# Lessons Learned from Collaborative Prototype Development Between University and Enterprises

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In this article, the focus is on the KIEMI research project ("Less is More: Towards the Energy Minimum of Properties" in English) conducted in Tampere University during the period of 2019-2022. In this project, we used the earlier developed Descriptive Model of Prototyping Process (DMPP) to guide university-enterprise collaboration. The project consisted of several pilot cases, with prototypes, which were done in collaboration with companies, tackling real-world problems. In this article, we review and evaluate the suitability of the DMPP for usage in a research project. The article explores the topic from two directions: the collaboration of university and enterprises, and the reusability of artifacts within the DMPP. The paper introduces several pilot cases made on the KIEMI project, and describes the usage of the DMPP in them. Furthermore, the paper evaluates the model, sets forward the challenges faced, and, finally, discusses topics for future research.

**Keywords:**
artifact,
reusability,
collaboration,
DMPP,
prototyping,
iterative design,
process model

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## 1 Introduction

Universities and other research organizations produce research results, typically in the form of publications, such as papers and technical reports. In addition, applied research produces prototypes with proofs of concept (PoC). This study presents the outcome of one university project, where proofs of concept were mainly implemented by building data-gathering prototypes.

The focus of this study is on the findings of the KIEMI project ("Vähemmällä Enemmän – Kohti Kiinteistöjen Energiaminimiä", or "Less is More: Towards the Energy Minimum of Properties" in English). The aim of the project was to develop proof-of-concept demonstrations and prototype applications that illustrate how cost-effective, open, and modular solutions could be utilized to improve the energy efficiency of existing, older buildings [1]. The KIEMI project was selected for analysis in this paper because of its large number of pilot use cases.

The goal of the KIEMI project was to save energy, and we worked towards this goal by developing and constructing data-gathering IoT sensor systems. We used the developed SW/HW framework [2] and the formerly developed descriptive model of the prototyping process (DMPP) [3]. The SW/HW framework generalizes prototype development into a group of necessary components and even more precisely the framework defines guidelines for constructing prototype systems to collect data for different purposes by reusing the required software and hardware components [2]. The DMPP was developed to guide the IoT prototype development process and can be used as a guideline when building a prototype. The DMPP contains the prototype development practices that have been applied in research projects between our university and enterprises. With these developed IoT prototypes, developers can receive valuable feedback on the possibility of implementing the application [3].

The following research questions were formulated during the project work. For this study, we wished to gain insight on the following topics:

- RQ1: Collaboration. How was university-enterprise collaboration executed in practice using the DMPP?
- RQ2: Reusability. How did the reusability of the artifacts in the DMPP steps support the workflow of the pilot cases?

University-enterprise collaboration (part of universities' third mission [4], [5]) has been used in previous projects and the DMPP model was developed into its current format based on the pilot cases of these previous projects. The KIEMI project also aimed to build prototypes in collaboration with companies for IoT type data gathering. Since we already had a completed process template, it was decided to put it to good use in this project as well, and RQ1 looks at the success of this issue.

Further, RQ2 focuses on the operation of DMPP sub-processes and how templates were created from them. The use of templates was intended to accelerate the operation. At the beginning, their significance was not understood, but by following the model the usefulness of the templates was noted. The same practices were observed when using the process model, so reuse was included in the review. The benefit and reusability of templates created specifically from reporting was monitored as it was expected to speed up the implementation of some steps.

The structure of this paper is as follows: In Section II, we review the related research about universities' third mission, industry collaboration. Also the background of the KIEMI project is explained. In Section III, we introduce the DMPP and its connections with project work. Further, the implementation of university-enterprise collaboration in prototype development is described by means of process modeling notation. Section IV introduces the KIEMI project – its purpose, activities, goals, and outcome. Section V continues by describing the prototyping pilot cases performed during the KIEMI project. Section VI evaluates the usability of DMPP in the KIEMI project highlighting results of the project and pilot cases. Section VII summarizes the study, and includes a discussion and suggestions for future research on the topic.

## 2 Background

### 2.1 Third mission

It is a common conception that the modern university serves three main purposes: teaching, research, as well as a broader social function. The latter of these functions, commonly dubbed "The Third Mission" [4], [5], is regarded as including measures contributing to social impacts and interaction.

Industry-academia collaboration benefits those organizations that do not have their own R&D facilities. For example, companies can utilize the resources of a university to understand their modern-day software engineering problems. Industry has realized that it can support innovation and development processes when collaborating with researchers. [6]

Figure 1 illustrates how the process model approach can be used to align European Union policy and Finnish universities' missions in the form of applied research and collaboration.

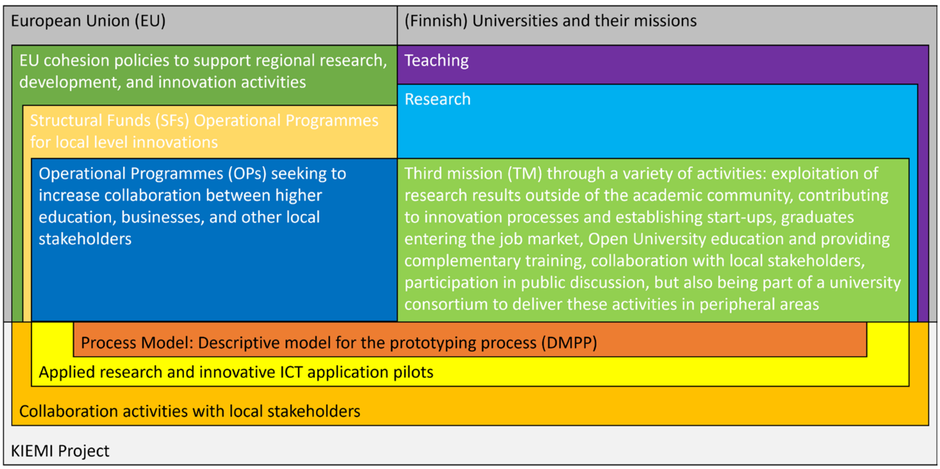


**Figure 1: Third mission concept with the KIEMI project**
Source: own.

The EU cohesion policy and EU Structural Funds (SF) are used through Operational Programmes (OPs) to make it possible to create innovative collaboration projects for local stakeholders. Finnish universities have extended their traditional teaching and research activities within the third mission (TM) to exploit research results for peripheral areas, i.e., in the form of collaboration with local stakeholders. [7]

The University Consortium of Pori (UC Pori) has longstanding and specialized experience of creating collaboration with local stakeholders using the EU SF and OPs through university facilities and resources [7]. The KIEMI project represents a continuation of the series of OPs executed at UC Pori in recent years.

In collaboration, the transfer of technology is an important part, because it innovates development processes and innovative products achieve improved business competitiveness. In the study by [8], innovation is considered as a process consisting of two phases: technology creation and technology transfer.

As seen in Figure 1, the KIEMI project was a framework for implementing collaboration and applied research methods in the form of innovative ICT application pilot cases for local stakeholders. The descriptive model for the prototyping process (DMPP) was the spearhead of the process, pulling all the pieces together.

### 2.2 Collaboration channels for interactions

Interaction between public research organizations and industry can be implemented through many kinds of collaboration channels. One way to classify collaboration channel types was done in [9], where channels were divided into four groups: traditional, services, commercial, and bi-directional. In this paper, collaboration in SF OPs can be seen as bi-directional collaboration between university and industry, where both parties benefit from the acquisition and development of the technological know-how necessary for the prototype. In addition to the technical content, the prototype usage must take into account the development of interconnections necessary for university-enterprise collaboration and their impact on future cooperation activities.

### 2.3 Innovation models for collaboration

In projects like KIEMI, collaboration activities are done several times; mostly each time with different SMEs or public organizations (or some unit or department from their organization). To simplify this for the reader, we use the term industrial development (ID) for these collaboration parties or stakeholders. In addition, in case some ID has their own research group or department or if there is a CEO with a researcher's mindset, their staff can be referred to as industrial research (IR). Similarly, the university research unit, as in the KIEMI project, can be defined as academic research (AR).

For successful collaboration management between ID and AR, it is useful to have a framework or process model to ensure that the collaboration and innovation activities inside it create solutions and PoC along with pilot cases and receive strong support from all parties from the very beginning.

In the study by Punter[8], two main stakeholder groups were identified: researchers and industrial practitioners, where the former (AR) act as a technology provider and the latter (ID) as a technology receiver. They also pointed out that AR and ID may have completely different values and targets for technology and collaboration activities. AR is interested in proving concepts for technology via pilot cases during projects. ID is looking for a statement or evaluation of the business benefits and costs of the technology and may see AR's PoC as a technology study without the necessity for proof, i.e., a production proof version.

With an EU OP (such as KIEMI), the ID types of collaboration are predefined in the OP requirements. The same set of requirements also contains targets for project results which can be related to certain products or services through ID or a target may be related to co-creation activities or to research and development activities between AR and ID. in this project, a production proof version is not included, only PoCs. It is assumed that ID will continue the production proof version from the results of the project.

The model used should take different types of ID into account. It should also take into consideration the fact that innovation activities and technology transfer may happen in all phases or steps. As an example, Punter [8] highlights a case where design work was able to add value for ID. Similarly, in projects, value can be produced in cases where some commercial product, already designed for a certain usage, has been applied in a new environment through pilot case activities.

Naturally, activities to develop a suitable collaboration model fall mostly to the party responsible for the project, as here on the AR side. The model and its efficiency define success for current and future collaboration between AR and ID.

A study by [10] presents the Certus model, which was developed at a Norwegian research-based innovation center. Their needs for a collaboration model contained similar elements to the DMPP model. They required deeper research knowledge of cocreation activities via problem definition and solving tasks and more active dialog between researchers and practitioners to align their expectations. They also wanted to ensure that the results and outputs from research projects that are created have practical relevance and benefit for their partners and that the results can be transferred and exploited effectively by their partners.

The Certus model [10] contains seven phases, from problem scoping to market research. Whereas the first four phases (problem scoping, knowledge conception, knowledge and technology development, and knowledge and technology transfer) can be regarded as similar to proof-of-concept development, the following three phases (knowledge and technology exploitation, organizational adoption, and market research) are more related to production proof activities.

## 2.4 The KIEMI project

The reduction of greenhouse gas emissions is one of the most challenging global objectives of the near future. Low carbon emissions, energy savings, a climate-friendly approach, and ecologically sustainable choices require new and innovative services, solutions, and products. One of the biggest potential areas where savings can be made is energy use in properties in Finland. The KIEMI project, carried out by Tampere University Pori unit, designed and developed methods and technologies that aid in finding and achieving the propertyand situation-specific ”energy minimum”, i.e., a situation where the minimum amount of energy is used while still preserving a comfortable environment within the building. In the KIEMI project, the primary focus was not on new properties or so-called ”smart buildings”, but on older buildings and apartments that do not contain modern automatic and intelligent devices commonly used for controlling the quality of the living and working environment.

Proof-of-concept demonstrations and prototype applications were developed in the KIEMI project that illustrate how cost-effective, open, and modular solutions can be utilized to improve the energy efficiency of buildings. Further, a decrease in overall energy usage will lead to cost savings related to energy expenses and reduce the carbon footprint caused by, for example, the heating, cooling, and air conditioning of buildings.

In the present world situation in 2023, the theme of the project, energy savings, is especially topical, at least in Europe. The KIEMI project partners consisted of organizations and companies who were able to take part in the pilot cases implemented during the project by providing properties, equipment, sensors, and measurement data or by acting as experts. The results of the project can be utilized by all those involved with the energy and resource efficiency of properties and housing-related wellbeing as well as the relevant private (companies) and public bodies (municipalities).

The commitment of the project partners to the project activities was based on the DMPP collaboration model developed in previous projects. In the KIEMI project, the focal point of the partner-specific co-operation varied, depending on how the partner wished to participate, and how they were able to contribute to the research. Collaboration and contribution to the project pilot cases took place roughly according to the following breakdown:

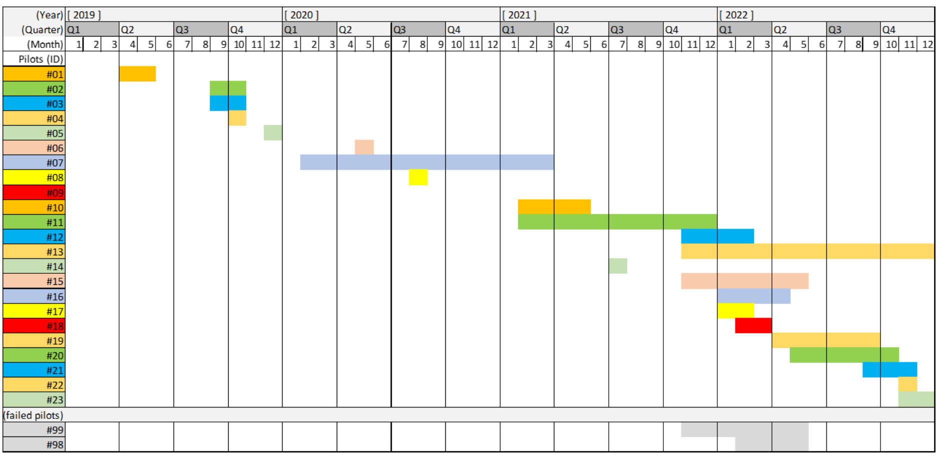


**Figure 2: Timeline of pilots in KIEMI.**
Source: own.

1. Identifying premises for use in the project (condition measurements in the properties)
2. Handing over existing property data for use in the project (interfaces with existing property measurement systems)

3. Determining measurement needs and planning pilot cases together (tailored needs for condition measurement of the target)
4. General development of condition measurement (developing sensor and measurement systems in collaboration with project partner)

During the project a total of 23 different types of pilot cases were carried out related to the energy efficiency and condition measurement of properties. The pilot cases conducted during the KIEMI project as well as the prototype systems developed for them and the technology testing have been reported extensively in the form of scientific articles (several internationally peer-reviewed research publications). Figure 2 shows the schedule of pilot case implementation by month and quarter over the duration of the project. For interrupted pilot cases, the timetable describes the time interval during which discussion and reflection took place.

## 3 Process model for prototyping: Descriptive model for the prototyping process (DMPP)

The purpose of this section is to present how the selected process model has supported the work within the projects. Our descriptive software process model for IoT prototyping was introduced in [3]. The DMPP was developed during a previous project where the prototyping focused on one area. The DMPP was developed using the descriptive process model (DPM) approach [11]. The basic concepts related to processes are role, activity, resource, and artifact. The example is illustrated by a developer (role) involved in software development (activity) using a programming tool (resource). The activity produces some software (artifact) used in a prototype system. The process data for the model is collected through interviews with the developers involved in the four different prototype development processes. Four prototype development projects and their outcomes were reported in several studies [12], [13], [14], [15]. The common factor in all of the studies is that they present developed IoT prototype systems that gather data.

When the KIEMI project started, we noticed that this DMPP could be an acceptable way to approach the subject. During the project, we actively searched for pilot cases (Step 0) where previously collected knowledge about prototyping IoT data-gathering systems could be used. Figure3 presents the DMPP [3] including steps one to six. The pilot case starts with an issue related to a suitable situation for the research group. The pilot case ends after it has been presented to the customer and other reports have been published. After the pilot case, there is also the possibility to add step 7 (Production proof mentioned in 2.3) which consists of following up the procedure, e.g., client or someone outside of the original pilot case group wishes to utilize the prototype or parts of it. The second possibility is that the developed prototype system goes into production and needs further support (this kind of situation is reported in [14]).

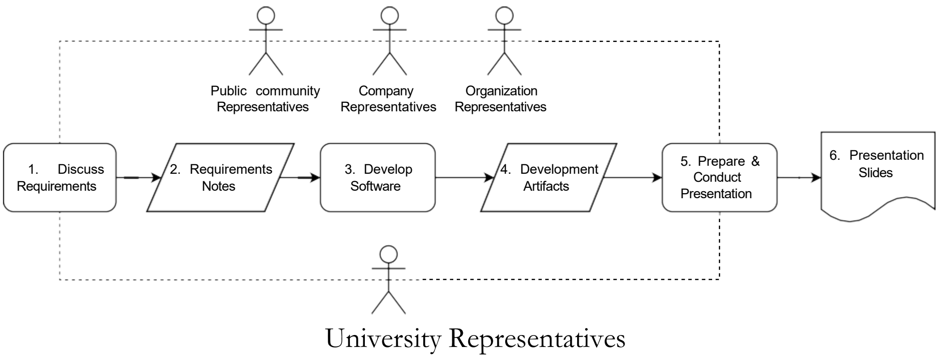


**Figure 3: Process model for prototype development.**
Source: Adapted from [3].

Figure 3 presents the DMPP model. The model includes six steps and the roles, activities, and artifacts can be described as followed using the SW/HW framework [3] and the DMPP [2]:

1. The first step starts from the requirements definition, a collaborative discussion between the developers and the client. The client defines what kind of data would be useful. The developer group starts to define the hardware and overall architecture of the system and how the data will be collected by the software. The selected hardware mostly determines the software environment and tools used. Benefit - Clarification of the problem item together with the customer. Limitation - Does the development team have sufficient expertise in the subject area?
2. The outcome of the discussion is the first artifact: for example, the prototype system requirements in the discussion notes. The developer group constructs the first architecture model of the component interconnections. For example, in IoT systems, we describe the practice of how to define a

system by reusing the system definitions of previous prototypes. Light documentation has been found to speed up stage completion, but may cause problems later if the system is put into production.

3. The third step is the software/hardware prototype development made by the research group including the project manager and SW/HW developers. The IDs' representatives are involved in the development process in the role of instructor. In this step, the SW/HW framework is used as the guideline for selecting the components for the prototype. The SW/HW framework gives guidelines and speeds up development when the operating process of suitable components has at least partially been thought through in advance. Reuse of components also makes it easier when the number of background studies decreases.
4. The fourth step introduces the working prototype artifact, which consists of the developed software and hardware components. Also, the interconnections of the components are tested. The testing process overall is usually only the functional testing of the prototype system. Additionally, the gathered data is inspected and if possible, compared to the expected results. Another notable issue is the fact that, if the system is later put into production, testing must be carried out more thoroughly.
5. The fifth step includes preparing the outcome of the development process. Further, this step includes presenting the prototype and its functionality to the ID. The SW/HW framework can be complemented if necessary.
6. The sixth step is to publish the results, for example, the prototype system, collected data, and analysis of the project. For example, in a university environment, the publication of results is important for supporting future research projects.

The process model in Figure 3 is a simplified presentation of the prototype development process. It gives abstract instructions for the operation with defined steps to implement the pilot case from start to finish. If all of the steps are performed, the level of the outcome is predictable. The model is sufficient for developing a prototype, and also makes it possible to add more activities if needed. For example, procedures such as iterations, testing, and customer testing could be included in the process. Further, because the model is developed from university pilot cases, it combines two factors: software/hardware prototype development and collaboration with customers. Both of these are discussed in the following section when the usability of the DMPP in the KIEMI project is evaluated.

## 4 DMPP utilization in the KIEMI project and technology transfer

The purpose of this section is to describe how the DMPP model was utilized in the work process of the KIEMI project. This section also describes how different parties were involved in the project, what kind of collaboration actions were taken during the DMPP steps, and which technology transfer actions occurred during the work process. Figure 4 presents an overall picture of the project, collaboration, and DMPP process in the form of the Business Process Model and Notation (BPMN, [16]).

### 4.1 Project partners

In the overall picture (in Figure 4) four groups can be recognized in their own swimlane:

1. EU OP and its program documents and goals (via OP documents and goals) must be taken into account for project content and implementation.
2. University within its third mission (TM) and its strategy (via University Strategy) which gives guidelines for research group activities and publishing of project work.
3. Project (like KIEMI) activities are carried by project team members (academic researchers, AR) and activities can be divided into three sub categories:
   a) Project management (Management) is responsible for implementation of the project plan (Project Plan) and reporting project results to the funding representatives of EU OP (OP supervision) as well keeping track of research publications for university representatives (Research supervision). Project management also acts as the selector of new prototypes in the form of collaboration and pilot case actions.
   b) DMPP process (DMPP) and its six steps (1-6), which are linked to each other and to collaborative actions with IDs via prototype and pilot case actions.
   c) Collaboration and Piloting (Collaboration/Piloting) which contains actions and paths supporting DMPP process steps.

4. Collaborative Organization(s) are representatives of collaborating IDs and with whom the content of prototypes and usage via pilot cases is co-created and codeveloped.

Technology transfer (and technology creation) takes place between AR and ID via project work and the work process used in it.

#### 4.1.1 The work process

In Figure 4 the work process of project work can be divided into the following actions (one to eight):

1. The project starts when the project administration (Management) is organized. The project administration defines/selects an appropriate pilot case (Select New Pilot Case), the resources and actions required for the content, and launches the pilot case (Start Pilot Case).
2. From the point of view of the project, a single collaborative pilot case starts (in Collaboration/Piloting) with the invitation of the collaborator (Collaboration Call) and the agreement on cooperation (Collaboration Ignition). For pilot cases #17, #18, #19, and #23, invitations to collaboration IDs were sent via a 3rd party.
3. The first phase of the DMPP process (Discuss Requirements) starts when the project has established contact with the collaborator (ID) and the actual discussion of requirements and objectives begins (Requirement Discussion). For pilot cases #17, #18, #19, and #23, we also received positive responses to collaborate. The project utilizes the discussion base created in previous discussions (Achieved Prototype Pilot Requirement Notes) as a basis for a new discussion. ID brings their views (needs and support and available partners or technical vendors (TV)) to the discussion. For example, needs can be related to certain sensors or measurements and support can be related to the facilities where measurements are made. This starts technology transfer actions between AR and ID/TV. The discussion will result in a decision to continue cooperation and (in a positive decision) the content of the next phase of the DMPP process, namely the requirement notes (Prototype Pilot Requirement Notes).

As the discussion produces a positive decision (OK To Initiate Prototype Pilot?), a pilot case (Prototype Pilot Ignition) and the third phase of the DMPP process (Develop Software) will begin (Start Prototype develop). On the ID side, the corresponding decision (OK To Initiate Prototype Pilot?) to proceed initiates support for prototype development and supports prototype piloting activities. In the event of a discussion producing a negative decision (or cooperation ending without successful agreement), the pilot case is reported to the administration as interrupted (Pilot Case Aborted), which then processes the interruption result. For pilot cases #98 and #99, collaboration was ended in the first phase of the DMPP process (Discussion).

4. In the third phase of the DMPP process (Develop Software), the prototype artifacts (software and hardware) needed in the pilot case are developed. The development of the prototype (Develop Prototype (SW/HW)) is guided by the requirements recorded in the previous phase (Prototype Pilot Requirement Notes in Requirement Notes) and utilizes any artifacts (Development Artifacts) that may have been generated in previous cases. Prototype development involves discussions and exchanges of information (Technical Discussion) with the ID and TV brought into the pilot case. New and advanced artifacts resulting from the prototype development phase are introduced to artifact management (Manage Artifacts in Development Artifacts), representing the fourth stage of the DMPP process. Pilot case #11 was an example of a case where both technology creation and technology transfer occurred between AR and ID.
5. The completion of the prototype development phase (Prototype Develop Ready) initiates the prototype pilot case execution phase (Execute Prototype Pilot in Collaboration/Piloting), where pilot case data and results are collected from the use of the prototype at the pilot case site (received from ID). The data collected in the prototype pilot case is included/added to the Development Artifacts (via Manage Artifacts) generated in the third step (Development Software).

   The piloting of a single prototype could take several weeks. For pilot case #19, data was collected for a period of several months and data collection was monitored online. On the other hand, pilot case #13 contained data for a period of over one year and data was collected afterwards from ID's

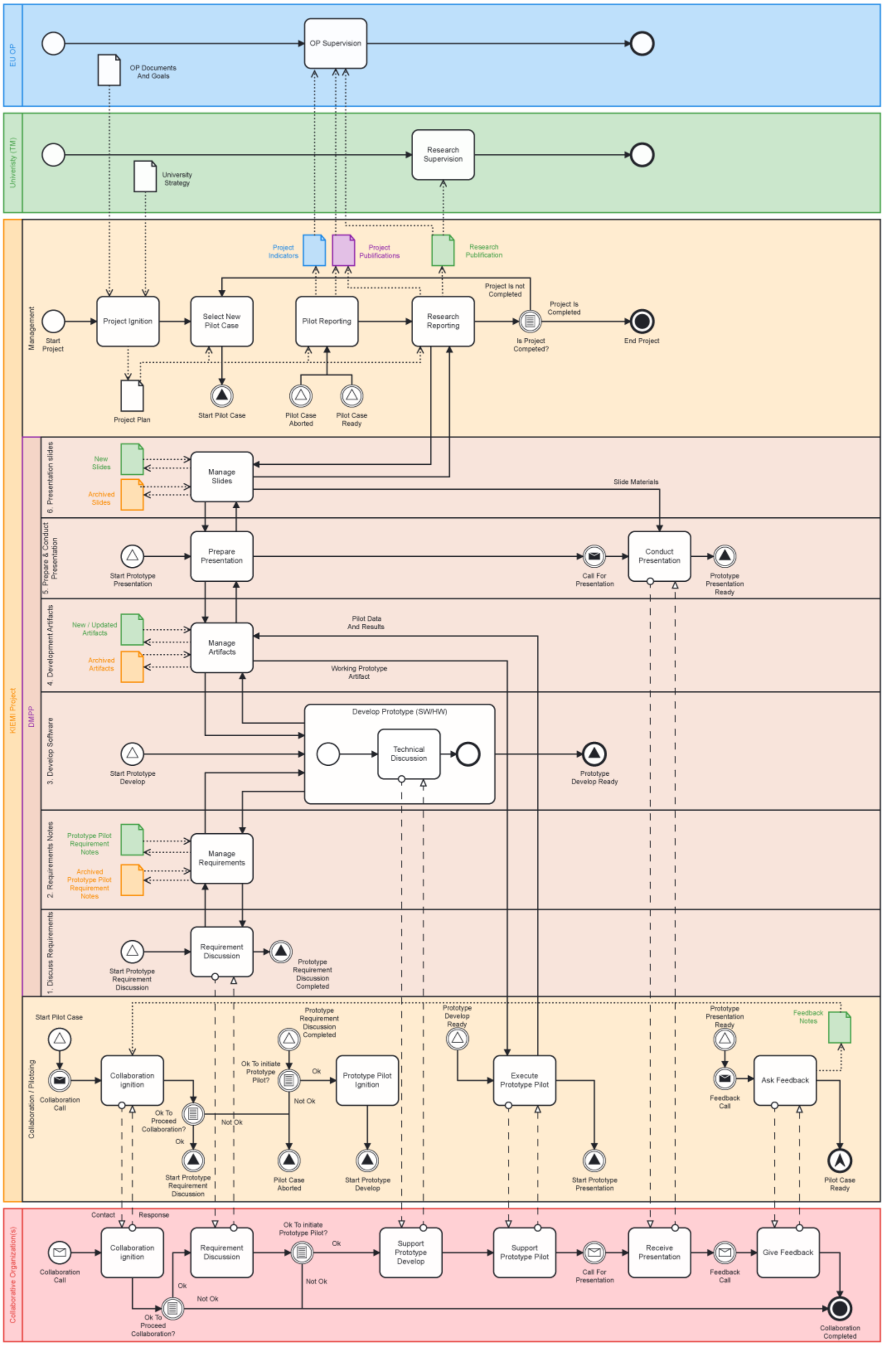


**Figure 4: Technology transfer in the Kiemi project.**

Source: The figure is available in [17].

database. The latter case also contained technology transfer between AR and ID to tune up ID's interface about database metadata information.

6. At the end of the prototype pilot case (Start Prototype Presentation), the penultimate stage of the DMPP process, the preparation phase for the presentation of the results is initiated. In this phase (Prepare Presentation in Prepare & Conduct Presentation), the artifacts generated during the prototype pilot case are compiled (via Manage Artifacts in Development Artifacts) into presentation materials for the final stage of the DMPP process (via Manage publications in Presentation Slides) and the presentation of the materials to ID (Conduct Presentation in Prepare & Conduct Presentation). In the preparatory phase, previous presentation materials (Archieved Slides via Manage Slides) can be utilized. The presentation schedule is discussed with ID (Call For Presentation) who gathers their team and TV for the meeting (Receive Presentation in Collaborative Organizations(s)). The presentation ends steps five and six of the DMPP process for collaboration tasks. (Prototype Presentation Ready). Pilot cases #17, #18, #19, and #23 were examples of technology transfer via a presentation and delivered report documents. Case #23 also included a representative from ID's TV side.
7. There is usually a feedback discussion (Ask Feedback/Give Feedback in Collaboration/Piloting) following the presentation (Prototype Presentation Ready) on the results obtained from the use of the prototype and the implementation of its piloting, as well as on the success of the collaboration. Feedback processing concludes the collaborative pilot case (Pilot Case Ready) and technology transfer actions between AR and ID/TV. Pilot case #10 contained a feedback discussion where ID felt that the collaboration was very successful and they requested another pilot case (#16 in the list) after the issue for the target facility had been solved thanks to the first pilot case.
8. At the end of the pilot case (Pilot Case Ready), the information is sent to the administration (Pilot Reporting), which records the project indicators and progress (via Project Indicators) for reporting to the EU OP financier (OP Supervision) on the pilot case. The administration is also responsible for sharing the research results (Research Reporting) through communication channels (via Project Publications) and to the university (Research

supervision via Research Publications). Actions for communication tasks are also reported to the EU OP financier (OP Supervision).

Artifacts and publication slides generated in the DPMM process may be published or distributed in connection with the news blog. Pilot cases #17, #18, and #19 were examples of (one way) technology transfer via news blogs for any other ID or individual interested in the topic.

When a single collaborative pilot case has ended, management decides on the need for another pilot case (Is Project Completed?). Once the required number of prototypes and their piloting work have been completed (or project time is coming to an end, it leads to the final tasks and the end of the project.

## 5 Pilot cases in KIEMI

The purpose of this section is to present the background or characteristics related to the pilot cases (comparison table) as well as to compare the activity levels of collaboration associated with the pilot cases.

Table 1 contains pilot case specific reference parameters. **Pilot cases** are numbered with a running identification number according to their starting time (see pilot case timeline in Figure 2). Comparative data has been compiled for each pilot case using six parameters. The **User Group** parameter describes the classification of the piloting target. Options include company (A), public operator (B), entity (C), and others (D). The **Stakeholders** parameter describes the classification of parties who joined the piloting target. Alternatives include subscriber (E), users (F), technical vendor (G), and developer (H). Several parties may have been involved in the piloting. The **DMPP usage** parameter describes the number of steps in the DMPP process utilized at the piloting site. Each pilot case may have utilized one or more, or even all of the steps. The **OTS used** parameter contains information on whether off-the-shelf components were used in the pilot case. The **Publish content** parameter includes information on whether the results of the pilot case were released in a transparently available format through a research publication (X) or project news blog (Y) or both. Some pilot case results were only handled internally. The **Collaboration activity level** parameter describes the collaboration activity of ID during the work process (in Fig. 4). For a couple of pilots some information was not yet available during the writing of this paper and that information is marked with (*).

**Table 1: Properties of pilot cases in the KIEMI project**

| Pilot case | User group (A/B/C/D) | Stakeholders (E,F,G,H) | DMPP usage (1-6 / 6) | OTS used (Yes/No) | Published content (-,X,Y) | Collaboration activity level (Low/Mid/High) |
|---|---|---|---|---|---|---|
| #01 | B | E | 3 | No | - | LOW |
| #02 | B | E | 3 | No | - | LOW |
| #03 | B | E | 5 | Yes | X | LOW |
| #04 | B | E | 3 | Yes | - | LOW |
| #05 | B | E | 5 | Yes | - | LOW |
| #06 | D | E | 3 | Yes | - | LOW |
| #07 | B | E+G | 3 | No | Y | LOW |
| #08 | D | E | 5 | Yes | - | MID |
| #09 | D | - | 6 | No | X | LOW |
| #10 | B | E+F+G | 6 | Yes | X+Y | HIGH |
| #11 | B | E+G | 6 | No | X+Y | HIGH |
| #12 | A | E+F+G | 5 | No | Y | MID |
| #13 | A | E+G | 5 | No | Y | MID |
| #14 | D | E | 5 | Yes | - | MID |
| #15 | B | E+F+G | 5 | Yes | X | LOW |
| #16 | B | E+F+G | 6 | Yes | X | LOW |
| #17 | C | E | 5 | Yes | Y | LOW |
| #18 | C | E | 5 | Yes | Y | LOW |
| #19 | C | E | 5 | Yes | Y | MID |
| #20 | A | E | 6 | Yes | - | MID |
| #21 | A | E | 3 (*) | Yes | - (*) | ? (*) |
| #22 | D | E+F | 4 | Yes | - | LOW |
| #23 | A | E+F | 5 | Yes | Y (*) | MID |
| (failed pilots) | | | | | | |
| #99 | A | E+G | 2 | N/A | - | - |
| #98 | A | E+G | 2 | N/A | - | - |

## 5.1 Pilot cases with high-level collaboration

In high-level collaboration, the counterpart (ID) demonstrates active cooperation at all stages of the work process. ID brings to the discussion stage a view of the features required for the prototype and its operating environment. ID also demonstrates its interest in the technical content of the prototype resulting from the development phase and is involved in the processing of observations made during the pilot case phase. In high-level cooperation, ID shows interest in the content of the results (report) and highlights their views on the exploitation of the results. It is clear that ID benefits from high-level collaboration in many ways.

Pilot case #10 is a good example of high-level collaboration. The target was a daycare center, which had received feedback about poor air quality inside the building. The first target was to measure the temperature, humidity, and CO2 values at different times and report the readings to the partner. The first results showed that at certain moments the temperature and CO2 values had risen. During the early phase meeting where the results were shown, we decided with the partner(ID) to continue and expand the pilot case. Expansion meant contacting the air conditioning equipment supplier(TV). This gave us an interface with the air conditioning system. In addition, they expanded the sensor number and type to collect data that was more specifically environmental. Our project team also used the previously developed visualization tool to this pilot case.

Outcome: This was the widest pilot case with several partners(TV and ID), using previously used and developed components.

### 5.2 Pilot cases with mid-level collaboration

In mid-level collaboration, the counterpart (ID) is involved at the beginning and end of the work process and in some way also involved in the development content of the work process. ID support may be required, particularly in situations where part of the prototype content is sourced from an ID-managed data source. In general, ID benefits from mid-level collaboration, at least from the perspective of external testing obtained for its own functions.

Pilot case #13 can be used as an example of mid-level collaboration. In this case ID had a vast amount of facilities at their disposal and they had already implemented a data sensor system and were using data analysis tools via their TV. For the pilot case, ID allowed AR to use their data (collected by ID's TV) for AR's tools to produce another kind of analysis from the data. ID did not participate in the actual SW development, but the use of data via ID's API during piloting required technical discussions. The benefit for ID from the piloting case was related to experience gained about their API and the knowledge received via the pilot case report.

### 5.3 Pilot cases with low-level collaboration

In low-level collaboration, the counterpart (ID) is involved in the work at the beginning (Discuss Requirements) and end of the process (Presentation Slides). In these cases, the project team has most often conducted a search for actors interested in collaboration and provided the test target, giving the ID the opportunity to obtain new information about its application through the report. Thus, AR also provides technology transfer to ID. For a project, low-level collaboration can also be beneficial. Piloting over a longer time period does not necessarily burden the project staff and the results obtained from the pilot case can be very useful for demonstrating the functionality of the prototype.

Low-level collaboration is also no obstacle to publicizing the results of the project - on the contrary, for example pilot cases #17, #18, and #19 (entities as user groups) and the disclosures generated from their results have contributed to the local visibility and reputation of the project. The presentation materials have also been utilized to obtain new, higher-level collaborative cases.

### 5.4 Failed pilot cases

In addition to the above levels of collaboration, it is also useful to point out exceptions where piloting collaboration ended or was interrupted. In the work process, piloting can usually be interrupted only in its initial stages.

The reason may be ID’s reluctance (or resource shortage) to initiate collaboration. ID is not interested even in free piloting if it does not promise immediate benefit; in practice, however, that requires some involvement. Piloting may involve TV on ID’s part, which is necessary but TV is reluctant (similar to ID’s own reluctance).

Another reason may be that something comes up during the discussion stage (Discuss Requirements) that makes it impossible to continue or not meaningful to continue the piloting.

Even after progressing to the technical stage of the DMPP process (Develop Software), a situation may arise where a developed prototype is found to be unworkable. From the point of view of collaboration, the work process is interrupted, although from the point of view of research, a non-working prototype is also part of the results of the research. If the idea works, the hardware can be replaced with more suitable hardware in the next iteration round.

Pilot cases #98 and #99 are examples of cases where collaboration was interrupted. In case #99, ID was interested in collaboration, but access to required data was managed via ID's TV's API and TV had little or no interest in collaboration. For case #98, ID was also interested in collaboration. During the discussion stage AR noticed that it would be too difficult to produce data in such a form that would work for ID's needs. In both cases proceedings (in discussion stage) were paused and finally project management decided to shelve the piloting case.

It is worth mentioning that in the work process there were also some cases where project management was asked to help to communicate with ID to make sure that the collaboration would continue. Interruptions in collaboration cause serious harm to the work process. For example, due to material limitations, when the test equipment is reserved at one site, the next piloting target cannot be handled.

## 6 Usability and evaluation of DMPP in the KIEMI project

The DMPP was developed for the production of prototypes at the university. The goal has always been to produce scientific results from the prototypes. The research group is from non-commercial institutions and therefore the focus is not on achieving financial goals. This subsection clarifies the advantages of different phases of the DMPP. The KIEMI project used the DMPP model to create prototypes together with collaborative partners. This project and its approach to the subject through prototyping demonstrated the functionality of the DMPP model, especially in prototyping projects like this one. The suitability of the different phases of the DMPP model can be assessed through the KIEMI project pilot cases as follows:

**Discuss requirements**: Most pilot case projects involve an external partner(ID) when discussing objectives. The level of collaboration varies a lot. In low-level collaboration e.g., in pilot cases #19 and #22, the partner provided the premises to perform the measurements. The partner does not make any special requests. The output for the partner is a report which may lead to further actions. If the collaboration is closer, as when the partner takes part in further discussions, the starting point is also directed more by the partner. In these cases, the partner mostly has some issue which should be researched, e.g., they have been notified of poor indoor air quality (pilot case #10). Usually in these cases, the original task assignment expands during the pilot case and more partners join in. The DMPP is suitable for this kind of activity because the non-commercial leader – the university research team – is focused on research goals rather than financial goals.

Further, the additional research/technical goals set by partners are shown to be applicable to the operation of the model within the iteration rounds. The best example of this kind of activity is pilot case #10 where the university research team led the pilot case and collected the necessary partners (e.g., ventilation technology supplier and building caretaker).

**Requirements notes** are an important part of documentation and their main purpose is to guide the pilot case in the selected direction. The usage of the DMPP shows the advantage of ”light documentation” for getting things started; the usage of previously defined architecture models and device configurations also speeds up the operation. The term ”light documentation” also means the reuse of the technological choices and definitions made in earlier pilot cases. The exception is pilot case #23, where the final report included a section on desired goals. Internal requirements are also mentioned in several cases, e.g., the research group wants to change or update some specific feature. The ”light documentation” idea is based on the ”Some Things Are Better Done than Described” [18]. Light documentation and process modeling is focused on the university and other research institution environments where the aim was prototyping rather than the development of commercial products. Of course, this leads to a larger amount of work if technology transfer to some partner starts from the prototype.

The **Develop software** phase uses the artifacts of previous requirements as a loose guideline. For example, UI [19] and backend [20] software developed in pilot case #09 were used in all subsequent pilot cases (excluding #11). In the DMPP, changes to the requirements are possible if it is seen to be of some benefit. Further, the requirement changes were not normally discussed with partners unless something was needed from them. The DMPP does not set requirements for the software or hardware components used, but we noticed that the usage of off-the-shelf components accelerated prototype development. The second advantage of these kinds of components is the ability to vary the prototype solutions when we have to conform to the requirements of the selected components.

**Development artifacts** are typically fully working prototype systems which are also the main goals of this phase for the DMPP. In the KIEMI project, this phase usually involved installing the prototype to collect data at a target provided by the partner. Most of the prototypes were working SW/HW prototypes, but there were also only SW prototypes for analyzing and visualizing the customer's collected data (#12 and #13). The main purpose of the DMPP is to produce a working prototype and therefore only the main functions of the prototype are utilized. Additionally, the documentation or testing could be done only partially. This kind of approach speeds up the development but could slow down the technological transfer later on.

The **Prepare & conduct presentation** phase is for reporting the results. In longer projects we noticed that the document reuse of skeleton reports accelerated this phase. In pilot cases #20 and #23 of the final phase of the KIEMI project we collected a skeleton report from pilot case #19. This automation sped up the reporting phase. This shows that when using the DMPP model, reporting will mostly include the same components.

**Presentation** and publishing of the results are the last phase in the DMPP. In successful pilot cases the partners are usually interested in further developing the prototype and the technology transfer will continue from this point. One significant advantage of the DMPP is the ultimate purpose of publishing the scientific material (pilot cases #03, #09, #10, #11, #15, and #16 have been published) and other public material from the pilot cases.

**Overall analysis** and DMPP's suitability for projects were shown in the KIEMI project. Two approaches were used in the project: the software development style and collaboration style. The DMPP is able to connect both styles. The project was shown to be successful for university-enterprise (AR-ID) collaboration in the context of prototype development. Further, based on the results in creating usable prototypes, the model can be seen as a success.

## 7 Conclusions

RQ1: Collaboration. **How was university-enterprise collaboration executed in practice using the DMPP?** The DMPP process was part of a project (Fig. 4) where the content was guided by the objectives set for the project (Management) and an individual prototype was made through collaboration (Collaboration/Piloting). The DMPP process was in the background (invisible to ID), but it was able to provide support for collaboration (AR-ID) through all of its six phases. The ability of the DMPP process to support technology transfer was highlighted in phases 1, 3, 4, and 5.

For Step 2 (Requirement Notes), the content was usually only left up to the project team (AR). Regarding companies (ID and their TV), it is unknown whether they had one of their own similar methods in place. At the very least, communication (emails) enabled ID (and their TV) to receive and store requirement-related data.

As far as Step 6 is concerned, ID received a report on the content and results of most pilot cases. For pilot cases where content was distributed through open channels (such as Project news blogs and Github in Presentation slides), ID (and TV) had the opportunity to catch up, not only with their own content, but also the content of other pilot cases.

The collaboration also demonstrated that university and corporate representatives have a very different view of technology, and therefore of pilot cases as a whole. Especially in small companies, the desire and ability to recognize the value and benefits contained in the prototype is often low, and the university needs to convince the collaborator of the benefits of a prototype that requires effort on their part.

In a longer-term project, it should be considered whether each prototype is intended for actual technology transfer or whether that stage will only come when satisfactory prototypes have been achieved. In practice, the project requires that pilot cases at the beginning of the project are conducted mainly with organizations offering test environments and only at the end does the content begin to involve technology transfer.

There was no investment in cost calculations or business models in the design of university prototypes and this may have contributed to the amount of interest shown by companies. To improve collaboration it is good to add a point where the company provides a (suitable general level) assessment of the prototype as well as the associated return on investment (ROI). With the feedback received, the research team would accumulate expertise in designing the next prototype and opportunities to produce a result that is of more interest to the company. The ability to produce prototypes valued by companies is a significant strength and advantage for a university operator that organizes projects. It is also an advantage for future project partner searches.

RQ2: Reusability. **How did the reusability of the artifacts in the DMPP steps support the workflow of the pilot case?** The use of the DMPP model led to the reuse of artifacts when the mode of operation remained the same even though the pilot cases changed. In the prototypes, we mainly used the same software and hardware components that had been used before. Further, we also always tried to introduce some new components, because this increased knowledge and expanded component-based variation. The DMPP uses light documentation to speed up prototype development, but we noticed that separate phases in different pilot cases started to contain the same type of documents. Therefore, the conclusion is that the DMPP leads to re-use of skeleton documents in different pilot cases.

The findings of the research presented above represent the context of a Finnish university and it would require more research to obtain universally applicable results. However, these observations and findings provide the basis for the possibility to extend the research to an external comparison between universities in different countries.

## 8 Summary

This article focused on the KIEMI research project conducted at the Pori Unit of Tampere University during 2019-2022. The project used the earlier developed Descriptive Model of Prototyping Process (DMPP) to guide university-enterprise collaboration. The project consisted of several pilot cases and prototypes, which were made in collaboration with companies, and offered real-world problems. This article reviewed and evaluated the suitability of the DMPP for this topic. The article dealt with the collaboration between university and enterprises, and reusability within the DMPP. The paper presented several pilot cases made in KIEMI, and described the usage of the DMPP. Finally, the paper evaluated the model, presented some of the challenges faced, and discussed future research topics.

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