexts (one location with actors moving through it such as a smart room), this will not work for our intended goal: the domain of personal well-being is highly dynamic and not all relations among the different context elements are fully understood.

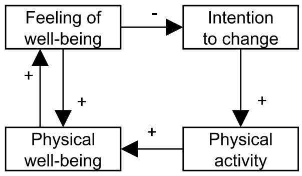


Figure 2: Two causal loops.

4 DYNAMIC WELL-BEING DOMAIN MODELS

In this section, we will provide a short description on the structure of Dynamic Well-being Domain Models (DWDMs). DWDMs consist of three types of modeling elements: i) variables, ii) causalities, and iii) norms. Figure 3 shows a DWDM for the Activity Coach.

4.1 Variables

In DWDMs, variables represent context factors and well-being conditions. Variables have several attributes: (i) annotations, (ii) unit of measurement, (iii) processing type, and (iv) measurement scale.

A variable's *annotation* captures if we, considering the current state of the sensor techniques, can *observe* the variable value, or that the variable can be influenced by the system directly. For example, it is possible to measure a user's "Physical activity" using accelerometers, making it an observable variable. The user's "Intention to change" on the other hand can not be obtained through sensors, but should be *deduced* by obtaining additional information, and reasoning about the variable's value. Variables that can be *controlled* directly by the system are more rare, as they tend to include only those context variables that are part of actuators. An example of such a variable is "Valve position," modeling the current position of a radiator valve in a temperature control system.

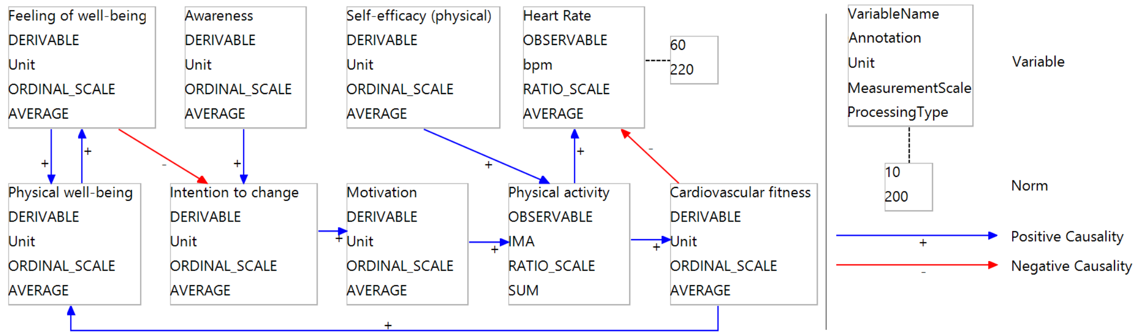


Figure 3: DWDM for the Activity Coach.

Variables may have a *unit of measurement*. Unlike the annotation, not all variables have this property: it is most common in variables that are observable. Units of measurement can be categorized as either being absolute (the value stands on it's own, such as the user's blood pressure), or relative (the value is relative to an other unit of measurement, such as the concept of cardiovascular fitness). Furthermore, units can either be time dependent (measurement of events occurring over a certain period of time, such as heart rate in beats per minute), or time independent.

The *processing type* of a variable affects the way a variable value should be processed. Variable value reading stands can stand on themselves, or can require additional processing. An example of the former is the user's current location, telling us something about the current context. Values of variables in the latter category require multiple sensor readings to reason about their value, such as the user's speed of traveling, for which we need at least two measurements of the user's location (to calculate the traveled distance), and the time required to travel between these.

Lastly, we distinct four types of *measurement scales* (Stevens, 1946) on which the values of variables can be measured. Using these, we can determine what value calculations may be performed. The nominal scale only allows for equality comparison, an ordinal scale makes it possible to create a ranking among variables, the interval scale adds detail regarding the size difference between measurements, and the ratio scale adds knowledge of a non-arbitrary 0 point.

4.2 Causalities

DWDMs consist of model elements that capture real-world context elements, their properties, and relations between them. In DWDMs, these relations are *causal relations*. They have two properties. The first is the direction. A relation has a source and a target, indicating which variable is affected by which other variable. By looking at the direction, we can reason about how variables are affected throughout the DWDM.

The second property is the polarity of the relation, i.e. if the causal relation is positive or negative. A positive causal relation from source to target indicates that an increase in the former will cause an increase in the latter; no guarantee about the time it will take to reach this increase can be given, nor does the relation say anything about the amount of change. The negative causality indicates that an increase in the source will result in a decrease in the target.

By combining causal relations, we can create *paths*. A path is sequence of one or more causalities, connecting two or more variables. A path does not contain a given variable twice. As per the direction of the relations, a path connects its start and ending variables indirectly. This allows us to reason about indirect effects. This can be done in two directions. Observe the picture in Figure 1. If we are to measure variable A and we see an increase in A, we can reason that this change will traverse through the system, affecting both B and C, increasing B and decreasing C. We call this process *forward reasoning*. On the other hand, if we were to measure variable C and see a decrease in it, we can reason that this decrease was caused by an increase in variable B, which in turn is caused by an increase in variable A. This process is called *reverse reasoning*.

In addition to paths, we can create *loops*. We define a loop as being a path in the model of which the starting and ending variable are the same. In Figure 2, we see an example causal graph with two loops.

The first loop we can identify, is *Feeling of well-being – Physical well-being – Feeling of well-being*. This loop contains only positive causalities. As such, an increase in *Feeling of well-being*, causes an increase in *Physical well-being*, which in turn causes an increase in *Feeling of well-being*. This models an exponential growth and is called a *reinforcing loop*. The second loop consists of *Feeling of well-being – Intention to change – Physical activity – Physical well-*

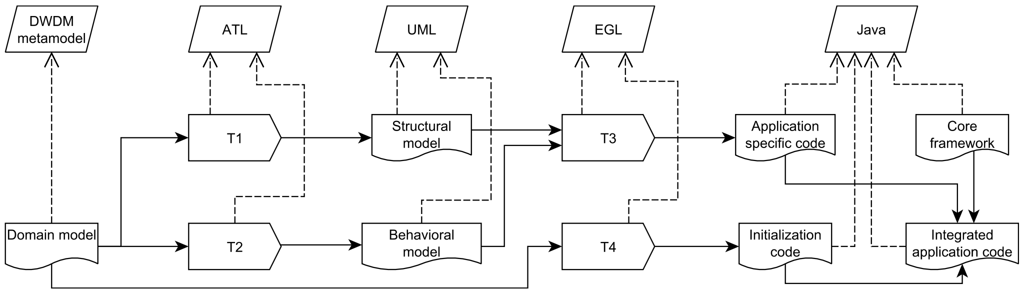


Figure 4: Development process and relations between models.

being – Feeling of well-being. In this loop we see both a positive and a negative causal relation: an increase in *Feeling of well-being* causes an decrease in *Intention to change*, resulting in a decrease in *Physical activity*, causing a decrease in *Physical well-being*, decreasing the *Feeling of well-being*. This last decrease causes an increase in the *Intention to change*. Such a *balancing loop* models a stable situation, as the increase of a variable eventually causes that same variable to decrease again.

4.3 Norms

(Merriam-Webster, 2014) defines a *norm* as "a set standard of development or achievement usually derived from the average or median achievement of a large group." We see a variable's norm as being a normal variable value for the general population; a norm might not always hold for an individual. For example, the norm for a resting heart rate is 60-100 BPM, but some athletes may have heart rates as low as 40-50 BPM. Norms have a range, with the values in this interval being considered healthy. Norms can be obtained from medical literature and through expert interviews.

5 TECHNOLOGIES USED

Model Development. For the development of the meta-models and editors, we have selected the Eclipse Modeling Framework (EMF). These plug-ins for the Eclipse IDE are widely used for meta-model development on the Eclipse platform. The meta-models created using EMF are in the ecore format, EMF providing means for the generation of editors for these.

Editor Development. The Graphical Modeling Framework (GMF) was used to create the graphical editors for our DSL. GMF provides us with a set of Eclipse plug-ins, allowing for the structured development of graphical editors for ecore-based models. To be able to graphically edit UML models, we integrated the UML2Tools plug-in when building the Eclipse-based editor.

Model Transformation. In our development process, we identify both model-to-model and model-to-text transformations. We have opted for two separate solutions for these. For the former, we selected the Atlas Transformation Language (ATL) as the best suited candidate. The ATL editor and transformation engine are provided as an Eclipse plug-ins. ATL outperforms other model transformation engines and has an active community (van Amstel, M. et al., 2011). For the model-to-text transformations, we opted for the use of the Epsilon Generation Language (EGL).

Core Framework. At the center of our executable application, we have a core framework implemented in Java. This framework is based on the architecture discussed by (Bosems, S. et al., 2013). It contains components that are deemed reusable and common for context-aware well-being applications. The application development process discussed in this paper extends this core framework with components that are specific to a single application.

6 TOOL SUPPORT

We have created a tool that supports the process in depicted in Figure 4. This was also described in (Bosems and van Sinderen, 2014b). Firstly, a domain model (which is an instance of the DWDM metamodel) that is specific to the application under development is created using the DWDM model editor. This application specific DWDM is a subset of a reference DWDM such as the one described by (Bosems, 2014), containing only variables relevant to the problem domain. A technology expert adds information regarding the hardware capabilities through variable annotations. When performed for our example, this results in the model depicted in Figure 3.

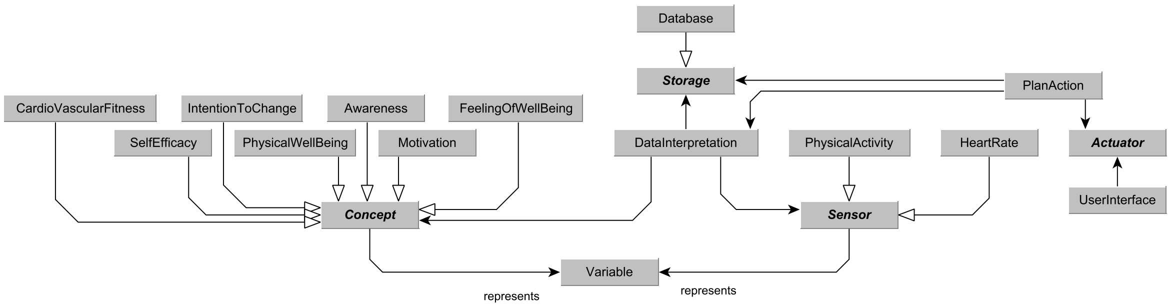


Figure 5: UML Class diagram for the Activity Coach.

Secondly, UML models are generated using model transformations. These models are refined by a software engineer to include bindings specific to the implementation platform. Finally, code is generated. This code partially originates from the application specific DWDM, partially it is generated from the software models. The generated code is added to a core framework to form the application that can be run on the intended platform.

7 MODEL TRANSFORMATIONS

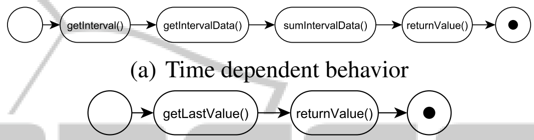
We have four transformations supporting our model-driven process (Figure 4). We will discuss each of these in this section. The source models for the model transformations are DWDM models, discussed in more detail by (Bosems and van Sinderen, 2014b).

7.1 Structure Generation

Using model transformation T1, we can generate the application structure model. In this transformation, we map a DWDM to a UML Class diagram. For the generation of the static application structure, we are primarily interested in *variables* and their properties.

When mapping the DWDMs to Platform Independent Model (PIM) level models, the variable annotations dictate the static application structure. For these diagrams, we assume a basic structure such as identified by (Bosems, S. et al., 2013). If the annotation is *observable*, a class extending the `Sensor` class is added to the model, if the annotation is *deducible*, a class extending the `Concept` class is added, and a variable with the *controllable* annotation causes the creation of a class extending the `Actuator` class.

When applying T1 to the DWDM in Figure 3, we obtain the class diagram shown in Figure 5.



(a) Time dependent behavior

(b) Time independent behavior

Figure 6: UML Activity diagrams for data processing.

7.2 Behavior Generation

Application behavior is more diverse and complex than application structure. The derivation of this behavior is based on several elements of the DWDMs and is done in transformation T2 which maps DWDM elements to UML Activity Diagrams.

7.2.1 Behavior from Variables

Besides the annotation, variables have other properties; these affect the application's behavior.

Firstly, the variable's *unit of measurement* affects the way data is processed. If the variable is time dependent, multiple sensor readings will have to be combined, while time independent values can be used without additional calculations. Results of these are found in Figure 6.

Secondly, there are two *processing type*s. For the first, we have to take the *average* value of the variable value. This is required for the application to be able to reason about the trend of a variable value. The second type of processing requires us to *sum* the variable values obtained. This is needed for variables of a time dependent nature, such as the *Physical activity* over the day: the obtained movement data has to be summed in order to gain the total amount of movement over the day.

Finally, the *measurement scale* dictates the granularity of feedback that can be given: a higher class of measurement scale the application can provide more detailed feedback. For example, while it can only be reasoned if the level of cardiovascular fitness (ordinal scale) increased or decreased, quantifying this value is not possible. The feedback given to the user can thus only be to increase or decrease his/her cardiovascular fitness. However, it is possible to see if a person was twice as active as the day before (ratio scale), not just more or less active.

7.2.2 Behavior from Relations

The causal relations described here have two effects on the behavior diagrams created from them. Firstly, we can calculate the values for deducible variables through reverse causal reasoning. Such application components (extending the `Concept` class) include the following method:

```
double getValue(Variable start) {
  double res;
  foreach (i in var.incomingRelations) {
    Variable src = i.source;
    if (src != start){
      res += i.source.getValue(start);
    }
  }
  return res;
}
```

Listing 1: Obtaining the value of a derivable variable.

This process will stop when variable is reached which is observable. Components representing such variables extend the `Sensor` class and have a `getValue()` method which returns the sensor value.

Secondly, the relations can be used for causal reasoning. Using this quality, we can make the application under development reason too. The behavior that can be mapped to UML Activity diagrams is *goal reasoning*. By performing a breadth-first search over the DWDM, starting from one initial application goal, it can be determined what should happen to the values of other variables in the DWDM, i.e. if they should be increased or decreased. For example, if the goal is to increase "Physical well-being," changes would include increasing "Cardiovascular health" and increasing "Physical activity". As the latter is an observable variable, the application can provide feedback in order to increase this variable.

Finally, when using the two types of loops identified, we can reason about the degree of change that will be happening in the user's well-being context, and predict future trends. Loops can not be exploited when deducing variable values.

7.2.3 Behavior from Norms

The norms captured in the DWDMs are mapped to `if-the-else` constructs in the UML Activity diagrams to control the boundary conditions for the application: although an overall goal graph has been generated through goal reasoning to obtain a certain overall target, the norms dictate immediate feedback: a goal might indicate that the user should move more, but for the current day the user has already reached his quota. In this case, the norm value overrules the goal, and as such steers the feedback given. We can say that the causal relations and the resulting goals prescribe the overall system operations and feedback, whereas norms regulate real-time feedback and interventions.

7.3 PSM Creation

The models (with the exception of the initialization code) generated so far are at the level of Platform Independent Models (PIMs): they are generic with regard to an implementation platform. To be able to generate code from them, platform bindings and additional information is required.

Although bindings to the implementation platform are not straight forward, as matching `Sensor` classes based on name is not directly possible, it is possible to partially support this in the future: by providing the developer with means to manually map `Sensor` class names to API names, the methods in the Sensor class can be supplied with mappings to API calls. However, additional non-functional requirements that are to be satisfied by the application, such as scalability, safety, and responsiveness, are not captured in the CIMs or PIMs. These are to be added manually.

7.4 Code Generation

By using model-to-text transformation T3, as shown in Figure 4, we can combine the information described in the structural and behavioral PSMs and generate application code. This application code contains those elements specific to the domain described in the domain model such as code to interface with those sensors needed to obtain context information, and code to calculate the values of context elements that can not be directly read by sensors.

As code generation has become common practice, we will not elaborate on this further.

7.5 Initialization Generation

Figure 4 shows that the application under development consists of three elements: (i) a core framework, (ii) an application specific part containing code to, among others, interface with sensors, and (iii) initialization code. This last element is obtained through model-to-text transformation T4.

As mentioned earlier, the application requires graph algorithms such as breadth-first search to obtain information and to guide the application's behavior. The graph information which was present in the domain model is, however, lost when transforming the structural and behavioral models. In order to be able to use the graph structure, it should be translated to the application's data model.

In the internal model, we store: (i) the variables present in the DWDM with all their properties, and (ii) the causal relations between the variables. This information is captured by instantiating the `Variable` class and the `Causality` class. These instances are then stored and used for goal reasoning.

7.6 Application Construction

With all code elements generated or created, they can be assembled. This is currently done manually. The core framework is taken as a basis, the files containing the application specific code are added in separate folders. These files are evaluated at run-time and their classes instantiated through Java Reflection.

8 APPROACH APPLICATION AND DISCUSSION

In this section, we will describe the application of our approach in four experiments and discuss the results.

8.1 Application

Our modeling and design approach has been applied in several settings to test their usefulness. Firstly, the DWDM editor tool was used to facilitate the discussion regarding the well-being domain among experts in the fields of physical and mental well-being. After explaining the modeling language, the experts could discuss and reason about the domain elements in their own field, and make connections to the other domain. This small scale workshop was facilitated by one of the authors of this paper, the resulting model can be found at (Bosems, 2014). Validation of this overall well-being model is currently being planned.

Secondly, a master graduation student was provided the DWDM editor to model the well-being domain and test the design process. No model-transformations were available, so further development of the application development was done by hand. The use of DWDMs was seen as useful to gain insight in the technical application requirements. Research was performed in to strategies for the selection of "relevant" domain variables, given a certain goal variable. Two strategies were identified and presented by (Soriano Perez, 2014).

Thirdly, four students in a postgraduate course on MDE were given the task to design an Activity Coach. They were given the DWDM editor, and implementations of model transformations T1 and T2, allowing them to generate PIM level models, as discussed in sections 7.1 and 7.2. The time limit for the experiment was 90 minutes. Results showed that the participants, i.e. software engineers, were highly technology focused, not fully exploiting the domain knowledge and models; participants were aimed at creating a software solution, rather than thinking of the specifics of the domain the application would be to focus in when developed. Due to this narrow focus, DWDMs were not used correctly. Additional experiments are needed for further validation.

Finally, one of the authors compared the usage of the process and model transformations discussed, with the development of an application from scratch. It was found that a full development of an application using the structured method was faster than the manual creation of an application. It should, however, be noted that due to in-depth knowledge of the "desired" application structure, behavior and possible implementation, the manual design and development of the system was faster than what could be expected when dealing with a new type of application. As such, this experiment can be considered biased in that the time required for the manual construction was lower than what can be expected when the application structure and behavior is unknown.

8.2 Discussion

Although results show that our approach for the well-being domain has benefits over traditional software engineering models, and that these benefits can be exploited when they are used to guide the design and development of well-being applications, there are some considerations to be taken into account.

Firstly, the current process does not include steps for the creation of a user interface. For this type of application, the presentation to and interaction with the user is of key importance; if the UI does not perform adequately, the user will disregard the application.

Secondly, the current DWDM editor lacks features that may improve usability. For example, the ability to group, merge or hide modeling elements would increase developer productivity.

Finally, the process relies on the input DWDM to be valid. If this model is not valid, the resulting application will be flawed too.

9 CONCLUSIONS AND FUTURE WORK

Even though the domain of person-centric, context-aware well-being is rapidly growing, modeling and development methods dealing with the specific challenges of these applications are still scarce. To bridge the gap between domain and technology experts, we have created a modeling language that allows stakeholders to capture the relevant domain variables and the causal relations between them, while focusing on the future user rather than the technology used. The resulting model can then serve as the input for a model transformation supported development process. We have illustrated this with a motivating example.

Through four case studies, we have shown that the proposed process can indeed speed up application development, but does require the right mindset from the domain and technology experts. Future work includes the improvement of current tool support to increase designer productivity. Furthermore, the reference DWDM should be valid for it to be a useful development starting point. This validation should be conducted among experts in the fields of physical and mental well-being.

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