Requirements Engineering and Building Construction: Requirements Engineering for a Synagogue Kitchen with Use Cases and Scenarios

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Abstract. [Context and Motivation] Use cases and scenarios (UCaSs) are used in Requirements Engineering (RE) to illustrate a system's interactions with its users' roles to achieve the users' functional goals. UCaSs help achieve completeness in the specification of the system's requirements, to achieve an alignment between the needs of the system's client and the ultimate implemented system. **[Question/Problem]** Are UCaSs applicable to the RE for building construction? **[Principal Ideas/Results]** This paper describes an experience in applying use UCaSs to help determine the requirements for a synagogue kitchen. The authors conducted a use-case-and-scenario-driven requirements analysis based on the original kitchen plan produced by a professional architect. From the difficulties in the plan exposed by the UCaSs, it became apparent that no serious RE was done to produce the original plan. Application of UCaSs to and a flow analysis of the original plan allowed the authors to produce an improved plan for the kitchen and to demonstrate to the synagogue kitchen's client why the improved plan is better for the kitchen's purposes. Nevertheless, for reasons that are not entirely clear, the client appeared to be reluctant to use the new plan and said that he would be sticking with the architect's plan. **[Contribution]** Thus, the paper ends up showing the benefits of applying UCaSs in building architecture and construction.

Keywords: Building construction, Building layout, Floor plans, Requirements specification, Scenarios, Use cases

1 Introduction

Use cases (UCs) and scenarios are used in Requirements Engineering (RE). They aim to illustrate a system's interactions with its users' roles to achieve the users' functional

goals. UCs and scenarios (UCaSs) help achieve completeness in the specification of the system's requirements. They, therefore, help to achieve an alignment between the needs of the system's client and the ultimate implemented system. UCaSs are used also in other engineering domains such as usability engineering [1] and system engineering [2–4] for much the same purposes.

A building supports lots of different actors and uses. Personal experience and other evidence [5–9] show that only a few actors and uses are considered during the requirements analysis for the building. Instead, only the main activities and high-level statements about the building's purposes are considered to arrive at a plan for the building.

Since the plan for a building is what directs the building's construction, in RE terms, the plan for a building serves[4] as the requirements specification for the building, and the activities leading to the production of the plan serve as the RE for the building.

This paper describes an experience in applying UCs to help determine the requirements for a synagogue kitchen. The authors received from the Rabbi of the synagogue a plan for the proposed kitchen. The authors conducted a use-case-and-scenario-driven requirements analysis based on the original kitchen plan produced by a professional architect. From the difficulties in the plan exposed by the UCaSs, the authors suspected that no serious RE was done to produce the original plan. The Rabbi confirmed this suspicion.

Application of UCaSs to and a flow analysis of the original plan allowed the authors to produce an improved plan for the kitchen and to demonstrate to the Rabbi why the improved plan is better for the kitchen's purposes. Nevertheless, for reasons that are not entirely clear, the Rabbi appeared to be reluctant to use the new plan and stated his intention to stick with the architect's plan.

Section 2 of this paper describes the experience, giving the original plan, the set of scenarios used to demonstrate the flaws in this plan, and a modified plan. It then steps back and identifies a complete set of UCs for a kitchen, applies them to the first and second plan, and offers the third and final plan. It concludes by describing the Rabbi's reaction to the final plan. Section 3 does a deeper, flow analysis of the original and final plans and demonstrates clearly that the final plan meets the kitchen's requirements better than the original. Section 4 discusses the benefits of and the problems with applying UCaSs to requirements analysis for building construction. Section 5 concludes the paper with a description of possible future research.

2 The Kitchen Plan Experience

The Rabbi from a synagogue near author Berry sent to Berry the blueprints for the remodeling of synagogue's kitchen. The floor plan view of these blueprints are shown in Figure 1. The Rabbi asked to meet with Berry in person about these plans, and Berry agreed to meet with the Rabbi two days later in Berry's office.

Berry is an expert cook. He has catered two weddings including his own. He has used dozens of poorly designed kitchens to prepare meals. He designed a dream kitchen

[4] In the building industry, a *plan* is a link to design activities. The building industry considers the *brief*, from which an architect produces the plan, to be the *requirements specification*. In RE terms, the brief serves as a statement of the goals from which the plan is produced.

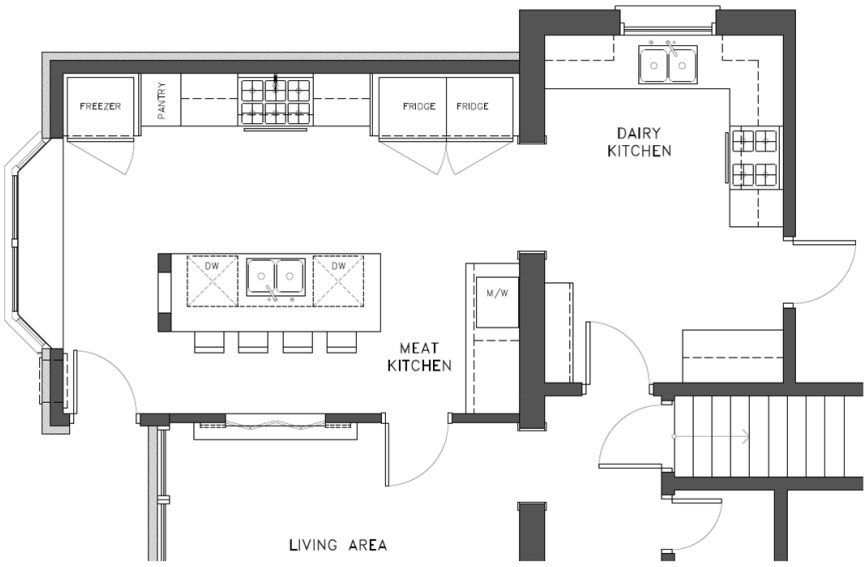

Fig. 1. Plan of Kitchen Sent by Rabbi to Berry

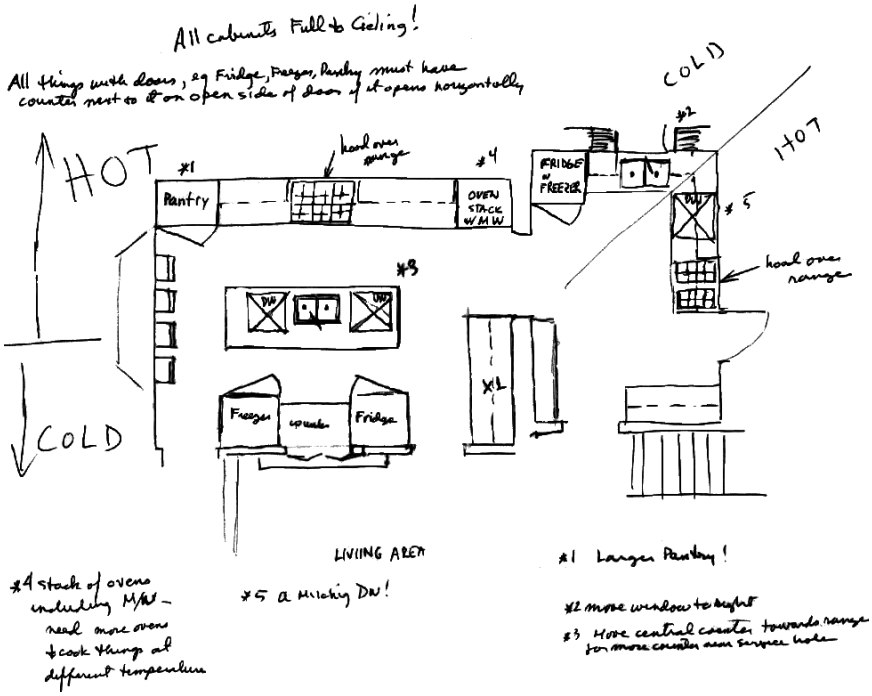

Fig. 2. Berry's Hand-Drawn Alternative Plan of Kitchen

for his own house, which was built from scratch to his and his family's specifications [5]. From all this experience, Berry was immediately bothered when he saw the design of the kitchen shown in Figure 1. In preparation for the upcoming meeting with the Rabbi, he prepared a hand-drawn alternative plan, that shown in Figure 2.

When the Rabbi came for the meeting, he revealed that his main purpose in sending the plans to Berry was to solicit a contribution from Berry towards the building of the new kitchen. Berry politely declined to contribute, citing personal reasons that the Rabbi understood. Berry asked the Rabbi if he would like to hear his thoughts about the plan itself. The Rabbi replied in the affirmative.

2.1 UCaS-Driven Walkthrough the Architect's Plan

Berry explained first his cooking expertise and that he had designed the kitchen for his dream house in Israel. He explained also that he had undergone two house remodelings and one construction from scratch in three different countries. The constructed house included the dream kitchen. Berry quipped that he had thought that the Rabbi had heard about Berry's cooking expertise and that he thought that the reason the Rabbi sent to him the plans was to get his comments. The Rabbi remarked with a smile, "That's a stretch!"

Berry then finger walked through the original and new plans guided by five specific scenarios:

1. coming home from shopping,
2. preparing to cook food
3. cooking food,
4. serving food,
5. cleaning up after eating food.

The Rabbi protested that his wife, not he, does these activities, but Berry convinced him that he could use his imagination and still see the problems with the original plan and how the new plan was better.

With a typical scenario from the "coming home from shopping" use case, Berry was able to show the Rabbi that

1. there is no convenient counter on which to put groceries that are to go into the freezer and the right hand refrigerator, marked with the boxes labeled "1" in Figure 3,
2. and, while adjacent to the left-hand refrigerator, marked with the box labeled "2", is a counter on which to put groceries that are to go into that refrigerator, that refrigerator's door opens in a direction that makes moving items from the counter to the refrigerator difficult.

With a typical scenario from the "preparing to cook food" UC, Berry was able to show the Rabbi that

3. Problems 1 and 2 occurred in the reverse direction, i.e., that it was not convenient to move food from either refrigerator or the freezer to a counter,

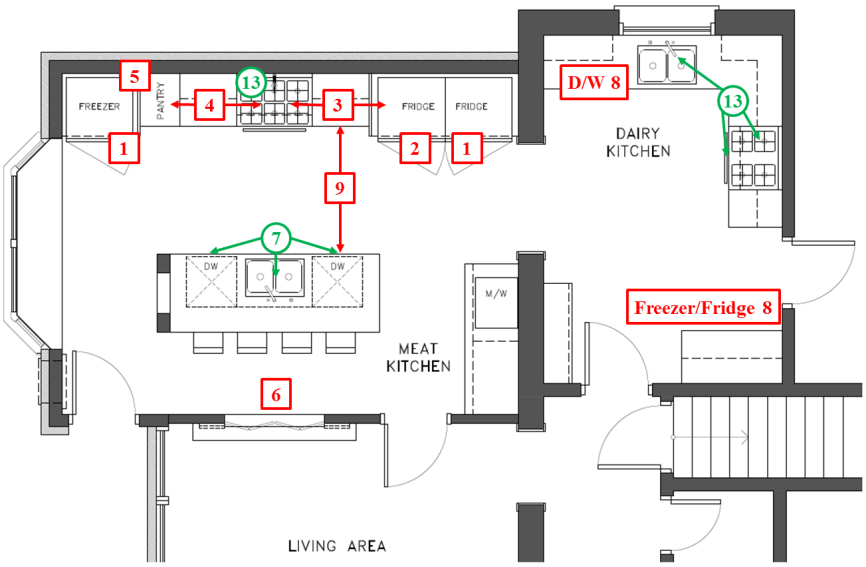

Fig. 3. Annotated Original Plan of Kitchen

4. and, as marked by the box labeled “Freezer/Fridge 8”, the lack of refrigerator and freezer in the dairy kitchen means that one could be taking dairy foods out of the meat kitchen refrigerators and freezer and putting them on counters in the meat kitchen while cooking a meat meal, increasing the danger of mixing meat and dairy, contrary to the rules of preparing kosher food.

With a typical scenario from the “cooking food” UC, Berry was able to show the Rabbi that

5. as marked by the boxes labeled “3” and “4”, the placement of stove near the refrigerators and near the pantry and freezer *could* force the refrigerators and freezer to work harder to keep their contents cold and *could* subject the goods in the pantry to damaging temperatures higher than normal room temperature,
6. and by the way, as marked by the box labeled ”5”, the warm exhaust from the freezer *could* subject the goods in the pantry to damaging temperatures higher than normal room temperature.

With a typical scenario from the “serving food” UC, Berry was able to show the Rabbi that

7. as marked by the box labeled “6”, there was no large enough counter top on which to put prepared food being sent from the meat kitchen to the dining room in the area called “Living Area” in the bottom center of the plan.

With a typical scenario from the “cleaning up after eating food”, Berry was able to show the Rabbi that

8. as marked by the box labeled “D/W 8”, the lack of a dishwasher in the dairy kitchen meant that dairy dishes would have to be washed in a dishwasher designated as dairy in the meat kitchen, increasing the danger of mixing meat and dairy, contrary to the rules of preparing kosher food.

The Rabbi said in response to Problem 8, that the two dishwashers in the meat kitchen are for meat. Berry then asked where is the dairy dishwasher? The Rabbi answered that there is none and that for dairy meals, they will use the sink in the dairy kitchen. Berry replied that if there will be enough people on Friday night (when meat is eaten) to justify having and using dishwashers, then there will surely be enough people on Shavuot (when dairy is eaten) to justify having and using a dairy dishwasher. The Rabbi replied that they will use paper plates in that case. Berry remarked that using paper plates is considered environmentally unsound.

With all the scenarios from all the UCs considered, Berry was able to show that,

9. as marked by the box labeled “9”, the central island is too far from the stove side of the meat kitchen to allow the island’s top to serve as a counter during cooking at the stove or for holding food going into or coming from inside the refrigerators.

Berry showed the Rabbi that there are some good points to the plan,

- that the two dishwashers in the meat kitchen, as marked by the circle labeled “7”, are adjacent to the sink,
- that there is a faucet for dispensing water directly over the stove to make it easy to add water to a cooking pot without having to carry it over to a sink or having to carry water from the sink to the stove.

2.2 Berry’s Hand-Drawn Plan

Berry explained to the Rabbi that his hand-drawn plan in Figure 2 has

- the freezer and one refrigerator on one side of the meat kitchen,
- the stove and microwave oven on the other side of the meat kitchen and the microwave oven combined with a stack of ovens to give more ovens for preparing large meat meals,
- one refrigerator has been moved to the dairy kitchen and turned into a combined refrigerator–freezer to give both a freezer and a refrigerator to the dairy kitchen,
- a dishwasher has been added to the dairy kitchen,
- each kitchen has a cold side and a hot side, each of which contains all the appliances consistent with its temperature.

Therefore, Berry explained, the hand-drawn kitchen plan avoids all of the problems with the original plan that were observed by finger walking through the five scenarios.

Berry admited that there are drawbacks to the hand-drawn plan in Figure 2. In particular,

- the pantry, although a bit farther from the stove than before is still quite near to the stove on the hot side of the meat kitchen,
- there is no pantry in the dairy kitchen to keep dairy items completely out of the meat kitchen,

Berry promised to work on solving these problems.

2.3 Downstream Costs

Getting back to the original plan, Berry explained to the Rabbi that if he were to go ahead and have the original plan implemented, then his wife and other cooks would fairly quickly discover the problems exposed by the scenarios, the first time they did any of the scenarios. They would be wishing for changes, changes that would cost about $20K to implement. Berry guestimated this figure based on his past remodelings; the guestimate is probably on the low side, because it's been a while since Berry has done any remodeling. Berry suggested in all seriousness that if the Rabbi got the architect to make the changes he suggested *before* construction started, Berry's ideas will have saved over $20K in future work[5]. Berry concluded, "There is my $20K donation!" The Rabbi smiled.

Before the Rabbi left Berry's office, Berry asked him if the professional architect that drew the original plans had asked the questions that Berry had asked. The Rabbi's answer was a very simple "No!"

The conclusion is that, as observed by Berry in three previous occasions [5, 6], there was no serious requirements analysis on the parts of the home designing architects. In the three previous occasions and in this occasion with the synagogue kitchen, a significant part of the needed requirements analysis was conducted by the customer or by a friend of the customer.

2.4 Full Set of UCs and Berry's Final Plan

Based on his own experience with kitchens, Berry developed a full set of UCs that can be used by any architect in interviews with a house building customer to discover requirements for a kitchen. These scenarios cover both normal kitchens and kosher kitchens that have additional constraints such as keeping meat and dairy foods separate. These use cases are shown in the tree-structured UC diagram of Figure 4. In this diagram, each cooker-accessible UC but one is extended (in the UML sense) by two or more subUCs that refine the cooker-accessible UC. Each extension subUC, which is also a leaf UC, is labeled by the letter that names the full text UC of Table 1 that is obtained by reading the text in each UC on the path in the tree from the Cooker to the label. There are some additional non-labeled lines, each giving a color followed by "lines", whose purpose will be explained in Section 3.

Table 2 shows a list of principles that Berry has learned over the years of using and designing kitchens, principles that can be used to tame the too many degrees of freedom that any kitchen's design has when only UC-generated requirements are known.

Applying these UCs and these principles, Berry devised a new plan that would solve the problems observed in the hand-drawn plan. Figure 5 shows Berry's final plan. Each of the kitchens has at least one refrigerator and one freezer, possibly combined into one unit. Each kitchen has at least one dishwasher, and each dishwasher is near a sink. The sink in each kitchen has a garbage disposal. Each kitchen is divided into three zones:

1. hot, containing stoves, ovens, ranges, microwave ovens, and dishwashers;

[5] Berry was thinking of the well-known data that show that the cost to repair a defect in software grows exponentially with each succeeding lifecycle stage [10].

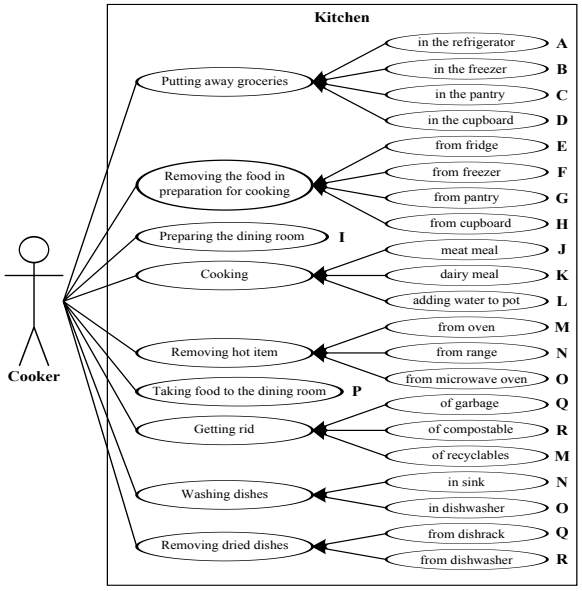

Fig. 4. UC Diagram of Kitchen UCs

Table 1. Kitchen UCs in Tabular Form

Id	UC	Color
A.	coming home from shopping and putting food away in refrigerator	black
B.	coming home from shopping and putting food away in freezer	black
C.	coming home from shopping and putting food away in pantry	black
D.	coming home from shopping and putting food away in cupboard	black
E.	removing food from refrigerator in preparation for cooking	orange
F.	removing food from freezer in preparation for cooking	orange
G.	removing food from pantry in preparation for cooking	orange
H.	removing food from cupboard in preparation for cooking	orange
I.	removing dishes from cupboard and taking them to dining room	gray
J.	preparing to cook and cooking a meat meal	orange
K.	preparing to cook and cooking a dairy meal	orange
L.	adding water to pot that is being cooked	orange
M.	removing hot item from oven	green
N.	removing hot item from range	green
O.	removing hot item from microwave oven	green
P.	taking food to dining room	green
Q.	getting rid of garbage	NONE
R.	getting rid of compostables	NONE
S.	getting rid of recyclables	NONE
T.	washing dishes in sink	red
U.	washing dishes in dishwasher	red
V.	removing dried dishes from dishrack and putting them away	blue
W.	removing dried dishes from dishwasher and putting them away	blue

Table 2. Kitchen Principles and Requirements, Including for Kashrut

R1	There should be a counter top next to or very near anything that opens or is hot, e.g., a refrigerator, a freezer, a pantry, a cupboard, a dishwasher, an oven, a range (so that one does not have to hold any item take from the anything or put it on the floor).
R2	For anything that has a door with vertically placed hinges, there should be a counter on the side not having the hinges, so that moving items to and from the thing from and to the counter does not have to go around the thing's door.
R3	Separate hot things from cold things, e.g., an oven from a freezer.
R4	Separate hot things from room-temperature things, e.g., an oven from a pantry.
R5	Separate cold things from room-temperature things, e.g., a freezer from a pantry (because the exhaust of a cold thing is warm).
R6	Divide the kitchen into three regions, hot, cold, room temperature. Each region should be contiguous.
R7	A dishwasher should be adjacent to a sink.
R8	If you have separate kitchens for meat and dairy, each should be at least minimally functionally complete, i.e., one should not have to go over to the other kitchen to do any part of a job being done in one kitchen.
R9	One never has too much counter space.
R10	One never has too much cupboard space.
R11	One never has too much pantry space.
R12	The counter next to a hot thing should have a burn-resistant top.
R13	Adding water to someone on the range or in the over should not require carrying water or a pot over a floor. (The carrying, if any, should be over counter tops.)
R14	Cabinets should all the way to the ceiling to get some dust-free storage for very low frequency items, to take advantage of the space to the high ceiling, to avoid dust-trapping space between the tops of cabinets and the ceiling, and to avoid building a useless hollow filler between the tops of cabinets and the ceiling.

2. cold, containing refrigerators and freezers;
3. room temperature, containing pantries,

and the cold and room temperature zones are on the side opposing that with the hot region in each kitchen.

Each kitchen has a pantry that is bigger than in the original plan and that is in the kitchen's room-temperature region. In the meat kitchen, the central island was moved to be equidistant from the hot and cold walls, so that

1. its counter could be used both from the hot side and the cold side
2. there is enough room on either side of the island for smooth circulation around the island.

The chairs that were in between the island and the now cold wall were moved to the bay window off on the side. The bay window now has a table-height ledge that can be used for eating while sitting at the chairs.

Berry sent this final plan to the Rabbi, suggesting that *this* plan be given to the architect so that he or she could update the full plans accordingly.

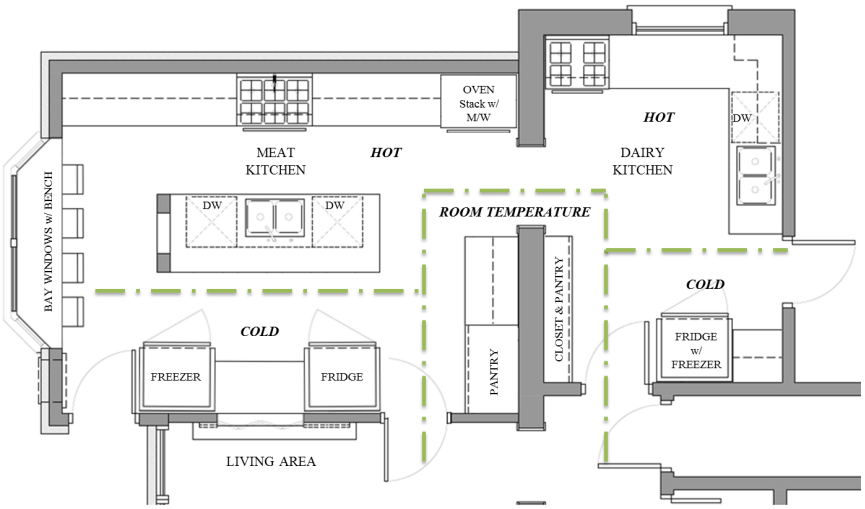

Fig. 5. Final Alternative Plan of Kitchen with Zones Shown

2.5 Follow Up Conversation with Rabbi

Berry visited the Rabbi two and a half months after sending the final plan to him on another matter. Berry asked the Rabbi, "So, how is the kitchen coming?" The Rabbi answered, "Fine", not answering what Berry thought was the obvious follow-up question. So Berry asked, "So, what plans are you using?" The Rabbi answered, "We are using the original plans, but we did change the direction of the refrigerator and freezer doors." Berry asked, "You did not use any of the ideas in the plan I sent?". The Rabbi's answer was "No, we kept the same basic layout."

Berry sighed and said, "While I am an academic and often do strange research, in this case, I am very serious about the problems that this layout will cause in the use of the kitchen. I am totally convinced that the suggestions I made will save you about $20K down the line." The Rabbi nodded, adding "My wife is happy with the plan; so I am." Berry continued, "Look, I will make this one offer — I don't want to be in the position of being a nudnik (harasser) — I offer to meet with you, your wife, the architect, and anyone else to *show* them the problems with the original plan and my ideas for avoiding them. It's up to you. If you don't take me up on my offer, I will leave you alone about this." The Rabbi smiled and thanked Berry.

So far, Berry has not heard back from the Rabbi.

3 A Deeper Analysis of the UCs with the Plans

Based on the information supplied by Berry from his experience, Mauger decided to do a deeper UC analysis than Berry had done, using a simplified version of the tool he has been developing. Mauger decided to illustrate each UC from Figure 4 and Table 1 on each plan by drawing on the plan the path through the plan taken by the cooker in

following a typical scenario of the UC. Figures 6 and 7 show the result of this superposition of the UC paths on the plans. The color of the path lines for the scenarios for each UC in Column 2 of Table 1 is given in Column 3; a whole group of related UCs share one color. Thus, for example, each "coming home from shopping and putting food away" UC is traced by a black path through the plans.

These superpositions of UCs on the plans made it possible to evaluate the usability of the kitchens specified by the plans. It became possible to test Berry's claims about the plans. For example, by comparing the two plans for the lengths of the black paths between refrigerators and freezers and their nearest counter tops, it is possible to see clearly that Berry's claims about Problems 1 and 2, about putting new food into the refrigerators and the freezer, are correct.

3.1 Architect's Original Plan

The superposition of all UC paths on the original plan from the professional architect shows that the flows through the actual kitchen would be quite messy and long.

- The distance between the central island and the stove of the meat kitchen is large and would require a lot of walking on the part of the cooker.
- Almost half of the meat kitchen, the bottom left part in the plan, seems not to be utilized in any path. Thus, all the traffic seems to be confined to the other half of the meat kitchen, the top right part in the plan.
- There are too many paths for UCs involving open food (i.e., not in the merchandizing packages) between the meat kitchen and the dairy kitchen, increasing the risk of mixing meat and dairy foods, in violation of the rules for preparing kosher food and maintaining kashrut.

Thus, the superposition of the UC paths on the original path supported Berry's claims and showed some additional points that he had not thought of. It provides a visual explanation of the problems that Berry notice, an explanation that might have helped him to make his point more forcefully with the Rabbi.

3.2 Berry's Final Plan

The superposition of the same UC paths on the final plan produced by Berry tells a very different story.

- The distance between the central island and the stove of the meat kitchen is smaller than in the original plan and would require less walking on the part of the cooker.
- The space in each kitchen has a clearer use and is more thoroughly utilized than in the original plan, in particular with the paths covering more of the meat kitchen.
- Rules about keeping meat and dairy foods separate are more strongly observed, as no paths, save for those bringing food home from shopping pass through both kitchens.

In addition, in the meat kitchen, there is a nice symmetry in the paths between the counters adjacent to the stove and the central island and in the paths to the refrigerator and freezer.

These paths suggest further improvements to the final plan.

- The pantry could be closer to the central island because the pantry contains food that could be used during cooking.
- The cupboards containing dishes should be close to the living area and to at least one dishwasher to facilitate setting the dining table during cooking and later returning cleaned dishes to the cupboards. Note that the existence of two dishwashers in the meat kitchen makes it easier to wash the cooking and dining meat dishes at the same time if it is not desired to have a dishwasher noisily cleaning the cooking dishes while eating.
- To satisfy the previous point, the pantry and cupboard on the bottom right of the meat kitchen could be swapped so that the cupboard, which could contain the dining dishes, is closer to the dining table.
- The likely contents of each cupboard should be specified in order to be able to more accurately draw the paths for UCs involving food, dishes, cookware, etc.
- One of the meat kitchen dishwashers could open on the other side of the central island to be closer to the dining table and the dining dishes cupboard.
- A faucet could be added above the dairy kitchen stove to facilitate adding water to food being cooked on or in the dairy stove.

As usual, some of these new ideas could conflict with meeting other requirements.

Unfortunately, there was no information about the location of garbage and trash cans and recycling bins in the original plan. So, it was impossible to determine paths for UCs Q, R, and S. Nevertheless it is clear that at least set of these cans and bins should be as close as possible to each of the meat kitchen central island and the dairy kitchen sink and dishwasher in order that a bag of garbage or trash be carried from the kitchens to its can in a path that is as short as possible.

4 Discussion and Conclusion

The experience has shown that UCaSs are helpful not just in RE for software, but also for building construction. UCaSs definitely helped Berry to arrive at his final plans for the synagogue kitchen. From just a few of them, he was able to identify several problems in the original plan. With a full set of UCs, he was able to devise an improved plan that better met the requirements for a kosher synagogue kitchen than did either the original plan or the hand-drawn plan.

The question that remains is "How exhaustive is the set of UCs given in Figure 4 and Table 1?" Even one missing UC could bring more requirements and have an impact on the final plan. Fortunately, kitchens have been around for a long time and are well understood. The number of kitchen use cases is limited by the fact that a kitchen is used primarily for cooking, preparing for it, and cleaning up after it. So it should be possible to develop a truly exhaustive set of kitchen UCs in a reasonable amount of time.

An observed benefit of UCaSs that is applicable in the analysis of *any* system's requirements is that they allow focusing on the system's details as well as on its overall picture. By drawing UC paths on the two plans, Mauger was able to find more requirements or kitchen principles and new UCs not identified by Berry. In fact, Mauger's analysis seemed to be an iterative analysis on the global system or main picture that could help the requirements engineer, the client, or the architect to better understand

the system or building to design. Timing, e.g., potential simultaneous performance of UCs, was not considered at all even though it could be a critical issue, as people's paths will likely cross when more than one UC is done at a time.

The number of UCs analyzed is severely limited when the time-consuming analysis is done manually. Moreover, human cognitive limitations would prevent manual consideration of simultaneous combinations of UCs. Therefore, there is a need for automated tools to carry out the clerical, automatable parts of this analysis, to free up the people to do the thinking about the results. There is a general need for computer-aided requirements analysis in the building industry [7]. There is a lot of simulation software that could help the requirements engineer to simulate all the possible UCs and combinations thereof [11–13].

Mauger's analysis was done on a two-dimensional plan. This analysis could be done on a three-dimensional model of the kitchens to improve the evaluation of the specified kitchen. Moreover, all the analysis was done on a polished plan delivered to its client. A better idea would be to do the analysis as soon as possible in the project development, during the initial meetings with the client and soon thereafter. Mauger's PhD research addresses doing this analysis early in the building lifecycle. He is dealing with all this information and providing abstract models of them in order to provide an automated tool for evaluation of an architect's proposals during his or her design [14].

5 Future Work

During the experience, some mysteries and questions arose that need to be solved and answered.

1. Why had not the professional architect for the kitchen done more thorough requirements analysis, perhaps using UCaSs (or whatever else architects call them)?
   (a) Did the professional architect know how to do requirements analysis or even about it?
   (b) Do professional architects even learn about requirements analysis in their architectural education?
2. Why did not the Rabbi make use of Berry's plan, which clearly meets his requirements better than the architect's plan?
   (a) Did the Rabbi agree with the author's assessment of the plans?
   (b) Did the Rabbi not believe Berry's claim about the high downstream costs to fix the defects in the architect's plan?
   (c) Were there other requirements, not stated, that trump the requirements that the authors used to evaluate the plans?
   (d) Was the Rabbi embarrassed or afraid to show Berry's plan to the professional architect?
3. Why is the experience reported in this paper so similar to Berry's other experiences [5, 6] in which he *had* to do his *own* requirements analysis for the houses he was remodeling or building, in order to achieve a satisfactory result?
   (a) Is poor requirements analysis part of the construction industry's business model, to ensure that additional money is spent fixing the results of poor requirements analysis before construction?

4. Is there anything that requirements engineers for software systems can learn from the building industry?

Answering some of these questions is the goal of the second author's PhD research.

Acknowledgments

Mauger's work was supported by the National Research Fund, Luxembourg. Berry's work was supported by NSERC grant NSERC-RGPIN227055-00 and by an NSERC–Scotia Bank Industrial Research Chair NSERC-IRCPJ365473-05. The authors would like to thank the Rabbi for the information and discussions about his synagogue's kitchen.

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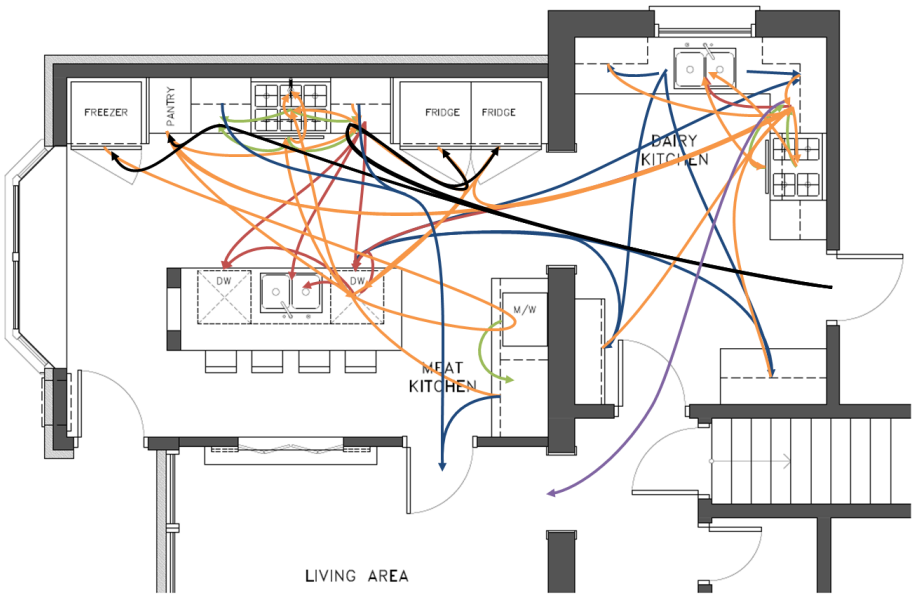

Fig. 6. Architect's Original Plan with Superposed UC Paths

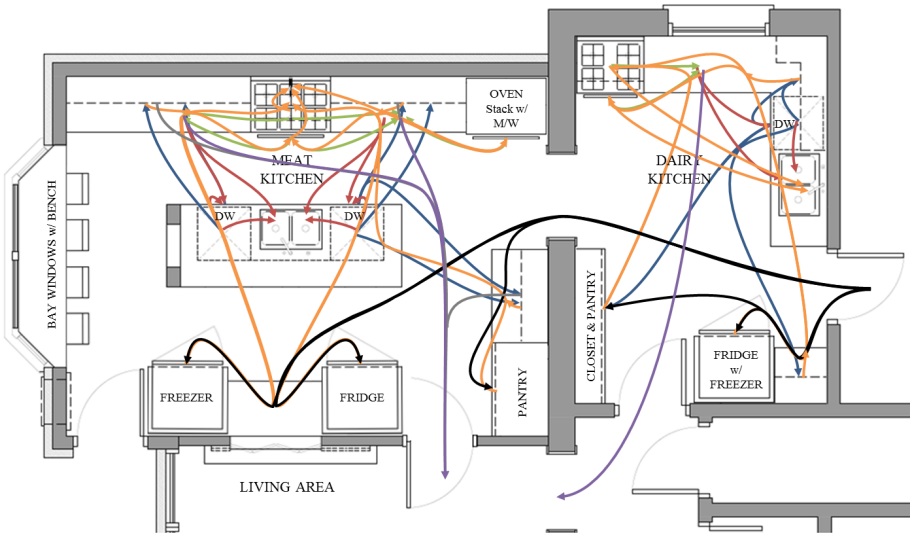

Fig. 7. Berry's Modified Plan with Superposed UC Paths