Analysis and optimization of IKEA’s test methods for kitchen articles

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Analysis and optimization of IKEA’s test methods for kitchen articles

From system to detail

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Abstract

IKEA offer a 25 year warranty with most of their kitchen articles, which has led to more extensive testing conducted according to current European and international standards. An assembled kitchen unit is used in all the tests but a translation into the effect on the individual parts of the unit is needed. The aim of this thesis is analyze the test methods, to prioritize which kitchen units to test and to find a test closer to the manufacturing process of particle boards for the over-opening test of pivoting doors.

A way to prioritize in the range was made possible by creating risk factors based on usage frequency in combination with mechanical calculations on load cases of doors and drawers. User behavior in the kitchen was studied in contextual interviews and these showed that most behavior is tested by IKEA with the most important exception of forces applied to knobs and handles. An analysis of usage frequency and test methods showed that the amount of cycles in the durability tests of doors and drawers could be revised. The technical properties of particle boards were compared to test results from over-opening tests, without finding any correlations. This lead to experiments on the break-off scenario of hinges with the result that a correlation was found between the deformation of the holes used for attaching the hinges and the over opening break-off load. Since the experiments were made on a small scale it is recommended that the correlation is investigated on a larger scale. Optimally a correlation could be found between hole deformation and a technical property of the particle board. The consequence would be that the over-opening test could be replaced or supported by a demand on the technical property of the particle board.
Examensarbete MMK 2013:73 IDE 105

Analys och optimering av IKEAs testmetoder för kök
– Från system- till detaljnivå

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Sammanfattning

IKEA erbjuder idag 25-års garanti vid köp av de flesta av sina köksartiklar, vilket har lett till mer utförliga tester som utförs enligt nuvarande europeiska och internationella standarder. I alla testerna används en fullständig köksamölbel men en översättning på testets inverkan på de ingående delarna behövs.

Syftet med det här arbetet är att analysera testmetoderna, att kunna prioritera vilka köksamöbler som ska testas och att hitta ett test närmare tillverkningen av spånskivan för överöppningstestet av svängdörrar.

First and foremost this thesis was only possible thanks to all the information and help provided by the employees at IKEA of Sweden and at Swedspan. It was IKEA that provided the topic of the thesis in the first place and were open to modifications on the way. The guidance and support of our supervisor Malin Augustsson at IKEA was crucial for the development of the thesis.

We also want to thank Sofia Sjödin for her fast replies and Klas-Ola Nilsson, Oscar Lindkvist, Tony Bengtsson, Patric Smedberg, Hans Fernegård, Marcus Malmén, Mathias Karlsson and all the people at IKEA Test Lab for their patience with all our questions.

A visit at the particle board manufacturer Swedspan with a guided tour by Daniel Schwartz was a great source of inspiration. The first experiment would not have been possible without the use of either equipment or help at Swedspan.

Last but not least we want to thank our supervisor Conrad Luttropp at KTH for helping us to take a step back and looking at all the work conducted from a broader point of view in order to be able to find a logical path through the work.

Per Bråvander and Maria Månthen

Stockholm, August 2013
Nomenclature

Abbreviations

SWR  Screw Withdrawal Resistance
SWR wps  Screw Withdrawal Resistance with plastic socket
EN  European Standards
CEN  European Committee for Standardization
P2  Particle board class by CEN used for furniture
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1. Introduction

This chapter gives a short project background as well as a description of the project framework.

1.1 Background

The kitchen is commonly said to be the heart of the home and is exposed to a lot of wear and tear through cooking, cleaning and other activities. IKEA is one of the larger vendors of kitchen solutions with costumers all over the world. IKEA’s vision is to create “a better everyday life of the many people”, with the goal to sell well designed and functional furniture to as many people as possible by keeping the prices low, (IKEA, 2013). During the latest years the traditional kitchen architecture has been scrutinized resulting in a new kitchen system that was unveiled in 2013. The vision to reach many people can be achieved since the IKEA GROUP is now present in 44 countries and employs 139,000 people, (IKEA, 2013).

IKEA has a 25-year warranty on their kitchen units that covers faults in material or production, discovered in domestic use. Amongst others the following articles are included in the warranty; cabinet frames, doors, drawers of one model and drawer fronts. If a problem occurs and IKEA considers it to fall under the warranty they will either repair the product or replace it with a new or similar product, (Inter IKEA Systems, 2013b). Hence they need thorough test methods to secure the high standards needed to comply with this warranty. Today these test methods are primarily built on the security and durability tests from standards that are designed for storage furniture in general with supplementary specifications for kitchens. Although the standards are based on experience from furniture manufacturers and other organizations the user behavior that motivated these seems to have been lost in time. One example of the extensive testing is that the cyclic tests of drawers and pivot doors are extended from 80 000 cycles to 200 000 cycles, to better suit the intense use of the kitchen furniture. The furniture tests, so called system tests, are performed on assembled kitchen units i.e. a complete cabinet frame with door, hinges and handle attached, but the separate parts of the unit does not have individually assigned mechanical tests.

The kitchen cabinets are made of particle board with a melamine foil and this material is a vital component within the IKEA range. The properties of the particle board are therefore paramount for the understanding of kitchen article testing.
1.2 Purpose

The overall aim is to analyze the test methods at IKEA, from a system level down to the detail by finding a test method that is closer to the particleboard manufacturing process and focused on the frame and not the assembled unit. The aim is to do this transformation from system to a detailed by looking at the horizontal force test of pivoting doors, in order to ensure overall quality at a higher degree.

In order to make the testing less time consuming another purpose is to find a way to decide which kitchen articles out of the wide range should be prioritized, by analyzing the worst case configurations in regard of frequency of use and exposure to forces and high loads. Both creating a new test method and prioritizing what in the range to test will save IKEA both time and money. In addition, this thesis aims to investigate if user behavior is covered by the tests conducted by IKEA and to make recommendations on future test methodology.

1.3 Method

An understanding of kitchen articles at IKEA, their test methods and the particle boards of the cabinet frames was gathered from interviews at IKEA and at a manufacturer of particle boards, as well as by studying literature on the subject. Prioritization of what to focus on in the testing of the wide range of kitchen furniture was achieved by creating a risk factor based on usage frequency and by making mechanical calculations of the load cases of the different combinations within the range. A user study in form of contextual interviews conducted in domestic kitchens made out the background analysis of the test methods. The behavior found in the contextual interviews was compared to the test methods conducted by IKEA to see if all the user behavior was covered in the current tests. From the contextual interviews the critical situation of over–opening a cabinet door was identified. The situation was studied in detail and the first hypothesis was formed based on a presumed mechanical situation of the over–opening scenario. In Experiment 1 the hypothesis was investigated by comparing mechanical properties of cabinet frames to the test results from an over–opening development test made on the frames. This lead to the forming of a second hypothesis that was investigated in Experiment 2 where tests were conducted on a cabinet with part of a door attached with one hinge. Observations during the second experiment culminated in yet another hypothesis that was investigated in Experiment 3 with a new experimental test method.
1.4 Scope

Since the range of IKEA’s kitchen articles is very extensive, the focus of this thesis was narrowed down to only include cabinets with drawers or pivoting doors. This excludes a few combinations that were considered to be special solutions of infrequent use. Amongst others cabinets with sliding doors, roll-fronts and glass doors were left out. Corner cabinets, horizontal cabinets, doors for fridges or freezers and the two story drawer with pull out function were excluded as well. High cabinets and cabinets for built-in appliances are not directly included, but drawers and doors with the maximum height of 100cm attached to these are.

In regard of test methods the scope includes analysis of mechanical tests and not tests concerning chemicals, fire or other aspects. In addition, the studied test methods were limited to the tests conducted by IKEA or those found in European and international standards.
2. Kitchen articles

In this chapter the kitchen range of IKEA and the particle boards used for the cabinet frames are described.

2.1 Range

A kitchen consists of many types of kitchen units that at IKEA are categorized into base cabinets, wall cabinets, high cabinets, and cabinets for built-in appliances. Generally all cabinets consist of a frame made of particle board with a melamine foil, doors or fronts of numerous varieties, drawers of different types or shelves and varying interior fittings.

The base cabinets are positioned on legs on the floor and can contain shelves, drawers and other interior solutions in many combinations. For a description of the general measurements of a cabinet see Figure 1.

![Figure 1. General measurements for a kitchen cabinet.]

The wall cabinets are hung on the wall and most often contain shelves but sometimes also drawers. Both high cabinets and cabinets for built-in appliances have the possibility of many combinations of doors, drawers, shelves and other interior fittings. The cabinets themselves and the built-in appliances are not covered in this thesis but some of the doors and drawers that can be attached to them are.

IKEA’s new kitchen system comes in a wide variety of measurements for cabinets, doors fronts and interior fittings, which leads to a vast number of possible combinations why the focus of this thesis is combinations with doors or drawers. All doors with a height up to 100 cm, all drawers and current drawer and possible future drawer fronts are covered. The door and drawer front models are made of varying materials where the heaviest model has a density of approximately 700 kg/m³ which therefore was the assumed density in all the calculations.
2.2 Particle boards

To better understand the material of kitchen cabinet frames made by IKEA, literature on particle boards, current standards and articles on mechanical properties were studied. An interview at a particle board manufacturer was also conducted.

Mechanical properties of particle boards

Particle boards consist of wood particles in form of wood chips or shavings bound together by urea resin glue. The mix of wood and glue is formed into a large sheet which is later pressed into a compact board. Particle boards are often produced with different layers, where the core layer is made of larger wood particles and the surface layer of smaller particles mixed with a higher amount of glue, (Burström, 2001). For a detailed description of the manufacturing of particle boards and what influences the quality see Appendix A.

The most important technical properties of particle boards are covered by a European standard by the European Committee for Standardization (CEN). In the EN 312:2010 standard (European Committee for Standardization, 2010) the technical properties specifications of particle boards of different categories are stated. Particle boards intended for furniture fall under the group P2, which is boards for interior fitments (including furniture) for use in dry conditions, (European Committee for Standardization, 2010). This is the board type used in kitchen cabinet frames at IKEA, (Inter IKEA Systems, 2011). There are additional properties that particle board manufacturers monitor but the ones demanded by the European standard (EN) are bending strength, Young’s modulus, internal bond and surface soundness. Bending strength and Young’s modulus are both measured in the same test where a test piece is bent until it breaks, (Swedspan, 2013). Internal bond is measured by gluing loading blocks to both sides of a sample piece of the board and pulling them apart while measuring the maximum force before rupture, (European Committee of Standardization, 1993a). In other words internal bond is the tensile strength perpendicular to the face of the board, (European Committee of Standardization, 1993a). The result of the internal bond test is that the attachment between the particles in the core layer of the board is measured, (Swedspan, 2013). According to (Wadell, 1998) surface soundness is basically a test of the force needed to pull a glued test body from the surface of the board. The demands on the mechanical properties of P2 particle boards are presented in Table 1.
Table 1. The mechanical property demands in SS-EN 312:2010.

<table>
<thead>
<tr>
<th>Mechanical properties of P2 particle boards with thickness 13 -20 mm</th>
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</thead>
<tbody>
<tr>
<td>Bending strength</td>
</tr>
<tr>
<td>Young’s modulus</td>
</tr>
<tr>
<td>Internal bond</td>
</tr>
<tr>
<td>Surface soundness</td>
</tr>
</tbody>
</table>

Except from the properties presented in Table 1, the SS–EN 312:2010 standard also put demands on the dimensions of the board, the moisture content, the tolerance of mean density within the board and formaldehyde release, (European Committee for Standardization, 2010). Formaldehyde exists both naturally in the wood itself and as an ingredient in the glue, (Swedspan, 2013). In Europe there is a formaldehyde directive called E1 whereas the USA uses another method. The amount of formaldehyde in particle boards used by IKEA is a lot less than the allowed emission in the E1 directive, (Swedspan, 2013).

Another important property is the density of the board, with a normal span between 550 and 750kg/m³, (Blümer, 1992). Values for density is not officially demanded by either EN standards or IKEA, but the latter have made investigations into the effect of density on the quality of the particle board and have thought about making a density demand to their providers, (IKEA Employee 2, 2013). CEN does on the other hand have a standard ready for the testing of density called the EN 323 (European Committee for standardization, 1993b), where the volume and weight of samples are simply used to calculate the density.

A very particular mechanical property that is interesting in regard of kitchen furniture since the hinges of doors and runners of drawers are attached with screws, is Screw Withdrawal Resistance (SWR). SWR is the resistance to axial withdrawal of a screw from the face of the board. In the test method described in EN 320:2011 a screw is first inserted into a predrilled hole in a test piece, and then withdrawn from the board. The maximum force needed to remove the screw is measured as the SWR, (European Committee for Standardization, 2011).

Swedspan regards the properties that affect SWR the most, as the thickness of the surface layer, the density of the surface and the internal bond. Only the internal bond is affected by the middle layer whereas the other properties depend on the surface layer, (Swedspan, 2013). In a study to investigate the SWR in furniture (Vassiliou & Barboutis, 2005) found that screw withdrawal strength was lower for screws with plastic sockets than without sockets for two out of the three manufacturers tested, whereas one of the manufactures got higher SWR with a screw and plastic socket. This is of interest since IKEA uses screws with a plastic socket for their kitchen furniture. Vassiliou and Barboutis think that the length and quality of the material of the socket is the reason for the bad results for screws
with sockets. Sockets with the same length as the screw and with a good quality of plastic got better SWR results. In the study it was also found that SWR was improved with higher density of the particle board and that the melamine foil did not affect the screw withdrawal strength greatly, (Vassiliou & Barboutis, 2005). In another study it was found that SWR decreased with larger pilot holes for screws in particle boards, (Haftkhani, et al., 2011).

Room for improvement

Swedspan thinks it is better to use a particle board demand based on a function instead of overall specifications of the properties as the P2 requirement in the EN standard, since it makes it possible for the manufacturer to fit the production process to the function criteria, (Swedspan, 2013). As it is today the manufacturer produces different types of particle board and uses these to test the function specified by the byer. The mechanical properties of the board that fulfills the function demand are then used as a bill of requirements for the board produced for the byer, (Swedspan, 2013). This could mean that a demand on a mechanical property is wise if the byer knows for certain that this technical property correlates with the function.

The property the industry usually uses to ensure their economic gain is the density, since two thirds of the costs for producing particle boards are material costs. If the density is lowered, other parameters can be changed to improve the mechanical properties of the board, (Swedspan, 2013). The answer by (Swedspan, 2013) to the question of making a demand on the density of the board was “Why not make a demand on the SWR?” since the test is possible for most manufacturers who test internal bond as it uses the same equipment. If a demand on SWR was used, there are other methods to achieve this than raising the density, for example the shape of the wood particles could be changed or smaller particles could be used in the surface layer, (Swedspan, 2013).
3. Standardized tests

3.1 Laws and standards

In Sweden the safety of consumers in contact with goods and services is ensured by the Product Safety Act, (Svensk författningssamling, 2004a). In all the member states of the EU there are similar laws protecting the safety of the users where it is stated that the EN standard shall be fulfilled (European Parliament and the Council of the European Union, 2001). According to the act all goods, including kitchen furniture, have to be safe for the customer to use and the manufacturer has to secure this by testing the product according to EN standards. If the goods is proved unsafe for the customer the manufacturer have to take action by for example make a recall of the product and if the manufacturer does not live up to this they can be fined, (Svensk författningssamling, 2004a). Konsumentverket is the supervisory authority in Sweden that controls that the Product Safety Act is fulfilled by testing goods on the market, (Svensk författningssamling, 2004b).

The Product Safety Act shows that manufacturing companies can get heavy economic consequences by selling unsafe goods, which is one of the reasons why kitchen manufacturers test their furniture and usually does this using European standards (EN). If the product is not covered by a current EN or Swedish standard the safety of the product still have to be ensured but without a stated test method. The test methods to be used for testing furniture in the EU are currently stated in the EN standard EN 14749:2005 (European Committee for Standardization, 2005). Though the laws and standards are different worldwide there exists one international standard for furniture testing called ISO 7170:2006 (the International Organization for Standardization, 2006).

The standards are based on experience from furniture manufacturers and other organizations rather than by user studies. The original behavior documentation that motivated the test methods has been lost with time, (IKEA Employee 1, 2013). To ensure the safety and quality of their products worldwide IKEA test their furniture according their own test instructions based on both EN and ISO standards with a few additions and changes, (IKEA of Sweden, 2006). All tests included in the EN
3.2 Test methods

There are many similarities and some differences between the EN standard, the ISO standard and the tests conducted by IKEA. In the following text the test methods and conditions for the tests are summarized for the three protocols and a more detailed description is given in Appendix B.

Tests conducted on pivoting doors

The EN standard, the ISO standard and IKEA describe four tests that can be conducted on pivoting doors called vertical load, horizontal load, slam shut and durability. The vertical load test is conducted by hanging a load on the door and swinging it back and forth for 10 cycles, Figure 2. (European Committee for Standardization, 2005), (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006). The vertical load used by IKEA is 30kg (IKEA of Sweden, 2006).

![Figure 2. In the vertical load test a load is attached to the door and the door is swung back and forth.](image)

The horizontal force test is conducted by applying a horizontal force to the fully opened door and forcing the door further open 10 times, Figure 3 (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006). IKEA uses a force of 60 N for this test (IKEA of Sweden, 2006).
To perform the slam shut test the door is slammed shut using a string and weight, Figure 4, (the International Organization for Standardization, 2006).

The durability test is performed by attaching two loads of 1kg each to the door and opening and closing the door during a number of cycles. In the ISO standard the highest suggested amount of cycles is 80,000 but IKEA use as many as 200,000 cycles, (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).

Which of the tests that is included in the different test standards and protocols can be seen in Table 2, for further details on the test methods and comparisons see Appendix B.
Table 2. Mechanical test of kitchen doors included in the ISO standard, EN standard and conducted by IKEA

<table>
<thead>
<tr>
<th></th>
<th>ISO *</th>
<th>EN **</th>
<th>IKEA ***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vertical load</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Horizontal load</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slam shut</td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>Durability</td>
<td></td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

X=included

* (the International Organization for Standardization, 2006)
** (European Committee for Standardization, 2005)
*** (IKEA of Sweden, 2006)

Tests conducted on drawers

For drawers and other extension elements the standards and IKEA describe six possible test methods, vertical load, durability, slam open, slam shut, stopping mechanism and displacement of bottom. The vertical load test is conducted by fully opening the empty drawer and applying a vertical force 10 times to one of the top corners of the drawer front, Figure 5 (European Committee for Standardization, 2005) (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006). The force used by IKEA is 250N (IKEA of Sweden, 2006).

![Figure 5. In the vertical load test a load is applied to one of the top corners of an open drawer.](image)

In the durability test the loaded drawer is opened and closed (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006). The load is either based on volume or a set load for the drawer type. In the ISO standard the highest suggested amount of opening and closing cycles is 80000 but IKEA use 200000 cycles, (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).
For the slam open test the drawer is loaded and slammed open 10 times. The load is set by calculating the free volume of the drawer and multiplying it with a predefined load per volume unit. The slam shut test is conducted in the same manner as the slam open test except that the drawer is shut 10 times instead of being opened. In the stopping mechanism test all the loaded drawers are opened fully and a horizontal pulling force of 200N is applied to the handle of the drawer, (European Committee for Standardization, 2005), (IKEA of Sweden, 2006).

In the displacement of drawer bottom test, weights are placed on the bottom of the drawer, and a force is applied 10 times at the middle of front and back of the drawer a, Figure 6, (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).

![Figure 6. In the displacement of bottom test two forces are simultaneously applied to the back and front of the drawer.](image)

Which of the test methods that are conducted according to the ISO standard, the EN standard and by IKEA is showed in Table 3, for further details on the test methods and comparisons see Appendix B.

Table 3. Mechanical tests for kitchen drawers conducted in the ISO standard, EN standard and by IKEA.

<table>
<thead>
<tr>
<th>Test Method</th>
<th>ISO *</th>
<th>EN **</th>
<th>IKEA ***</th>
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</thead>
<tbody>
<tr>
<td>Slam open</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Slam shut</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Stopping mechanism</td>
<td></td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>Vertical load</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Displacement of drawer bottom</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
<tr>
<td>Durability</td>
<td>X</td>
<td></td>
<td>X</td>
</tr>
</tbody>
</table>

X= included

* (The International Organization for Standardization, 2006)
** (European Committee for Standardization, 2005)
*** (IKEA of Sweden, 2006)
Test conditions

When the tests are set up the worst case configuration of the furniture is assembled according to its instructions. Both the ISO and EN standard use the same sample for all tests of one component (European Committee for Standardization, 2005), (the International Organization for Standardization, 2006). IKEA not only use the same sample for all tests of one component but also conducts all tests associated with the unit the component is attached to on the same sample unit (IKEA of Sweden, 2006).

The sequence in which the test methods are performed differs from the three different test protocols. In the ISO and EN standards it is recommended that the tests are conducted in the order they are presented in the standard documents (European Committee for Standardization, 2005), (the International Organization for Standardization, 2006). Whereas IKEA conduct what they consider safety tests first and then quality tests, (IKEA Employee 1, 2013). The sequences for the tests according to the different test instructions can be seen in Table 4.
Table 4. The sequence of the test methods stated in the ISO standard, the EN standard and by IKEA.

<table>
<thead>
<tr>
<th>Test sequence</th>
<th>ISO *</th>
<th>EN **</th>
<th>IKEA ***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pivoting doors</td>
<td>Vertical load</td>
<td>Pivoting doors</td>
<td>Vertical load</td>
</tr>
<tr>
<td></td>
<td>Horizontal load</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Slam shut</td>
<td></td>
<td>Slam open</td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Drawers</td>
<td>Vertical load</td>
<td>Stopping mechanism</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Durability</td>
<td>Slam open</td>
<td></td>
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<tr>
<td></td>
<td>Slam shut</td>
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</tr>
<tr>
<td></td>
<td>Slam open</td>
<td></td>
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<tr>
<td></td>
<td>Displacement of drawer bottom</td>
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</table>

* (the International Organization for Standardization, 2006)
** (European Committee for Standardization, 2005)
*** (IKEA of Sweden, 2006)

What have to be monitored during the tests also differ between the three test protocols. The EN standard has the easiest criteria to fulfill where the only condition for an approved test is that the tested part is still attached to the unit after the test (European Committee for Standardization, 2005). The ISO standard has more thorough demands for what have to be monitored than the EN standard and has amongst other the criteria that deformation of the unit that will lead to impairment of its function is have to be noted in the protocols (the International Organization for Standardization, 2006). IKEA have even more criteria to look for than the ISO standard and takes it so far as to monitor negative effect of the appearance on the unit and noise induced (IKEA of Sweden, 2006). More details on criteria and the conditions prior to testing can be seen in Appendix B.
4. User and range

This chapter describes how a selection within the wide range is made possible through creating risk factors based on usage frequency and applying mechanical calculations to the possible combinations. An analysis of the test methods based on the usage frequency and a user behavior study is also presented.

In the large range of IKEA’s kitchen the question is: “What should be tested?” Since the amount of combinations is vast it is not feasible to test every possible combination of kitchen articles. Instead a focus should be on the worst case scenarios and the weakest links. With the aim to make it possible to prioritize in the huge system of kitchen combinations, the usage frequency for doors and drawers, mechanical calculations on the worst load cases and observations on user behavior in the kitchen was made. Other goals were to see if the user behavior was tested and to identify a critical situation that later was studied in detail.

4.1 Risk factor based on usage frequency

One way to differentiate the kitchen range and to prioritize what to test is to look into what frequency cabinets with different content are used in a kitchen. The aim was to create a set of risk factors for kitchen doors and drawers based on frequency of use. To accomplish this, information from a study on usage frequency from a manufacturer of hinges and drawer runners was used and an additional study was conducted to verify the prior. Finally the test methods by IKEA were analyzed in regard of usage frequency and risk factor.

Frequency studies

Blum, a manufacturer of hinges and drawer runners, has made a study where they have monitored the opening and closing cycles of kitchen doors and drawers during 20 years, (Blum, 2011). In the study the frequency of use is sorted around the content of cabinets with either doors or drawers and the mean amount of opening cycles is presented. The average data for drawer cycles during 20 years show that drawers containing garbage are opened 210 000 cycles, drawers containing flatware 90 000 cycles and utensils 30 000 cycles. As seen in Table 5, drawers containing pots, food ware and plates are opened a similar amount of cycles as
drawers with utensils in them and the rest of the categories even less used (Blum, 2011).

Table 5. Approximations of frequency of use for drawers.

<table>
<thead>
<tr>
<th>Item</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garbage</td>
<td>210 000</td>
</tr>
<tr>
<td>Flatware</td>
<td>90 000</td>
</tr>
<tr>
<td>Utensil</td>
<td>30 000</td>
</tr>
<tr>
<td>Pots</td>
<td>29 000</td>
</tr>
<tr>
<td>Food ware</td>
<td>28 000</td>
</tr>
<tr>
<td>Plates</td>
<td>26 000</td>
</tr>
<tr>
<td>Electro equipment</td>
<td>19 000</td>
</tr>
<tr>
<td>Crockery</td>
<td>15 000</td>
</tr>
<tr>
<td>Textiles</td>
<td>5 000</td>
</tr>
</tbody>
</table>

(Blum, 2011)

Average data for door cycles during 20 years show that doors of cabinets containing garbage are opened 205 000 cycles, drawers containing food ware 49 000 cycles and utensils 31 000 cycles. As seen in Table 6 doors of cabinets containing other categories vary from 29 000 to 10 000 cycles, (Blum, 2011).

Table 6. Approximations of frequency of use for doors.

<table>
<thead>
<tr>
<th>Item</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garbage</td>
<td>205 000</td>
</tr>
<tr>
<td>Food ware</td>
<td>49 000</td>
</tr>
<tr>
<td>Utensil</td>
<td>31 000</td>
</tr>
<tr>
<td>Electro equipment</td>
<td>29 000</td>
</tr>
<tr>
<td>Crockery</td>
<td>21 000</td>
</tr>
<tr>
<td>Glasses</td>
<td>21 000</td>
</tr>
<tr>
<td>Textiles</td>
<td>15 000</td>
</tr>
<tr>
<td>Cleaning supplies</td>
<td>10 000</td>
</tr>
</tbody>
</table>

(Blum, 2011)

A small study was made to validate the frequency analysis by Blum where two participants monitored how often they opened and closed doors and drawers during one week, Appendix C. In the study drawers containing flatware was most frequently opened followed by drawers containing utensils. Since the observed kitchens did not have their garbage disposal in drawers the study confirmed the Blum study. Regarding doors the study confirmed that cabinets containing garbage was the most commonly opened, but the study contradicted that the cabinets containing food ware was the second most commonly opened in favor of cabinets containing china and glasses.
Risk factor

Based on the usage frequency risk factors were created for drawers and doors depending on their intended use. The risk factor ranges from 1 to 3, where 3 represents the most frequently used and 1 the least frequently used. Drawers intended to contain garbage received the risk factor 3, drawers with flatware got the risk factor 2 and drawers with other content was assigned the risk factor 1. Table 7.

<table>
<thead>
<tr>
<th>Drawer content</th>
<th>Risk factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garbage</td>
<td>3</td>
</tr>
<tr>
<td>Flatware</td>
<td>2</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
</tbody>
</table>

The first two categories with the highest risk factors were chosen because these were the most commonly used and it is possible to predict which drawers in the kitchen range that will be used for garbage and flatware. On the other hand it is harder to predict if a drawer will be used for utensils, pots or any of the other categories presented in Table 5, which is the reason why drawers not containing garbage or flatware are combined into one category.

Drawers with a depth of 45cm are considered intended to for the position under the sink, where the garbage disposal often is situated, and were appointed the risk factor 3. All drawers of low height are considered intended for flatware with a risk factor of 2 and the rest of the drawers get the risk factor 1.

Doors of cabinets intended to contain garbage was assigned a risk factor of 3, whereas doors intended for other categories were assigned the risk factor 1, Table 8. The step from 3 directly to 1 for cabinets not containing garbage was based on the wide gap between the user frequencies as seen in Table 6.

<table>
<thead>
<tr>
<th>Cabinet content</th>
<th>Risk factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Garbage</td>
<td>3</td>
</tr>
<tr>
<td>Other</td>
<td>1</td>
</tr>
</tbody>
</table>

Cabinet doors with a width of 40cm and a height of 60 or 80cm and doors with a width of 60cm and a height of either 60 or 80cm are considered intended for cabinets containing garbage and are assigned with the risk factor 3. The doors with the risk factor 3 are all possible and likely to be put under the sink where the garbage disposal is commonly placed. All other sizes of doors are considered for cabinets with other content than garbage and were thus given the risk factor 1.
Analysis of usage frequency and test methods

Approximations from the user study by Blum are the basis for the durability tests of kitchen furniture by IKEA. To ensure a 25 year warranty the amount of cycles performed by IKEA was increased from the 80 000 suggested in the ISO 7170 standard to 200 000, (IKEA Employee 2, 2013). A closer look at the study can lead to revised cycles for the durability tests on kitchen solutions based on their assumed use. When considering cabinets containing garbage disposal only, more cycles than 200 000 would be needed to cover 25 years since the frequency of use is higher than 200 000 for 20 years according to (Blum, 2011). On the other hand an average of the frequency for all doors or drawers is far below 200 000, which means that 200 000 cycles is a good compromise if all sizes are tested with the same amount of cycles. In other words drawers and doors of cabinets containing garbage are not fully fulfilled by the durability test with 200 000 cycles but the rest of the doors and drawers are excessively tested.

The use over 20 years leads to the drawers containing garbage being opened 10 500 cycles/year, flatware 4 500 cycles/year and utensils 1 500 cycles/year if the frequency of use from the Blum study is divided over 20 years, (Blum, 2011). This gives an estimation of cycles opened during 25 years to 262 500 for garbage, 112 500 for flatware and 37 500 for utensils. If the durability tests conducted on drawers were to be based on the content, all the drawers intended for garbage could be tested with 262 500 cycles instead of 200 000. With the same rezoning this leads to all drawers with the risk factor 2 being tested with 112 500 cycles and the ones with factor 1 being tested 37 500 cycles. For the cabinet doors the average cycles is 10 250 cycles/year for garbage and 2 450 cycles/year for food ware. This gives an estimation of cycles opened during 25 years to 256 250 for garbage and 61 250 for food ware. This means that all doors with the risk factor 3 could be tested 256 250 cycles and all doors with the risk factor 1, 61 250 cycles instead of 200 000.

4.2 Identification of critical combinations

Looking at the vast range of IKEA’s kitchen combinations it is crucial to pinpoint those which are more exposed to frequent usage and heavier loads to be able to identify the weakest link in the kitchen system. By quality proofing these specific combinations and by focusing on the tests for these, the overall quality of the kitchen system as a whole can be considered improved.
In order to make a selection of the worst combinations within the kitchen range simplified mechanical models of the load cases for doors and drawers were made, Appendix D. The mechanical calculations from the models were applied to the range and put into a table in Microsoft Excel, (Microsoft Office 2010). That way the least critical combinations could easily be filtered out. As stated earlier, the combinations in focus in this project are limited to drawers and doors, but the same methodology could easily be applied to other parts of the kitchen range as well.

From the mechanical calculations, Appendix D, an overall assessment value could be created by combining the risk factor drawn from usage frequency and load cases on doors and drawers in IKEA’s range. The risk factor was multiplied with different load cases and the products were added up into the overall assessment. This led to that the combinations with lowest assessment values could be filtered out, leaving the range to prioritize. For the drawers both the load used in the durability test and a load purely based on the volume of a drawer were used. The volume calculated of the drawers was the worst case volume, which is if the drawer was placed at the bottom of a cabinet without drawers or shelves above it. In case of the doors both the situations with a vertical and a horizontal load were used. An example of what the tables looks like can be seen in Table 9 and Table 10.
Table 9. The selection of critical drawer combinations were made in Excel with mechanics applied to drawers from IKEA. Observe that the list is filtered on overall assessment values 3 and above and the ones scoring 9 and 10 are only possible combinations and not actually combinations that are sold.

* The assessment value is calculated as \((\text{rebased durability torque}) \times \text{risk} + (\text{rebased 0.35-test torque}) \times \text{risk}\), where the rebased values are transformed values on a scale 0-10.

<table>
<thead>
<tr>
<th>Drawer general dimensions (WxD)</th>
<th>Front width</th>
<th>Front height</th>
<th>Front weight ((\rho=700\text{kg/m}^3))</th>
<th>Durability test load [kg]</th>
<th>Drawer volume [dm³]</th>
<th>Test-load (0.35kg/dm³) [kg]</th>
<th>Resulting torque (Durability test load) [Nm]</th>
<th>Resulting torque (test-load 0.35kg/dm³) [Nm]</th>
<th>Risk factor based on Blum studies</th>
<th>Rebased overall assessment value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>60x60</td>
<td>60</td>
<td>40</td>
<td>3.0</td>
<td>41</td>
<td>117</td>
<td>117</td>
<td>135</td>
<td>135</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>80x60</td>
<td>80</td>
<td>40</td>
<td>4.0</td>
<td>56</td>
<td>159</td>
<td>159</td>
<td>181</td>
<td>181</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>40x60</td>
<td>40</td>
<td>10</td>
<td>0.5</td>
<td>25.0</td>
<td>20</td>
<td>20</td>
<td>83</td>
<td>35</td>
<td>2</td>
<td>3</td>
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<tr>
<td>60x60</td>
<td>60</td>
<td>10</td>
<td>0.8</td>
<td>25.0</td>
<td>31</td>
<td>31</td>
<td>88</td>
<td>50</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>80x60</td>
<td>80</td>
<td>10</td>
<td>1.0</td>
<td>25.0</td>
<td>41</td>
<td>41</td>
<td>93</td>
<td>65</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>80x60</td>
<td>80</td>
<td>40</td>
<td>4.0</td>
<td>35.0</td>
<td>166</td>
<td>166</td>
<td>138</td>
<td>199</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>60x60</td>
<td>60</td>
<td>40</td>
<td>3.0</td>
<td>35.0</td>
<td>102</td>
<td>102</td>
<td>107</td>
<td>108</td>
<td>3</td>
<td>6</td>
</tr>
<tr>
<td>60x45</td>
<td>60</td>
<td>60</td>
<td>4.5</td>
<td>35.0</td>
<td>152</td>
<td>152</td>
<td>113</td>
<td>154</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>60x45</td>
<td>60</td>
<td>80</td>
<td>6.0</td>
<td>35.0</td>
<td>203</td>
<td>203</td>
<td>120</td>
<td>200</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td>60x60</td>
<td>60</td>
<td>60</td>
<td>4.5</td>
<td>25.0</td>
<td>183</td>
<td>183</td>
<td>110</td>
<td>214</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>60x60</td>
<td>60</td>
<td>80</td>
<td>6.0</td>
<td>25.0</td>
<td>245</td>
<td>245</td>
<td>118</td>
<td>279</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>80x45</td>
<td>80</td>
<td>40</td>
<td>4.0</td>
<td>35.0</td>
<td>138</td>
<td>138</td>
<td>114</td>
<td>143</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>80x45</td>
<td>80</td>
<td>60</td>
<td>6.0</td>
<td>35.0</td>
<td>206</td>
<td>206</td>
<td>123</td>
<td>205</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>80x45</td>
<td>80</td>
<td>80</td>
<td>8.1</td>
<td>35.0</td>
<td>275</td>
<td>275</td>
<td>132</td>
<td>267</td>
<td>3</td>
<td>10</td>
</tr>
<tr>
<td>80x60</td>
<td>80</td>
<td>40</td>
<td>4.0</td>
<td>35.0</td>
<td>166</td>
<td>166</td>
<td>139</td>
<td>200</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>80x60</td>
<td>80</td>
<td>60</td>
<td>6.0</td>
<td>35.0</td>
<td>248</td>
<td>248</td>
<td>150</td>
<td>288</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>80x60</td>
<td>80</td>
<td>80</td>
<td>8.1</td>
<td>35.0</td>
<td>331</td>
<td>331</td>
<td>161</td>
<td>376</td>
<td>1</td>
<td>4</td>
</tr>
</tbody>
</table>
Table 10. The selection of critical door combinations were made in Excel with mechanics applied to doors from IKEA.

* The assessment value is calculated as (rebased vertical load)*risk+(rebased horizontal load)*risk+(rebased screw withd.)*risk, where the rebased values are transformed values on a scale 0-10.

<table>
<thead>
<tr>
<th>Door width</th>
<th>Door height</th>
<th>Door weight</th>
<th>Number of hinges</th>
<th>Vertical load at hinge without ext. load [N]</th>
<th>Horizontal load without ext. load [N]</th>
<th>Vertical load with ext. load [N]</th>
<th>Horizontal load with ext. load [N]</th>
<th>Screw withdrawal load per inner screw (METOD) [N]</th>
<th>Risk factor based on Blum studies</th>
<th>Assessment value*</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>80</td>
<td>2.5</td>
<td>2</td>
<td>12</td>
<td>5</td>
<td>159</td>
<td>63</td>
<td>74</td>
<td>1</td>
<td>12</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
<td>2.6</td>
<td>2</td>
<td>13</td>
<td>20</td>
<td>160</td>
<td>352</td>
<td>201</td>
<td>1</td>
<td>21</td>
</tr>
<tr>
<td>40</td>
<td>60</td>
<td>3.9</td>
<td>2</td>
<td>19</td>
<td>18</td>
<td>166</td>
<td>217</td>
<td>201</td>
<td>3</td>
<td>55</td>
</tr>
<tr>
<td>40</td>
<td>80</td>
<td>5.2</td>
<td>2</td>
<td>26</td>
<td>17</td>
<td>173</td>
<td>159</td>
<td>201</td>
<td>3</td>
<td>53</td>
</tr>
<tr>
<td>40</td>
<td>100</td>
<td>6.5</td>
<td>2</td>
<td>32</td>
<td>17</td>
<td>179</td>
<td>127</td>
<td>201</td>
<td>1</td>
<td>18</td>
</tr>
<tr>
<td>60</td>
<td>40</td>
<td>3.9</td>
<td>2</td>
<td>19</td>
<td>43</td>
<td>166</td>
<td>571</td>
<td>328</td>
<td>1</td>
<td>29</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
<td>5.8</td>
<td>2</td>
<td>28</td>
<td>38</td>
<td>176</td>
<td>355</td>
<td>328</td>
<td>3</td>
<td>76</td>
</tr>
<tr>
<td>60</td>
<td>80</td>
<td>7.8</td>
<td>2</td>
<td>38</td>
<td>37</td>
<td>185</td>
<td>263</td>
<td>328</td>
<td>3</td>
<td>72</td>
</tr>
<tr>
<td>60</td>
<td>100</td>
<td>9.7</td>
<td>2</td>
<td>48</td>
<td>36</td>
<td>195</td>
<td>212</td>
<td>328</td>
<td>1</td>
<td>24</td>
</tr>
</tbody>
</table>
Based on these calculations the range could be narrowed down to those combinations exposed to most frequent use and heaviest loads. Both from a testing- and a consumer perspective, through looking at both test loads based on the durability tests and also at the worst case volume which leads to a quite dramatic load at the bottom drawer.

The fact that the kitchen system allows the user to configure it freely is a good reason to look into the specifics of the user behavior in a kitchen environment.

4.3 User behavior

Kitchen units are used daily by a large number of people, all of them using different types of doors, drawers etc. and in different ways. What is done to the kitchen units affect them mechanically by strain and wear and should thus be covered by the mechanical tests conducted by the manufacturer. To be able to investigate if the domestic use of kitchen units is in fact covered by the test methods used the user behavior was studied in contextual interviews. The aim of the study was to find out how customers handle their kitchen units at home, with a focus on the mechanical use of doors, drawers, handles and knobs and to analyze if the behavior is tested by IKEA. The activities from the observations are compared to the tests conducted by IKEA to see if all activities and different strategies are fulfilled by the test methods.

Method for investigating user behavior

To find out about the user behavior in domestic kitchens, user observations were conducted in the form of contextual interviews. According to the inventor of contextual design a contextual interview is a field interview conducted in the user’s workplace. The user is observed and asked about their actions while they perform their work. This leads to information on the actual actions of the user and not information on what the user think they do, (Holtzblatt, et al., 2005), which was the reason for using this method in the study. Using the information by Holtzblatt, et al., 2005 users were observed in their domestic kitchen while doing tasks such as preparing food, washing up, emptying the dishwasher and cleaning. During the observations the participants were told to go about their chores as usual and the observer did not participate or affect the actions by the users. The participants were filmed part of the time, some inquiries were made and notes were taken by the observer on the user’s actions. All actions resulting in forces applied to the drawers, doors, handles and knobs and all motions affecting them were documented. The main focus was to observe how drawers and doors were being used, mainly how they were opened and closed.
Five sessions of observations were held, which should be sufficient since Holtzblatt, et al., 2005 state that four to twelve contextual interviews are needed to gather enough information on a population. Observed actions called activities can be seen as a collection of steps taken to complete a piece of work. Different users can use different sets of steps to achieve an activity. These sets of steps represent strategies to finish a task, (Holtzblatt, et al., 2005). To make the analysis possible the activities from the observations are grouped around the intent for the activities and sorted into different strategies. All activities and strategies are compared to the test methods conducted by IKEA to analyze if the behavior is tested. The resulting activities and strategies of the contextual interviews can be seen in Appendix E.

**Analysis of activities affecting drawers**

All the activities that affect drawers except from one have corresponding test methods conducted by IKEA, Table 11.

Table 11. The activities affecting drawers with different strategies and their corresponding test conducted by IKEA.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Strategy</th>
<th>Corresponding test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open drawer</td>
<td>Open smoothly</td>
<td>Durability</td>
</tr>
<tr>
<td></td>
<td>Slam open</td>
<td>Slam open</td>
</tr>
<tr>
<td></td>
<td>Open while pulling down</td>
<td>Durability and vertical load</td>
</tr>
<tr>
<td>Close drawer</td>
<td>Close smoothly</td>
<td>Durability</td>
</tr>
<tr>
<td></td>
<td>Slam shut</td>
<td>Slam shut</td>
</tr>
<tr>
<td></td>
<td>Close while pulling down</td>
<td>Durability and vertical load</td>
</tr>
<tr>
<td></td>
<td>Close interior drawer with exterior drawer front</td>
<td>Not tested</td>
</tr>
<tr>
<td>Support</td>
<td>Support oneself on drawer front</td>
<td>Vertical load</td>
</tr>
<tr>
<td></td>
<td>Pull oneself up using drawer front</td>
<td>Vertical load</td>
</tr>
<tr>
<td>Play</td>
<td>Child sitting down in drawer</td>
<td>Vertical load</td>
</tr>
</tbody>
</table>

The smooth opening and closing of drawers is tested by IKEA in the durability test of drawers although the velocities may differ some. It is unclear how frequently drawers are slammed shut and open. One of the test persons slammed the drawer open half of the times during the observation and always slammed them shut. Many of the other test persons also slammed their drawers shut. This suggests that this might occur more often in one kitchen unit than the 10 times it is tested by IKEA, (IKEA of Sweden, 2006). Furthermore it is probably as likely that the situation occurs after 20 years of use as in the first year which indicates that it preferably should be tested after the durability test. The combination of a vertical load and the opening or closing motion of a drawer is not covered by the tests, but by testing the two steps separately the activity is tested. This situation will probably only occur if
the user tries to open a drawer positioned higher than their shoulders, e.g. small children opening the top drawer.

Closing an interior drawer by pushing it close with an exterior drawer front is not covered by the official tests conducted by IKEA. This strategy for closing a drawer was observed for all the test persons with a kitchen containing interior drawers behind exterior drawer fronts. If the interior drawer was opened it was later closed by pushing it close with the exterior drawer front causing the drawers to slam into each other, Figure 7.

![Figure 7. The interior drawer is closed by colliding with the exterior drawer front.](image)

Both strategies for supporting oneself on a drawer front is covered by the vertical load test since none of the forces applied seemed to be anywhere near the 250N used in the tests conducted by IKEA, (IKEA of Sweden, 2006). In the first strategy the test person supported themselves with a hand on the drawer front as seen in Figure 8.
Figure 8. A force was applied to the top of a drawer front when the user supported himself on it.

The second strategy where a child access equipment in a high drawer by pulling herself up with a hand resting on the top of a drawer will probably only occur with small children. The situation where one of the children played with a drawer by sitting down in it is covered by the vertical load test on extension elements performed by IKEA, since the weight of the child was assessed to 24kg.

Activities affecting doors

All activities affecting cabinet doors are tested by IKEA with the exception of slamming the door shut, Table 12.

Table 12. The activities affecting doors with different strategies and their corresponding test conducted by IKEA.

<table>
<thead>
<tr>
<th>Activity</th>
<th>Strategy</th>
<th>Corresponding test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open door</td>
<td>Open smoothly</td>
<td>Durability</td>
</tr>
<tr>
<td></td>
<td>Open while pulling down</td>
<td>Durability and vertical load</td>
</tr>
<tr>
<td></td>
<td>Open further than intended</td>
<td>Horizontal load</td>
</tr>
<tr>
<td>Close door</td>
<td>Close smoothly</td>
<td>Durability</td>
</tr>
<tr>
<td></td>
<td>Close while pulling down</td>
<td>Durability and Vertical load</td>
</tr>
<tr>
<td></td>
<td>Slam shut</td>
<td>Not tested</td>
</tr>
<tr>
<td>Support</td>
<td>Support oneself on knob, handle or edge of base cabinet door</td>
<td>Vertical load</td>
</tr>
<tr>
<td></td>
<td>Hanging on to handle or knob on wall cabinet door</td>
<td>Vertical load</td>
</tr>
<tr>
<td>Play</td>
<td>Hanging from door and swing back and forth</td>
<td>Vertical load</td>
</tr>
</tbody>
</table>

Opening and closing a cabinet door while pulling it down by the handle or knob is occurred frequently in the user study, Figure 9.
Figure 9. Some of the test persons pulled the handle down while opening and closing wall cabinet doors.

Nothing during the observations suggests that the vertical force was greater than 30kg used in the vertical load test, and since the forces seemed less than the 2kg used in the durability test it is possible that the situations are covered by the durability test in itself. The strategy seen in Figure 10 where the door of a cabinet was forced open further than the intended 125° is covered by the horizontal load test since the force seemed smaller than 60N used by IKEA.

Figure 10. The door of a cabinet is forced open further than intended when a child leans on the open door.

Slamming a cabinet door shut does not correspond to any of the tests conducted by IKEA. All the strategies for supporting oneself on a door are on the other hand covered by the vertical load test by IKEA. The forces applied in the observations
were not near 30kg and it is highly unlikely that the force would be greater than 30kg under any circumstances. If the force is applied by a load hung from the door or applied to the top edge of the door should have no consequence since the doors are fitted with at least two hinges. Two different strategies were observed of the intent to support oneself on a cabinet door. The first strategy occurred when the test persons supported themselves on base cabinet doors. They rested their hands on the top of the door or held onto the handle or knob while reaching either up or down. In some cases the test persons were reaching for something on a shelf above. In other cases they bent down reaching for something on the floor or for the garbage disposal and used the door for support when straitening up, Figure 11. These situations mostly occurred for the cabinet containing the garbage disposal.

![Figure 11. The user supports oneself on the knob of the door while bending down.](image)

The other strategy was used on wall cabinet doors while reaching for a high shelf. The test persons usually held on to the handle or knob for support when they reached into a cabinet, which resulted in pulling the handle or knob down, Figure 12.
Figure 12. The handle or knob of the door is used for support while reaching for a high shelf.

Since the weight of the child was assessed to less than 30kg the situation where one of the children played with a door by swinging from it is covered by the vertical load test performed by IKEA.

**Activities affecting knobs or handles**

None of the activities affecting knobs or handles mechanically have corresponding IKEA tests, Table 13.

Table 13. The activities affecting knobs or handles with different strategies and their corresponding test conducted by IKEA

<table>
<thead>
<tr>
<th>Activity</th>
<th>Strategy</th>
<th>Corresponding test</th>
</tr>
</thead>
<tbody>
<tr>
<td>Open drawer</td>
<td>Open while pulling down</td>
<td>Not tested</td>
</tr>
<tr>
<td>Close drawer</td>
<td>Close while pulling down</td>
<td>Not tested</td>
</tr>
<tr>
<td>Open door</td>
<td>Open while pulling down</td>
<td>Not tested</td>
</tr>
<tr>
<td>Close door</td>
<td>Close while pulling down</td>
<td>Not tested</td>
</tr>
<tr>
<td>Support</td>
<td>Support oneself on knob, handle or edge of base cabinet door</td>
<td>Not tested</td>
</tr>
<tr>
<td></td>
<td>Hanging on to handle or knob on wall cabinet door</td>
<td>Not tested</td>
</tr>
<tr>
<td>Play</td>
<td>Pull oneself up using handle on drawer</td>
<td>Not tested</td>
</tr>
<tr>
<td>Access towel</td>
<td>Using handles or knobs as foothold</td>
<td>Not tested</td>
</tr>
<tr>
<td></td>
<td>Pulling handle or knob when using attached towel</td>
<td>Not tested</td>
</tr>
</tbody>
</table>

The activities where the doors and drawers are opened and closed while pulling the handle down are tested in regard of the doors and drawers themselves. On the
other hand the activities are not tested if you consider the knobs or handles. No tests corresponding to the situations where the users supported themselves on handles or knobs of doors or drawers exists either.

The situation where a child climbed to the counter top by using the drawer handles as a ladder does not affect the drawer except from the attachment of the handles or knobs to the drawer front, Figure 13. She was around four years old and her weight was approximated to 24kg by the mother. The strain on the drawer is probably small, but the strain on the handles or knobs and their attachment to the drawer front is of more importance.

![Figure 13. A child uses the handles of the drawers as a ladder when climbing to the counter top.](image)

The activity where the knob or handle of a door or drawer was affected by a force from pulling a towel on it is only partially tested. When tests are conducted on drawers and doors the equipment is often attached to the handle or knob resulting in a test of the horizontal force on the knob or handle. But these tests are specified for the drawers and doors themselves without specifications on what handles or knobs to use. This leads to that the horizontal force is only tested on a few random handles and knobs. The pulling force most likely consists of a vertical force as well which is not covered in any tests.

**Critical situations**

The aim for looking into critical situations was to decide on one situation to study in detail. In most of the user behavior the frame of the cabinets and the particle board it was made of was considered to be the weakest link. Out of the behavior
observed during the contextual interviews three were considered particularly critical in regard of the cabinet frame and its fasteners.

- Over-opening a cabinet door by applying a horizontal force.
- Applying a vertical force to a door by supporting oneself on it.
- Applying a vertical force to a door a drawer front by supporting oneself on it.

The over-opening of a cabinet door by applying a horizontal force was chosen as the critical situation to study in detail. The particle board areas where the hinges are attached were considered the weakest link that was investigated further.
5. Experiment 1: Technical properties

This chapter presents a comparing study of the technical properties of the particle boards and test results from development over-opening tests made at IKEA. The experiment was conducted in collaboration with the particle board manufacturer Swedspan.

5.1 Introduction

Previously made development tests on different cabinet frames, Table 14, show that there are differences in the test results between the samples, even though the specifications of the particle boards are the same, i.e. the P2 requirement which states requirements for bending strength, modulus of elasticity, internal bond and surface soundness, see Chapter 2.2. The test made at IKEA, was the horizontal force test where the over-opening of a door was tested according to Figure 14, where $F$ is the applied load and $h$ is the height of the door. The test passes if the door is still attached to the cabinet frame without damage after 10 load cycles of 60N. Two heights of doors were used in the test, a high and a low door.

<table>
<thead>
<tr>
<th>Particle Board number</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Over-opening test result</td>
<td>Fail</td>
<td>Pass</td>
<td>Fail</td>
<td>Fail</td>
<td>Pass</td>
</tr>
</tbody>
</table>

Figure 14. The over-opening test scenario, where $F$ is the load of 60N applied 10 times and $h$ is the height of the door.

It is of interest to study the technical properties in relation to these test results, to find the most significant parameter in regard of the correlation to the over-opening test results. In order to find a correlation between these test results and the
technical properties of the boards an experiment was carried out at Swedspan, a manufacturer of particleboards in Hultsfred. Another interesting factor to examine is whether the quality of the board is homogeneous and if the boards fulfill the P2 requirements.

5.2 Purpose

The purpose of this experiment was to thoroughly examine the technical properties of five different particle boards made for kitchen base cabinets. These results were then compared with the previously made over-opening test results in order see if there was a correlation between a specific technical property and the over-opening test result.

5.3 Hypothesis

To fully understand the over-opening scenario it was simplified to a basic mechanical schematic, Figure 15, where F is the applied load, N is the resulting force at the edge of the hinge plate and SWR is the force the screws will hold.

![Figure 15. The mechanical schematic of the over-opening test, where F is the applied load, N is the resulting force at the edge of the hinge plate and SWR is the force the screws will hold.](image)

The hinge is attached to the frame by two screws and plastic sockets on the hinge plate of the hinge shown in Figure 16.
Based on the theory about particle boards, Chapter 2.2, Appendix A, and discussions at Swedspan (Swedspan, 2013), the technical properties that could have influence on the over-opening test results were narrowed down.

An interesting point made at Swedspan was that the P2 requirement might not be the best way to specify quality of particle boards since different functions require very different properties, (Swedspan, 2013). It is therefore interesting to look at properties that could influence the specific function. In this case the focus was on the over-opening test and the break-off scenario at the hinge plate in the same test. This means properties that directly or indirectly affect the capability of holding the hinge plate in place with two particle board screws were the most interesting properties. Therefore properties that are connected to the screw-holding performance are of great interest. The maximum load the screws can resist before breaking loose is defined as SWR (Screw Withdrawal Resistance) (European Committee for Standardization, 2011), which can be described by the simplified schematic in Figure 17.

From this viewpoint a hypothesis was formulated as follows: There is a correlation between SWR or other technical properties of the particle board and the over-opening test results.
5.4 Method

To examine the hypothesis a number of technical properties were measured, see Table 15.

Table 15. List of technical properties that could possibly influence the over-opening test result.

<table>
<thead>
<tr>
<th>Property</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>SWR (Screw Withdrawal Resistance)</td>
<td>N</td>
</tr>
<tr>
<td>SWR wps (Screw Withdrawal Resistance with plastic socket)</td>
<td>N</td>
</tr>
<tr>
<td>Internal Bond</td>
<td>MPa</td>
</tr>
<tr>
<td>Yield Strength</td>
<td>MPa</td>
</tr>
<tr>
<td>Young’s modulus</td>
<td>MPa</td>
</tr>
<tr>
<td>Density</td>
<td>kg/m³</td>
</tr>
<tr>
<td>Density profile (Graph of density variation over a cross section of a board sample)</td>
<td>NA</td>
</tr>
</tbody>
</table>

Test sample preparation

To minimize differences between the experiment test results and measured production data from suppliers, the melamine foil on the boards was first sanded off. The particle boards were then cut into 50x50mm test samples according to EN 326-1 (European Committee of Standardization, 1994) and labeled according to a coordinate system to keep track of the test piece location on the board. The pieces where measured, weighed and prepared for the test equipment.

Screw withdrawal resistance test

The prepared sample pieces were cut out with an existing pre-drilled hole in the center of the test piece, which was used for a 12mm deep plastic socket made for the hinge plate. The screw was drawn into the socket, leaving approximately 2mm of the head to attach it to the test equipment rig, Figure 18 and Figure 19.

Figure 18. Test piece for SWR test with plastic socket.
The samples used to measure SWR without plastic socket were prepared in a similar way with the exception of using a predrilled hole. Therefore a 5mm in diameter hole was drilled in the center of the test piece and a particle board system screw was tightened in a special test block allowing a screw depth of 12mm into the particle board, Figure 20 and Figure 21.
To perform the test the test equipment applies a pulling force by moving the upper end of the rig 12mm/min while the increasing force is plotted, and the maximum force before break-off is recorded, Figure 22.

![Figure 22. Example plot of SWR test.](image)

**Internal bond Test**

In accordance with EN 319 (European Committee of Standardization, 1993a) the test piece was glued onto two metal plates, Figure 23, which was used to attach the sample to the test equipment rig.

![Figure 23. Test piece for internal bond test.](image)

The test was performed the same way as for the SWR test logging the increasing force until breakage.

**Yield Strength and Young's Modulus Test**

To test yield strength and Young’s modulus a prepared test piece with dimensions 410x50mm was bent in the test equipment between two supports 360mm apart, as seen in Figure 24.
The test was performed by logging the force and flexure extension until breakage, Figure 25, which also gave Young’s modulus and the yield strength for the test sample.

Density Test

Density was simply given by measuring and weighing the test pieces’ with high precision, dimensions $\pm 0.05\text{mm}$ and weight $\pm 0.1\text{g}$, and calculating the density based on the volume, according to (European Committee for standardization, 1993b).
Density Profiles

The density profile was given by an x-ray of a 50x50mm test sample and plots of the density over the cross section as can be seen in Figure 26.

Figure 26. Example density profile.
## 5.5 Results

The experiment test results of the technical properties of the particle boards can be seen in Table 16.

Table 16. Experiment 1 test results, where the test status refers to the over-opening test results and whether a high or low door was tested in that test.  
\(\bar{x}\) stands for mean value, \(n\) for number of test samples and \(s\) for standard deviation.

<table>
<thead>
<tr>
<th>Property</th>
<th>Board 1</th>
<th>Board 2</th>
<th>Board 3</th>
<th>Board 4</th>
<th>Board 5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Test Status</td>
<td>Fail</td>
<td>Pass</td>
<td>Fail</td>
<td>Fail</td>
<td>Pass</td>
</tr>
<tr>
<td>Tested door type</td>
<td>Low</td>
<td>High</td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td>Density [kg/m(^3)]</td>
<td>(\bar{x})</td>
<td>652</td>
<td>n</td>
<td>25</td>
<td>s</td>
</tr>
<tr>
<td>Internal bond maximum load [N]</td>
<td>1104</td>
<td>10</td>
<td>90</td>
<td>(\bar{x})</td>
<td>775</td>
</tr>
<tr>
<td>Internal bond tensile stress (P2 req.: 0.35) [MPa]</td>
<td>0.44</td>
<td>10</td>
<td>0.04</td>
<td>(\bar{x})</td>
<td>0.31</td>
</tr>
<tr>
<td>SWR load [N]</td>
<td>764</td>
<td>10</td>
<td>58</td>
<td>(\bar{x})</td>
<td>647</td>
</tr>
<tr>
<td>SWR load with plastic socket [N]</td>
<td>564</td>
<td>6</td>
<td>40</td>
<td>(\bar{x})</td>
<td>509</td>
</tr>
<tr>
<td>Yield strength (P2 req.: 11) [MPa]</td>
<td>11.17</td>
<td>5</td>
<td>0.45</td>
<td>(\bar{x})</td>
<td>11.86</td>
</tr>
<tr>
<td>E-modulus (P2 req.: 1600) [MPa]</td>
<td>3225</td>
<td>5</td>
<td>59</td>
<td>(\bar{x})</td>
<td>3163</td>
</tr>
</tbody>
</table>
5.6 Conclusions

By taking a closer look at some of the properties, no obvious correlation with the over-opening test results could be found. For example, the test result data of the average values for internal bond tensile stress, Figure 27, shows that the board with the lowest value (even below the P2 requirement) passed the over-opening test. Thereto, the board with the highest value failed the over-opening test.

![Average internal bond tensile stress](image)

Figure 27. Board average internal bond tensile stress.

A similar situation can be seen in the density test results. The board with the highest density failed the over-opening test and the board with lowest density passed, Figure 28.

![Density](image)

Figure 28. Average density for the five different particle boards shows.
Although the density does not seem to affect the over-opening test results, it does seem to have some impact on the SWR results. Figure 29 show that if SWR is plotted against density, there is a connection.

![Figure 29. SWR load samples trend.](image)

An analysis of the differences between the averages of the internal bond maximum load and the SWR loads, Figure 30, shows two noteworthy things. Firstly, even though the internal bond values vary a lot, both SWR and SWR wps values does not, which could mean that the internal bond value doesn’t influence the screw withdrawal resistance as much. This theory is also strengthened by the fact that the board with the lowest internal bond value actually passed the over-opening test. Secondly it is worth noting that the SWR results for screws with plastic sockets for all boards are lower than those for screws without sockets, which is supported by the findings of the study by (Vassiliou & Barboutis, 2005).

![Figure 30. SWR wps, SWR and internal bond average loads for the five different boards.](image)
But even though the SWR results has proven to be consequently higher than the SWR wps results, which could mean that a better function could be obtained by using screws without the plastic sockets, one should consider the user-friendly functionality of the plastic socket before making any decisions about changing this solution.

In addition to above conclusions there are a few more details about the test result worth noting.

- Young’s modulus for all the tested boards are a lot higher than the stated P2 requirement, which means that the boards are possible over-dimensioned in that sense.
- Since the technical properties do not always meet the requirements, this could indicate that it is hard to control the supplier’s quality with the existing tests.
- Spread results, regarding all parameters indicate that the boards are inhomogeneous.
- The density profiles differ too much across the boards to give a good correlation to the over-opening results, which also indicates board inhomogeneity.
- The fact that there are no obvious correlations between the particle board technical properties and the over-opening test results could be due to the limited number of over-opening test results.
6. Experiment 2: Break-off scenario

In this experiment quantitative and qualitative data on the break-off scenario was gathered by conducting over-opening break-off tests and by studying why the hinges broke loose.

6.1 Introduction

Since no obvious correlations between the over-opening test results and the boards’ technical properties were found, another experiment was designed to get more quantitative and qualitative test data. This experiment was carried out at the Royal Institute of Technology, KTH in Stockholm on kitchen cabinet test samples bought from IKEA Barkarby.

6.2 Purpose

The purpose of this experiment was firstly to get more over-opening tests results which could show to what degree the test results vary. Secondly the break-off scenario was to be studied in more detail to better understand what might cause the particle board to break when more force is applied than in the over-opening test.

6.3 Hypothesis

To be able to obtain more test data from only a few particle board samples, the over-opening test was redesigned with the assumption that the applied horizontal load was equally divided between the two hinges of a door. Hence it ought to be logical that the force applied in an over-opening test done on a cabinet with a full size door with two hinges would be equivalent to half the force applied to a downscaled version of the test with only a section of the door and one hinge, see Figure 31.
Moreover it was assumed that differences between a pulling force instead of a pushing force, as in the standardized test, is insignificant. In this case, the reason for choosing this method was simply due to available test equipment.

By downscaling the over-opening test as stated above it was possible to get more test results from a single board and therefore be able to study whether the over-opening test results varied much. It was also possible to study how the result differs between new and re-used sockets as well as for new or re-used pre-drilled holes.

Through examining the break-off scenario in more detail a theory about how the breakage occurs could be formulated.

The hypothesis of this experiment was therefore split into four parts:

1. The applied horizontal over-opening load is divided equally between the two hinges, i.e. the over-opening break-off load for a test made with one hinge is half as big as in the test with two hinges. In other words there is a conversion factor, $c_{EN}$, of 0.5.
2. The over-opening break-off test results will vary across the board.
3. The previously used holes and sockets will generate a lower over-opening break-off value.
4. The break-off will be caused by incrementally growing deformations on the particle board.

### 6.4 Method

The standardized over-opening test was performed according to EN 14749:2005 (European Committee for Standardization, 2005) with the alterations of using a pulling dynamometer instead of a pushing version, see Figure 32. Thereto an extra load cycle was added to record the break-off load. This was made to collect data which the test with one hinge could be compared with.
The downscaled over-opening test was performed on a full width (600mm) section of the door with a handle attached in order to be able to use the dynamometer. The hinge plate was attached to the cabinet frame using plastic sockets (new and reused, respectively) and screws intended for this use, Figure 33. The pre-drilled holes in the frame, both new and previously used for wall mounting screws, were used for the attachment. The test was performed through applying an incrementally larger load with the dynamometer at the center of the door section 100mm from the edge perpendicular to the door until the hinge plate broke loose from the cabinet frame. The highest load value, i.e. the break-off load, was recorded.

To gather the qualitative data from the break-off scenario, video was recorded to get a detailed look at the sequence of events.
### 6.5 Results

The test results from Experiment 2 can be seen in Table 17.

**Table 17. Experiment 2 test results.**

<table>
<thead>
<tr>
<th>Tests with two hinges (EN-test)</th>
<th>Average break-off load, $F_{two\ hinges}$ [N]</th>
<th>Number of samples</th>
<th>Standard deviation [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>New plastic sockets, new holes</td>
<td>66.7</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>New plastic sockets, holes previously used for wall mount</td>
<td>54.4</td>
<td>2</td>
<td>3.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Tests with one hinge</th>
<th>Average break-off load, $F_{one\ hinge}$ [N]</th>
<th>Average equivalent (two hinges) break-off load (with conversion factor $c_{EN}=0.5$) [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>New plastic sockets, new holes</td>
<td>35.0</td>
<td>70.0</td>
</tr>
<tr>
<td>New plastic sockets, new holes, back side</td>
<td>34.4</td>
<td>68.9</td>
</tr>
<tr>
<td>New plastic sockets, new holes, front side</td>
<td>35.3</td>
<td>70.6</td>
</tr>
<tr>
<td>New plastic sockets, holes previously used for wall mount</td>
<td>30.7</td>
<td>61.3</td>
</tr>
<tr>
<td>Reused plastic sockets, new holes</td>
<td>31.0</td>
<td>61.9</td>
</tr>
</tbody>
</table>
6.6 Conclusions

Looking at the relation between the full size over-opening test results and the downscaled version of the test, the data shows that according to Equation 1,

\[
\frac{F_{\text{over hanger}}}{F_{\text{two hinges}}} = \frac{35}{66.7} = 0.52
\]  

(1)

This is valid for new holes and sockets, which indicates that the first hypothesis seems fairly correct considering the small amount of test samples from the full size test.

The variation of the over-opening test results was lower than expected, which can be seen in Figure 34.

![Variation of over-opening break-off test results](image)

Worth noting about the variation is that no values are under 60N which is the limit for a passed EN-test, which means that an average of 70N over 27 samples is a good starting point if looking for an ideal number of tests to secure the quality of the boards. It should be added that these boards also passed the test made with two hinges.

As the third part of the hypothesis stated, the results for used sockets and holes are lower, as suggested by (Haftkhani, et al., 2011). The averages indicate there is a small difference, Figure 35, but the number of test samples for reused sockets is too small to tell for certain.
It was also observed, that the hole size was crucial for the over-opening break-off load, since a variation of 0.5mm in hole diameter resulted in an immediate break-off during the test.

Regarding the break-off scenario in detail it could be seen that during the over-opening the hinge plate was pried loose rather than pulled loose as the hypothesis in Experiment 1 was based on. This means that the force prying off the hinge plate is not perpendicular to the cabinet frame throughout the whole deformation sequence. It can only be considered an entirely perpendicular force before any deformation occurs, since deformation starts as soon as the door reaches its fully open position. Realizing this, yet another experiment was designed.
7. Experiment 3: Pre-deformation break-off

In this chapter Experiment 3 is described where a correlation between hole deformation and over-opening break-off load was investigated.

7.1 Introduction

The first two experiments indicated that the over-opening break-off ought to be seen from a different perspective. Therefore Experiment 3 was designed with focus on the boards’ deformation directly instead of focusing on specific properties. The experiment was conducted at the Royal Institute of Technology, KTH, Stockholm on the same kitchen cabinet frame samples as in Experiment 2.

7.2 Purpose

The purpose of this experiment was to design a deformation test of the particle board that could show a correlation between the over-opening test results and a measurable deformation of the board. Hence the deformation test could indicate whether or not the particle board would pass the over-opening test without actually performing the costly and time consuming over-opening system test.

7.3 Hypothesis

Based on the observation that the hinge plate was pried rather than perpendicularly pulled loose in the over-opening break-off scenario, the deformation test was built from the hypothesis that a pre-deformed hole would generate lower over-opening test results. Thus by deforming the predrilled holes in the cabinet frame to a number of different measurable levels, prior to attaching the hinge plate and performing the over-opening test, the tests would hypothetically generate a pattern between deformation and over-opening test results. The hypothesis was therefore simply expressed as: “There is a significant correlation between hole deformation and over-opening break-off load”.
7.4 Method

To find a correlation between over-opening break-off load and deformation, the deformation had to be done in a way similar to the deformation in the break-off scenario, simulating the prying movement of the hinge plate.

Therefore the deformation of the pre-drilled holes was made with a metal rod, exactly 5mm in diameter (same as the holes) which was attached very tight in a hole to a depth of 12mm (same as the socket used). By applying a force according to the schematic shown in Figure 36, at a distance of 100mm from the particle board surface, the hole was deformed. The rod length was adapted to minimize the bending of the rod yet still create a sufficient force at the attachment.

![Figure 36. Schematic over the hole deformation process, where F is the deformation force and α is the deformation angle.](image)

The deformation was made in a horizontal plane with the deformation force pointing outwards from the cabinet. To measure the deformation, the deformation angle, $\alpha$ was recorded as well as the size of the corresponding deformation force, $F$, see Figure 37.
After deforming a pair of holes with the same deformation forces the hinge plate and the door section was attached with sockets and screws in the pre-deformed holes to then be able to perform the over-opening test. Unfortunately another version of the socket had to be used due to a limited stock of extra sockets at IKEA Kungens Kurva. The experiment was corrected for these changes through making a number of over-opening tests without hole deformations which could be compared with the results from experiment number two which was made with the correct sockets but still on the same particle boards and with the same door section. This relation gives an approximate conversion factor,

\[ c_1 = \frac{F_{\text{new socket}}}{F_{\text{correct socket}}} \]  

(2)

The different sockets are shown in Figure 38.

In this experiment the width of the door section was 298mm instead of 596mm to better be able to differentiate the test results with the test equipment available. The over-opening result could still be compared with the results from Experiment 2, with another conversion factor, based on that the torque was maintained at the attachment according to Equation 3.

\[ F_{\text{full}}L_{\text{full}} = F_{\text{half}}L_{\text{half}} \]  

(3)
Where $L_{\text{full}}$ is the lever length of the full-width door section and $L_{\text{half}}$ is the lever length of the half-sized door section. $F_{\text{full}}$ and $F_{\text{half}}$ are the corresponding over-opening break-off loads. From equation 3, the relation between the over-opening break-off loads for the different door widths gives the conversion factor $C_{2\text{analytical}}$ according to Equation 4.

$$\frac{F_{\text{half}}}{F_{\text{full}}} = C_{2\text{analytical}} = \frac{L_{\text{full}}}{L_{\text{half}}} \tag{4}$$

This factor is verified by comparing the ratio between test results with the full-width door section and those from the tests with the new half-width door section, $C_{2\text{test}}$. Both tests were made with the new socket type.
7.5 Results

The test results from the first part of the test, made in order to create relations between the socket types and the door widths can be seen in Table 18.

Table 18. Results from over-opening tests without pre-deformed holes.

<table>
<thead>
<tr>
<th>Test</th>
<th>Average load [N]</th>
<th>Number of samples</th>
<th>Standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-hinge-test (correct socket type, full width door section)</td>
<td>35.0</td>
<td>27</td>
<td>5.4</td>
</tr>
<tr>
<td>1-hinge-test (new socket type, full-width door section)</td>
<td>26.0</td>
<td>4</td>
<td>2.6</td>
</tr>
<tr>
<td>1-hinge-test (new socket type, half-width door section)</td>
<td>63.3</td>
<td>6</td>
<td>5.7</td>
</tr>
</tbody>
</table>

Hence the ratio between the two socket types, $c_1 = 0.74$. The ratio between the over-opening break-off loads for the different door widths $c_{\text{test}} = 2.43$ according to the test results and can be compared to the analytical value, $c_{\text{analytical}} = 2.51$ which makes the test results seem reliable.

These conversion factors combined with the conversion factor, $c_{\text{EN}} = 0.5$ from Experiment 2 gives an approximate equivalent over-opening break-off load, $F_{\text{EN}}$ according to the EN-test made on two hinges.

The results from the second part of the experiment with pre-deformed holes can be seen in Table 19.

Table 19. Test results from over-opening test with pre-deformation of attachment holes.

<table>
<thead>
<tr>
<th>Tested deformation loads [kg]</th>
<th>Deformation load, $F_0$ [N]</th>
<th>Deformation angle (mean over the two holes), $\alpha$ [deg]</th>
<th>Average over-opening break-off load, $F_b$ [N]</th>
<th>Number of samples</th>
<th>Standard deviation</th>
<th>Equivalent EN-load, $F_{\text{EN}} = F_b / (c_{\text{EN}} * c_1 * c_2)$ [N]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.0</td>
<td>0</td>
<td>63.3</td>
<td>6</td>
<td>5.7</td>
<td>68.0</td>
</tr>
<tr>
<td>3</td>
<td>29.4</td>
<td>3.15</td>
<td>64.9</td>
<td>5</td>
<td>6.6</td>
<td>69.8</td>
</tr>
<tr>
<td>5</td>
<td>49.1</td>
<td>10.55</td>
<td>62.1</td>
<td>5</td>
<td>5.4</td>
<td>66.7</td>
</tr>
<tr>
<td>6</td>
<td>58.9</td>
<td>21</td>
<td>59.1</td>
<td>5</td>
<td>10.6</td>
<td>63.5</td>
</tr>
<tr>
<td>7</td>
<td>68.7</td>
<td>26.3</td>
<td>52.6</td>
<td>5</td>
<td>9.1</td>
<td>56.5</td>
</tr>
<tr>
<td>8</td>
<td>78.5</td>
<td>35.7</td>
<td>47.1</td>
<td>3</td>
<td>3.5</td>
<td>50.6</td>
</tr>
</tbody>
</table>
7.6 Conclusions

Comparing the over-opening test results to the degree of pre-deformation of the holes, there is a correlation, the larger the deformation, the lower the over-opening break-off load, Figure 39.

![Over-opening break-off load](image)

Figure 39. The deformation angle plotted against the over-opening break-off load shows a correlation.

If this correlation is to be compared with an equivalent over-opening break-off load, $F_{EN}$ according to the EN-test made on two hinges, the over-opening break-off load, $F_B$ can be scaled according to Equation 5.

$$F_{EN} = F_B/(c_{EN}c_1c_2)$$  \hspace{1cm} (5)

This equivalent load can be seen in Figure 40.

![Deformation angle vs equivalent over-opening break-off load](image)

Figure 40. The deformation angle plotted against the equivalent EN over-opening break-off load.
The over-opening test results are affected by the pre-deformation of the holes and it can also be seen that the deformation load correlates to the deformation angle, Figure 41.

![Deformation load vs deformation angle](image)

Figure 41. The experiments’ pre-deformation of the holes shows a clear connection between the deformation load and the deformation angle.

Because of these correlations it is possible to approximate the over-opening quality of a particle board only by performing the deformation test. This can be described by the following methodology:

1. Looking at a zoomed in section of the correlation between over-opening break-off load and the deformation angle, Figure 42, it can be seen that 60N (the limit to pass the over-opening test) according to the trend line of the test data corresponds to approximately 24 degrees deformation angle of the hole.

2. In Figure 43 it can be seen that a deformation angle of 24 degrees corresponds to approximately 65N deformation load.

3. Hence the following can be said: If the deformation angle is smaller than 24 degrees while performing the deformation with a force of 66N, the board is likely to pass the real over-opening test.
Figure 42. Zoomed in section of trend line showing correlation between over-opening break-off load and deformation angle.

Figure 43. Zoomed in section of trend line showing correlation between deformation angle and deformation load.
8. Summary of results

In this chapter the project results are summarized.

In a comparison of the usage frequency from the Blum study and tests conducted by IKEA, chapter 3.1 Risk factor based on frequency of use, it was found that cabinets containing garbage should be tested with more cycles in the durability test, while cabinets with other content could be tested with fewer cycles than today.

As could be seen in the user behavior study, Chapter 3.3, most of the user behavior is tested by IKEA. There are a couple of exceptions though, and the following are not tested by IKEA.

- Closing an interior drawer with an exterior drawer front.
- Slamming a door shut.
- Applying forces to knobs and handles.

The first experiment, where the technical properties of the boards and the test results from the development over-opening tests made at IKEA were compared, presented no apparent correlations. Some things can however be drawn from the experiment.

- Some properties like board average density and internal bond tensile stress did even contradict the test outcome directly in some cases.
- The fact that the test results from Experiment 1 varied across the boards gave an indication of board inhomogeneity.
- Plastic sockets generally generated lower SWR values compared to screws without sockets.
- Some of the development test boards’ technical properties differed from the P2 requirements, generally in terms of way higher Young’s modulus than the requirement, but also in one case with a lower internal bond tensile stress value than required.

In order to get more test data on over-opening a series of tests were performed on a different kitchen cabinet bought from IKEA. This second experiment showed a number of interesting things.

- An over-opening test made on one hinge instead of two gives a sufficient indication on whether the board will pass the EN-test made on two hinges, since the horizontal load was split in half between the hinges.
- Observations showed that the hinge was pried rather than pulled loose from the board during a break-off over-opening.
- The pre-drilled holes’ diameter is crucial for the function.
The first two experiments indicated that in order to control the board quality another approach was needed. Therefore the third experiment was designed with the intention to investigate a combination of functionality and technical properties. Hence Experiment 3 was built on measurable pre-deformation of the hinge’s attachment holes. The experiment resulted in a couple of interesting points.

- There was a significant correlation between the hole deformation load and the measurable deformation angle.
- It showed that there is a correlation between over-opening load and the hole deformation.
9. Discussion

Different margins of error regarding the test methods and experiments are discussed in this chapter.

9.1 Test methods and user behavior

Whether the velocities used in the slam open, slam shut and the durability tests of drawers correspond to user behavior is yet unclear. Although estimations were made using videos from the contextual interviews and the visit to the IKEA Test Lab and a short study in an example kitchen the results were not reliable enough to reach any conclusions. It did seem like a lower velocity was used by the test persons for slamming open a drawer. For slamming them shut on the other hand, part of the users seemed to use a higher velocity and part a lower velocity than in the slam open test. The velocity used in the durability test seemed generally slower than the velocity the test persons used for smoothly opening and closing both drawers and doors. But as the durability test is constructed not to overheat the doors and drawers hinges and runners from an unnatural amount of opening cycles in succession the difference in velocity is not of great consequence.

9.2 Experiments

A factor that was not taken into consideration during the experiments was the moisture content and conditioning of the particle boards. The technical properties for P2 are given at certain moisture content and in the test methods and EN standards it is stated that the test pieces should be conditioned to constant mass and certain moisture content before tested. With the time given this was not possible but this could have affected the test results.

It should also be pointed out that the experiments conducted were performed on the previous kitchen system, since the new kitchen system was released during the project. This means that the over-opening test results would probably differ. The calculations and the principle chain of thoughts are though applicable to the new system as well.

The last experiment was performed with slightly different matériel than the first two experiments, e.g. different sockets had to be used due to supply limits at the warehouse and time restrictions. Thus the results had to be corrected for these changes which probably led to slightly larger margins of error, but even if the exact results may differ some, the general relations would still be relatively unchanged.
Another reason for margins of error would be the limits of the test equipment. The dynamometer used in the over-opening test and the pre-deformation test was for example quite basic, with no functionality of recording maximum values etc. Therefore the measurements could vary a little due to reading errors.

It should be emphasized that the correlations found in Experiment 3 are only a general indication built on quite few test samples which is why more tests ought to be done in order to better prove the correlations. Mainly this is an alternative way to look at the quality ensuring process from another viewpoint, without having to perform the over-opening test in full. If a test were to be designed more specifically, the limits would have to be re-evaluated and the possibility of a safety margin would need to be considered. Say for example that the limit is set at 10% over the 60N over-opening load limit, this would mean that the same correlations could be used giving a limit deformation of 12,5 degrees at a deformation load of 50N while deforming the board according to the hole deformation test designed in Experiment 3.
10. Recommendations

Future recommendations for IKEA and an alternative solution is presented in this chapter.

10.1 Test methods

The kitchen range is extensive and the usage frequency of different combinations varies a lot, therefore some combinations could be tested less than 200,000 cycles whereas other combinations should be tested a little bit more (drawers under the sink especially). Yet in order to still be able to guarantee 25 years of use, the selection of which combinations to be tested differently has to be combinations with quite specific purposes, like the 45cm deep sink drawers for example.

It would be advisable to perform the slam open and shut test on drawers after the durability test since it occurs frequently and possible after many years of use.

Although both closing an interior drawer with an exterior drawer front and slamming a door shut are not covered by the tests conducted by IKEA they are probably not straining enough behavior to need a specific test method. Even though it creates a collision, closing an interior drawer with an exterior drawer front probably only affect the drawer front itself. This could lead to wear on the interior of the drawer front but except from this the activity is covered by the current drawer tests. There is a test method for slamming a door shut in the ISO 7170:2006 standard but the situation is probably not straining enough to demand this test method, (the International Organization for Standardization, 2006).

Knobs and handles should have their own test methods for mechanical loads since a lot of the behavior during the contextual interviews includes knobs and handles. Activities from the observations suggest that both a horizontal and a vertical load are applied to the knobs or handles in different situations. Of the observed activities the most stressing were when a child used the handles of drawers as foothold when climbing and when the adult test persons used handles or knobs as support when leaning on doors. It is not possible to estimate all the forces applied during the observations but the child climbing the handles had an estimated weight of 24kg which would lead to a load of approximately 240N. Although current IKEA protocols does not demand mechanical tests on knobs and handles they sometimes use an American standard called ANSI-BHMA A156 9-2003 that is sometimes used and could be included in future testing. The American standard covers the activities from the observations, especially since it states that handles should support a load
of 333N which is larger than the load from the climbing child (American National Standards Institute, 2003).

10.2 Experiments

Since the first experiment did not show a clear correlation between the over-opening test results and the technical properties of the boards the other experiments were designed from a slightly different approach, namely more from a deformation approach. Experiment 2 and 3 therefore gave more qualitative results. Experiment 1 showed though that the technical properties do not always meet the requirements which could mean that it is hard to control the supplier’s quality with existing tests.

In Experiment 3 it could be seen that there is a connection between the hole deformation and the over-opening results. Yet these results are from the boards bought at IKEA and tested at KTH, why there are no technical specifications on these boards. In terms of future testing it would therefore be of interest to perform all three experiments on the same boards to collect more data which would be easier to analyze. If the technical properties were to be compared to the hole deformation test instead of the over-opening test results directly there is a possibility of finding more apparent correlations. From that standpoint it would be possible to connect the technical properties to the actual over-opening results, given that the correlations found in Experiment 3 are valid. Figure 44 illustrates a possible chain of experiments and a more detailed methodology of how this could be done is presented in Chapter 10. 4 Future Experiment Methodology below.

Figure 44. Schematic over made experiments as well as a possible chain of experiments.

One way of investigating the correlations between the hole deformation and the technical properties could be to create a FEM–model of the particle board based on data from the production tests of the boards. From there a simulation of the hole deformation could be made to give an idea about whether the board would pass the over-opening test or not. It should be borne in mind though, that it is quite complex
to make such model, since the properties of particle boards are not linear at all. A simplified model could though be worth considering, based on data from density profiles and bending tests for example.

10.3 Alternative fastener solutions

An entirely different approach to achieving better over-opening test results could be to look at alternative solutions for the fasteners. If the fasteners were better suited to porous particle boards it could even be possible to lower the density and cost of the boards. Through looking briefly at other fastener solutions a number of low-level concepts were created. These concepts can be divided into three sub-categories; without socket, without screws or redesigned socket. These concepts can be seen in Appendix F.

10.4 Future experiment methodology

The boards tested are all considerably high density boards and since the densities within the density-range that was tested has not proven to affect the over-opening results, there is a possibility of lowering the average density, thus also the costs. But in order to do so the most crucial parameter still needs to be found. This could be done in a couple of different ways. One way would be to carry out further experiments on boards with clearly defined properties within a large range, i.e. boards with density between say 450 and 650kg/m³. Unfortunately that would not suffice because the number of parameters regarding particle boards is far greater than density only. This means that tests would have to be done on boards where other parameters like surface thickness, internal bond, yield strength and therefore indirectly size, form and type of particles, glue types, etcetera, has to be varied as well. Doing all these tests as EN standard over-opening system tests would be extremely time-consuming, whereas doing these tests as described in Experiment 3 would only take a fraction of that time!

This chain of thought can be further described as a number of action steps for future testing:

1. In order to secure the correlations between deformation angle, deformation load and over-opening break-off load, as was done in Experiment 3, more tests would have to be carried out in the same principal way. Preferably in a test lab with proper and accurate test equipment.
2. Tests to acquire the technical properties of those same boards would then have to be carried out in order to see if any board variations significantly affect the results in the over-opening test.

3. When a clear correlation between the over-opening break-off load and a specific deformation angle at a certain deformation load has been stated the bigger scale tests could begin.

4. Based on the tests it could at this point hopefully be said that if deforming a predrilled hole of exactly 5mm in diameter with a 5mm in diameter metal rod inserted to a depth of 12mm with a lever length of 100mm with a certain deformation load and the deformation angle falls below the limit angle it would mean that the board would pass the over-opening test. Like the data from Experiment 3 showed this could possibly be achieved with a deformation load of 50N with a limit angle of 12.5 degrees, which would correspond to an over-opening break-off load of approximately 66N (60N plus a safety margin of 10%).

5. Then, with this test method, tests could be carried out within the particle board manufacturing process to collect data in a much bigger scale.

6. This data could then be used to connect the numerous technical properties controlled during manufacturing to the deformation angles, which would give an indication on whether the board will pass the over-opening test or not.

7. By obtaining this data this way the boards’ properties could hopefully be better designed for the worst case situation with the benefit of possibly lowering the density and therefore also the costs!

The methodology of finding a technical property which affects a certain function through conducting a break-off and pre-deformation test could be applicable to other critical situations, e.g. leaning on a door. By performing breakage tests and finding the weakest spot in the system and thereafter inflict that kind of deformation gradually while also performing corresponding breakage tests on these same samples, a correlation could hopefully be found between the breakage test result and the deformation inflicted. The deformation therefore needs to be measurable and it has to correlate with the destruction factor, e.g. a deformation load, a number of wear cycles or a certain time under stress or anything that can be connected to the kind of deformation that is causing the system to fail during a functionality test basically. That way these correlations can be used to predict when the system breaks by only causing the deformation with a certain load, time or equivalent to a sample and measure the deformation made. If this deformation falls below the limit value given by the found correlations, the system quality could be ensured without actually performing the whole system function test.

Summarized, this methodology could be described as:
1. Find the weakest spot in a system for a desired function by performing a breakage test.
2. Find a way to inflict a kind of deformation similar to what is causing the breakage. The deformation needs to be measurable.
3. Find a correlation between the factor causing the deformation and the deformation made.
4. Inflict the deformation gradually and perform corresponding breakage tests to find a correlation between the breakage test results and the measurable deformation made.
5. Find out how large the deformation and the factor causing the deformation is for a limit breakage value, using the correlations between the breakage test results, the measurable deformation and the factor causing the deformation.
6. Then, perform a deformation test on a sample component using the found deformation factor and measure the deformation made. If the deformation falls below the limit value the system is OK.

If such a methodology with the proper correlations is found, it could possibly be implemented at a larger scale by the manufacturer linking the deformation test results of the component to specific technical properties. This would make it possible to on a detailed level design a system with high functional quality.
11. References


European Committee of Standardization, 1993a. EN 319 Particle boards and fiber boards - determination of tensile strength perpendicular to the plane of the board, Brussels: Swedish Institute of Standardization.


IKEA of Sweden, 2006. *IOS PRF 0032*.


IKEA, 2013. *About IKEA*.


Swedspan, 2013. *Particle Board Technology* [Interview] (12 April 2013).


Appendix A.  
Manufacturing of particleboards

Manufacturing of particle boards

When manufacturing particle boards the first step is to cut the wood, consisting of wood chips, wood shavings, logs etc., into wood particles of the wanted size, Appendix A, Figure 1.

The particles are dried before being sorted into different sizes. Then particles of an appropriate size are mixed with glue for the layers of the board. The mix of wood particles and glue is distributed in layers on large conveyor belts. In some cases the sheet of particles and glue is cold compressed before going into the hot press where they are formed into compact sheets by the influence of the glue, the heat, the humidity, pressure and time. The last steps of the production are to cut the sheet into boards and cool them, Appendix A, Figure 2. (Blümer, 1992) (Swedspan, 2013)
Appendix A, Figure 2. A cooling wheel at the end of the particle board production line.

Some mechanical properties are continuously controlled during production while other properties are measured manually on samples from the production. The weight and thickness of the sheet is continuously measured after the press, (Blümer, 1992) (Swedspan, 2013). At Swedspan they look for cracks and pores in the boards with ultra sound and then use x-rays to get the density profile of the board and to find foreign particles, (Swedspan, 2013). The moisture content of the sheet is also continuously measured before going into the press, (Swedspan, 2013). At Swedspan, a Swedish manufacturer of particle boards and sub supplier for IKEA, the traceability of the continuous measurements of the particle board sheet is around 15 minutes, (Swedspan, 2013). How often the manual controls of samples are made depend on the factory, at Swedspan they make them every 8 hours, (Swedspan, 2013). In the manual controls at Swedspan they measure density, internal bond, Young’s modulus and bending strength, (Swedspan, 2013). They also measure SWR on samples with the screws used in IKEA furniture occasionally, (Swedspan, 2013).

The raw material of the wood particles affect the quality of the particle board, amongst others the density of the wood type in the particles affect the properties of the board. Wood particles of different shape and size have different mechanical properties according to (Swedspan, 2013). A mix of the different sizes and shapes of the particles affect the properties of the board according to (Blümer, 1992). In detail the amount of dust in the particles used for the surface layer affects the yield
strength and internal bond of the boards, (Blömer, 1992). The addition of glue to the particles is paramount for the quality of the particle board. All the steps of the process including the storage of the particles, the storage of the resin, the dosage of glue and the method of mixing the glue and wood particles all influence the quality of the resulting board, (Blömer, 1992). The content of the glue, especially the formaldehyde, influence the properties of the board since the urea resin glue used is weaker when containing less formaldehyde, (Blömer, 1992). All the aspects of compression influence the quality of the particle board, (Selahattin, et al., 2011). The compression aspects also determine the density profile of the board that in turn defines some of the mechanical properties (Blömer, 1992).
Appendix B.

Test methods in detail

Test conditions

The worst case configuration of the furniture is assembled according to its instructions. The fittings are tightened at the assembly and are not allowed to be re-tightened later, unless the manufacturer specifically requires it. The temperature during the test is between 15° C and 25° C in an indoor climate. Before the test is conducted the product to be tested is stored indoor climate during at least one week. Unless otherwise specified all drawers or baskets not tested at the moment shall be uniformly loaded with 0.2kg/dm³ and all horizontal surfaces with 0.65kg/dm². The drawer load is calculated by first determining the free volume which is the volume of the drawer from its interior bottom to the first obstructing surface above (European Committee for Standardization, 2005) (the International Organization for Standardization, 2006) (IKEA of Sweden, 2006).

In the EN standard and IKEAs test instructions it is stated that parts accessible in normal use and moving in relation to each other should be positioned at ≤8mm or ≥ 25mm from each other though out the movement. In hinges the distance between the moving parts shall be ≤8mm at all times during the movement (European Committee for Standardization, 2005) (IKEA of Sweden, 2006).

Both the ISO and EN standard use the same sample for all tests of one component (European Committee for Standardization, 2005), (the International Organization for Standardization, 2006). IKEA not only use the same sample for all tests of one component but also conducts all tests associated with the unit the component is attached to on the same sample unit (IKEA of Sweden, 2006).

The ISO standard for testing furniture suggested loads and masses presented in furniture categories 1, 2 and 3 where the furniture categories span from domestic to contract applications (the International Organization for Standardization, 2006). The tests at IKEA and the tests in the EN standard both state one load to be used for each test of kitchen furniture (European Committee for Standardization, 2005), (IKEA of Sweden, 2006).

What have to be monitored during the tests are presented for the ISO standard, the EN standard and IKEA in Appendix B, Table 1.
### Appendix B, Table 1. Monitored aspects for mechanical tests of kitchens

<table>
<thead>
<tr>
<th>Monitored aspects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fracture of joint or component.</td>
</tr>
<tr>
<td>Loosening of joint intended to be rigid by applying hand pressure.</td>
</tr>
<tr>
<td>Wear or deformation of a component leading to impairment of its function.</td>
</tr>
<tr>
<td>Loosening of fixing units of the component.</td>
</tr>
<tr>
<td>Impairment of part, component or unit</td>
</tr>
<tr>
<td>That the tested part is still attached to the unit after the test.</td>
</tr>
<tr>
<td>Fracture of joint or component.</td>
</tr>
<tr>
<td>Loosening of joint intended to be rigid by applying hand pressure.</td>
</tr>
<tr>
<td>Wear or deformation of a component leading to impairment of its function.</td>
</tr>
<tr>
<td>Loosening of fixing units of the component.</td>
</tr>
<tr>
<td>Apparent deterioration of the function.</td>
</tr>
<tr>
<td>Noise induced.</td>
</tr>
<tr>
<td>Deformation with a negative effect on the appearance.</td>
</tr>
<tr>
<td>Change in the motion pattern.</td>
</tr>
</tbody>
</table>

* *(the International Organization for Standardization, 2006)*
** *(European Committee for Standardization, 2005)*
*** *(IKEA of Sweden, 2006)*

### Tests conducted on pivoting doors

**Vertical load**

A load is hung 100mm from the edge furthest from the hinge of the door, Appendix B, Figure 1. The door is swung back and forth 10 cycles with each cycle lasting 3 to 5 seconds. The starting position is at 45° from fully closed and the end position is at 10° from fully opened (European Committee for Standardization, 2005), (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).

For IKEA the maximum speed is 6 cycles/minute (IKEA of Sweden, 2006).
Appendix B, Figure 1. In the vertical load test a load is attached to the door and the door is swung back and forth.

**Horizontal load**

A horizontal force is applied to the fully opened door at 100mm from the edge farthest from the hinge and at half its height, Appendix B, Figure 2. The load applied 10 times (the International Organization for Standardization, 2006) (IKEA of Sweden, 2006).

For IKEA it is stated that the force is applied for 10 seconds and that the test is only conducted on doors with a maximum angle of 135° at the fully opened position (IKEA of Sweden, 2006).

Appendix B, Figure 2. In the horizontal force test a horizontal force is applied to the open door.
Slam shut

The test is not performed on doors fitted with a damper mechanism (the International Organization for Standardization, 2006).

A string or a cord is attached to the front of the door so that it will be perpendicular to the door in its fully closed position, Appendix B, Figure 3. If the door is fitted with a handle the string is attached to the middle of the handle, unless it is longer than 200mm in which case it is placed at 100mm from the top of the handle. The maximum height of the attachment position is 1200mm from the floor. If the door is not fitted with a handle the string is attached at half the height of the door 25mm from the edge furthest from the hinge (the International Organization for Standardization, 2006).

When the door is fully closed the string should be perpendicular to the front of the door. The string is not allowed to change direction more than 10°. At one end of the string it is attached to the door and at the other end it is attached to a test weight. Near the weight the string runs through a pulley. 10mm before the door is fully closed the weight should stop affecting the door (the International Organization for Standardization, 2006).

Depending on which is the smaller the weight shall either fall the necessary distance to close the door from a 30° opened position or it shall fall 300mm. The weight to be used is calculated by measuring the mass needed to just move the door and adding it with a weight depending on the furniture category. The door shall be closed 10 times using a weight of the calculated mass (the International Organization for Standardization, 2006).
Durability

Two loads of 1kg each are attached to the door with one of the loads at each side of the door, at the middle of the vertical centerline. The door is opened fully, but maximum to $130^\circ$ from the closed position, and closed again. If there is a stopping mechanism this should not be forced, but if there is a mechanism aiding the shutting or dampers these should be tested in each cycle of the test whiteout unnatural heating of the structure. The maximum recommended speed is 6 cycles/minute (the International Organization for Standardization, 2006) (IKEA of Sweden, 2006). For the ISO standard the maximum speed for opening is 3 seconds and the maximum speed for closing is 3 seconds (the International Organization for Standardization, 2006).

Loads and forces

The loads and masses used in the EN standard, the ISO standard and by IKEA are represented in Appendix B, Table 2.

Appendix B, Table 2. The loads and masses used in the mechanical test methods on pivoting doors.

<table>
<thead>
<tr>
<th></th>
<th>ISO *</th>
<th>EN **</th>
<th>IKEA ***</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Vertical load</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load</td>
<td>12, 20 or 30kg</td>
<td>30kg</td>
<td>30kg</td>
</tr>
<tr>
<td><strong>Horizontal load</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load</td>
<td>50, 60 or 70N</td>
<td>-</td>
<td>60N</td>
</tr>
<tr>
<td>Duration</td>
<td>10-30 s</td>
<td>10s</td>
<td>10s</td>
</tr>
<tr>
<td><strong>Slam shut</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load</td>
<td>moving mass + 2.3 .4kg</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td><strong>Durability</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycles</td>
<td>20 000, 40 000 or 80 000</td>
<td>-</td>
<td>200 000</td>
</tr>
</tbody>
</table>

* (the International Organization for Standardization, 2006)
** (European Committee for Standardization, 2005)
*** (IKEA of Sweden, 2006)

Tests conducted on drawers

Vertical load

The unloaded drawer is pulled out to its fully opened position. If the drawer is not fitted with a stopping mechanism 1/3 of its depth, or at least 100mm is left inside of the frame. A vertical static load N is applied 10 times to one of the top corners of the drawer front, Appendix B, Figure 4 (European Committee for Standardization, 2005), (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).
Durability

The drawer is loaded and opened and closed by applying an opening force where the user would normally apply the force for opening the drawer. In case of two handles the force is applied in between of the handles, and if the drawer is not fitted with handles the attachment is placed in height of the runners. The drawer is opened without forcing the stops and if it doesn’t have a stopping mechanism one third or at least 100mm of the drawer is left inside of the unit. If the drawer has runners fitted with dampers or self-shutting mechanisms the force and velocity shall be adjusted so these mechanisms function normally (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).

The drawer shall not be closed with an exaggerated force. The mechanisms of the drawer are not allowed to become overheated. To prevent this, a pause in the closed position is allowed. The opening rate is 6 to 15 cycles per minute which in the ISO standard is recommended at an average speed of 0.25 ± 0.1m/s (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).

In the IKEA test instructions it is stated that the drawer is opened and closed to 1 - 3mm from its fully opened or closed position. IKEA use a load based on the free volume of the drawer when testing all drawers of Model 2 but for the Model 1 drawers the loads are predefined maximum loads, all the test loads can be found in Appendix B, Table 3 (IKEA of Sweden, 2006), (IKEA of Sweden, 2012).
Slam open

The drawer is loaded and slammed open 10 times by using either a pneumatic device or a string and mass equipment. The force is applied with a velocity calibrated according to the weight of the drawer (European Committee for Standardization, 2005), (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).

The opening motion is started with the drawer positioned 300mm from its fully opened position or fully closed if it is fully opened before traveling 300mm. When 10mm of the motion remains until the drawer is fully opened it is allowed to move without exterior influence. If the drawer is fitted with a damper or self-shutting mechanism the drawer shall move freely 10mm before the damper or stopping mechanism (European Committee for Standardization, 2005) (the International Organization for Standardization, 2006) (IKEA of Sweden, 2006).

The testing equipment is attached to the handle of the drawer or in case of two handles in between of the handles. If the drawer is not fitted with handles the attachment is placed in height of the runners (European Committee for Standardization, 2005), (the International Organization for Standardization, 2006) (IKEA of Sweden, 2006).
Slam shut

The drawer is loaded and slammed shut 10 times by using either a pneumatic device or a string and mass equipment. The force is applied with a velocity calibrated according to the weight of the drawer (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).

The opening motion is started at 300mm from fully closed position of the drawer, or at fully opened position if a stopping mechanism hinders that long a motion. When 10 mm of the motion remains until the drawer is fully closed it is allowed to move without exterior influence. If the drawer is fitted with a damper or self-shutting mechanism the drawer shall move freely 10mm before the damper or self-shutting mechanism (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).

The testing equipment is attached to the handle of the drawer or in case of two handles in between of the handles. If the drawer is not fitted with handles the attachment is placed in height of the runners. The test is repeated 10 times (the International Organization for Standardization, 2006), (IKEA of Sweden, 2006).

If the drawer is not fitted with a stopping mechanism the IKEA test instructions instructs to leave 100mm of the drawers’ depth within the frame (IKEA of Sweden, 2006).

Stopping mechanism

The test is only applied to units with a mass ≥10kg. All the loaded drawers are opened fully and a horizontal pulling force of 200N is applied to the handle of the drawer. This is tested once for each drawer in the unit (European Committee for Standardization, 2005), (IKEA of Sweden, 2006).

Displacement of drawer bottom

Weights are placed on the bottom of the drawer, evenly distributed up against the front and back of the drawer. For the IKEA tests drawers with a free internal height of ≤10mm are loaded with 0.35kg/dm³, and drawers with a free internal height of ≥10mm are loaded with 0.2kg/dm³. For the ISO tests the drawers are all loaded with 0.2kg/dm³ (the International Organization for Standardization, 2006) (IKEA of Sweden, 2006).

At the middle of both the interior front and back of the drawer a force is applied approximately 25mm above the bottom of the drawer, Appendix B, Figure 5. This is repeated 10 times (the International Organization for Standardization, 2006) (IKEA of Sweden, 2006).
Appendix B, Figure 5. In the displacement of bottom test two forces are simultaneously applied to the back and front of the drawer.

Loads, forces and velocities

The specifics of the load cases, velocities etc. of the drawer tests are presented in Appendix B, Table 4.

Appendix B, Table 4. Specific details for the mechanical tests for kitchen drawers.

<table>
<thead>
<tr>
<th></th>
<th>ISO *</th>
<th>EN **</th>
<th>IKEA ***</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slam open</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>0.8, 1.0 or 1.1 m/s (35kg)</td>
<td>1 m/s (35kg)</td>
<td>1 m/s (35kg)</td>
</tr>
<tr>
<td></td>
<td>1.1, 1.3 or 1.4 m/s (5kg)</td>
<td>1.3 m/s (5kg)</td>
<td>1.3 m/s (5kg)</td>
</tr>
<tr>
<td>Load</td>
<td>0.2, 0.35 or 0.5 kg/dm³</td>
<td>0.2 kg/dm³</td>
<td>0.2 kg/dm³</td>
</tr>
<tr>
<td>Slam shut</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Velocity</td>
<td>0.8, 1.0 or 1.1 m/s (35kg)</td>
<td>-</td>
<td>1 m/s (35kg)</td>
</tr>
<tr>
<td></td>
<td>1.1, 1.3 or 1.4 m/s (5kg)</td>
<td>-</td>
<td>1.3 m/s (5kg)</td>
</tr>
<tr>
<td>Load</td>
<td>0.2, 0.35 or 0.5 kg/dm³</td>
<td>-</td>
<td>0.2 kg/dm³</td>
</tr>
<tr>
<td>Stopping mechanism</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Load</td>
<td>-</td>
<td>200 N</td>
<td>200 N</td>
</tr>
<tr>
<td>Vertical load</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force</td>
<td>100, 200, or 300 N</td>
<td>-</td>
<td>250 N</td>
</tr>
<tr>
<td>Duration</td>
<td>10-30 s</td>
<td>-</td>
<td>10 s</td>
</tr>
<tr>
<td>Displacement of drawer bottom</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Force</td>
<td>40, 60 or 70 N</td>
<td>-</td>
<td>70 N</td>
</tr>
<tr>
<td>Load</td>
<td>0.2 kg/dm³</td>
<td>-</td>
<td>0.35 or 0.2 kg/dm³</td>
</tr>
<tr>
<td>Durability</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cycles</td>
<td>20 000, 40 000 or 80 000</td>
<td>-</td>
<td>200 000</td>
</tr>
<tr>
<td>Load</td>
<td>0.2, 0.35 or 0.5 kg/dm³</td>
<td>-</td>
<td>35 kg/dm³</td>
</tr>
</tbody>
</table>

* (the International Organization for Standardization, 2006)
** (European Committee for Standardization, 2005)
*** (IKEA of Sweden, 2006)
Appendix C.
Frequency study

To get a general indication of the opening frequency of drawers and doors in a kitchen, an experiment where post-it notes were put on all drawers and doors in the participant’s kitchen was made. During one week the post-it notes were marked every time a door or drawer was opened.

Test #1

The kitchen in this example is fairly small and is situated in a studio apartment with the effect that the use for cabinets and drawers are combined which probably lead to them being opened more often than in larger kitchens. The exception in this kitchen is that the larder is split to various compartments which probably lead to opening the separate drawers/cabinets less frequently than if the larder only consisted of one large cabinet. The post-it notes were labeled as seen in Appendix C, Figure 1, 2 and 3.
Appendix C, Figure 2. An overview of test kitchen 1 with indexes:
Left wall cabinet (D), Middle wall cabinet (E), Right wall cabinet over oven (F), Base cabinet door under sink (H), Right base cabinet next to oven (I).

Appendix C, Figure 3. An overview of test kitchen 1 with indexes:
Left wall cabinet (F), G: right wall cabinet (G), J: Left drawer under oven (J), Top white drawer (K), Second topmost white drawer (L), Third white drawer from the top (M), Fourth white drawer from the top (N), Bottom white drawer (O), Top wood drawer (P), Second wood drawer from the top (Q), Third wood drawer from the top (R), Fourth wood drawer from the top (S), Fifth wood drawer from the top (T), Bottom wood drawer (U).
The most frequently used compartments in this experiment turned out to be the fridge followed by the waste cabinet under the sink, as seen in Appendix C, Table 1.

Appendix C, Table 1. The table shows the number of times the drawers and cabinets were opened during a week.

<table>
<thead>
<tr>
<th>Label</th>
<th>Storage type</th>
<th>Content</th>
<th>Opening frequency / one week</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Wall cabinet</td>
<td>Baking pen, ovenware</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>Fridge door</td>
<td>Fridge</td>
<td>82</td>
</tr>
<tr>
<td>C</td>
<td>Freezer door</td>
<td>Freezer</td>
<td>33</td>
</tr>
<tr>
<td>D</td>
<td>Wall cabinet</td>
<td>China, glasses</td>
<td>36</td>
</tr>
<tr>
<td>E</td>
<td>Wall cabinet</td>
<td>China, glasses</td>
<td>27</td>
</tr>
<tr>
<td>F</td>
<td>Wall cabinet</td>
<td>Larder</td>
<td>3</td>
</tr>
<tr>
<td>G</td>
<td>Wall cabinet</td>
<td>Larder</td>
<td>10</td>
</tr>
<tr>
<td>H</td>
<td>Base cabinet</td>
<td>Waste</td>
<td>59</td>
</tr>
<tr>
<td>I</td>
<td>Base cabinet</td>
<td>Cooking utensils, pots</td>
<td>21</td>
</tr>
<tr>
<td>J</td>
<td>Drawer</td>
<td>Cooking utensils, pans</td>
<td>8</td>
</tr>
<tr>
<td>K</td>
<td>Drawer</td>
<td>Cutlery</td>
<td>43</td>
</tr>
<tr>
<td>L</td>
<td>Drawer</td>
<td>Cooking utensils, knives, spatulas</td>
<td>17</td>
</tr>
<tr>
<td>M</td>
<td>Drawer</td>
<td>Cooking utensils</td>
<td>6</td>
</tr>
<tr>
<td>N</td>
<td>Drawer</td>
<td>Aluminium foil, plastic bags</td>
<td>5</td>
</tr>
<tr>
<td>O</td>
<td>Drawer</td>
<td>Baking utensils</td>
<td>2</td>
</tr>
<tr>
<td>P</td>
<td>Drawer</td>
<td>Mixer</td>
<td>8</td>
</tr>
<tr>
<td>Q</td>
<td>Drawer</td>
<td>Bowls</td>
<td>3</td>
</tr>
<tr>
<td>R</td>
<td>Drawer</td>
<td>Assorted</td>
<td>3</td>
</tr>
<tr>
<td>S</td>
<td>Drawer</td>
<td>Larder</td>
<td>8</td>
</tr>
<tr>
<td>T</td>
<td>Drawer</td>
<td>Larder</td>
<td>2</td>
</tr>
<tr>
<td>U</td>
<td>Drawer</td>
<td>Larder</td>
<td>0</td>
</tr>
</tbody>
</table>
Test #2

The second test was conducted in another kitchen (or rather kitchenette) which is seen in Appendix C, Figure 4.

Appendix C, Figure 4. Test kitchen 2.

Results of frequency of use can be seen in Appendix C, Table 2.

Appendix C, Table 2. The number of times the drawers and cabinets were opened during a week.

<table>
<thead>
<tr>
<th>Storage type</th>
<th>Content</th>
<th>Opening frequency / one week</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base cabinet</td>
<td>Wastebin</td>
<td>101</td>
</tr>
<tr>
<td>Base cabinet</td>
<td>Fridge</td>
<td>85</td>
</tr>
<tr>
<td>Drawer</td>
<td>Cutlery drawer</td>
<td>36</td>
</tr>
<tr>
<td>Wall cabinet</td>
<td>China and glasses</td>
<td>32</td>
</tr>
<tr>
<td>Wall cabinet</td>
<td>Dry goods and bread</td>
<td>21</td>
</tr>
<tr>
<td>Drawer</td>
<td>Cooking utensils, pots and pans</td>
<td>14</td>
</tr>
<tr>
<td>Drawer</td>
<td>Tea and non-frequently used cooking tools</td>
<td>11</td>
</tr>
<tr>
<td>Wall cabinet</td>
<td>Freezer</td>
<td>11</td>
</tr>
<tr>
<td>Base cabinet</td>
<td>Other (tools, flower pots etc.)</td>
<td>3</td>
</tr>
</tbody>
</table>
Appendix D. Calculations

To prioritize in IKEA’s range the following mechanical models were created.
The mechanics used for the drawer calculations can be seen schematically in Appendix D, Figure 1 and for the doors in Appendix D, Figure 2.

Appendix D, Figure 1. Schematic mechanics overview of the drawers.

Appendix D, Figure 2. Schematic mechanics overview of the doors.

$N_y$ and $N_x$ are the vertical and horizontal force on the hinges, $F$ is the external load and $m_{door}$ is the mass of the door.
From the mechanics overviews a number of parameters were defined and focus was set on the crucial ones in order to filter the combinations. Looking at the drawers, focus was set on the torque at the drawer attachment, $T$, which was simplified as seen in Equation 1,

$$T = \frac{d(m_d g + m_l g)}{2} + m_f d$$  \hspace{1cm} (1)

where $d$ is the drawer depth, $m_d$, $m_l$ and $m_f$ are the mass of the drawer itself, the drawer load and the drawer front, respectively and $g$ is the standard gravity of $9.81\text{m/s}^2$.

Regarding the doors, the focus was set on the horizontal and vertical forces at the hinges, both with and without an external load of 30kg, as well as on the force pulling the screws outwards during the horizontal force test.

The vertical force at the hinges, $N_y$, is given by Equation 2,

$$N_y = \frac{m_{door} g + F}{2}$$ \hspace{1cm} (2)

where $m_{door}$ is the mass of the door and $F$ is the external load.

The horizontal force is given by Equation 3,

$$N_x = \frac{m_{door} \left( \frac{w+b}{2} \right) + F \left( \frac{w-l+b}{l+2a} \right)}{}$$  \hspace{1cm} (3)

where $w$ is the door width, $b$ is the horizontal distance between the door edge and the hinge, $l$ is the horizontal distance from the door edge to the external force and $a$ is the vertical distance between the door edge and the hinge.

To calculate the approximate screw withdrawal forces, $S_1$ and $S_2$, a number of extra parameters had to be added according to the schematic in Appendix D, Figure 3.

Appendix D, Figure 3. Schematic over the screw withdrawal model.
Three balance equations, Equation 4, 5 and 6, were formulated as

\[ N_x - F_x = 0, \quad (4) \]
\[ -N_y + S_1 + S_2 = 0, \quad (5) \]
\[ -d_5 N_y - d_6 S_2 + F_z d_3 + F_y (d_2 + d_4 + d_5) = 0, \quad (6) \]

which together with the assumption that the relation between the two screw withdrawal loads could be described according to Equation 7,

\[ S_2 = \frac{d_5 + d_6}{d_5} S_1. \quad (7) \]

The desired screw withdrawal loads could then be calculated as in Equation 8,

\[ S_2 = \frac{F_x d_3 + F_y (d_2 + d_4 + d_5) - F_y}{d_5 \left( 1 + \frac{d_5}{d_5 + d_6} + \frac{d_z}{d_6} \right)} \quad (8) \]

and Equation 9,

\[ S_1 = \frac{S_2 d_5}{d_5 + d_6}. \quad (9) \]
Appendix E. Results from contextual interviews

The aim of the observations was to find out how customers handle their kitchen units at home. The biggest focus was to document how drawers and doors were being used, mainly how they were opened and closed. All forces applied to the drawers and doors, and in extension also knobs and handles, and all motions affecting them were documented.

According to (Holtzblatt, et al., 2005) activities can be seen as a collection of steps taken to complete a piece of work. Different users can use different sets of abstract steps to achieve an activity. These sets of steps represent strategies to finish a task. The activities from the contextual interviews were consolidated and only activities including drawers, cabinet doors, knobs and handles are presented here. The activities from the observations are grouped around the intent for the activities and sorted into different strategies.

Strategies affecting drawers

Open drawer
With the intent to open a drawer three different strategies were observed.

Open smoothly
One of the strategies was to open the drawer smoothly by guiding it with one hand throughout the motion, not letting it slam open. This was the most common way of opening a drawer.

Slam open
A less common way of opening the drawer was when the drawer was slammed open. The opening motion was then started with one hand on handle or knob of the drawer and then the drawer was let go off to stop on its own, which created a slam open situation.
Open while pulling down

The last strategy was observed when a child opened a drawer positioned over her head. She opened the drawer by pulling it down by the handle at the same time as she pulled the drawer out.

Close drawer

Four different strategies were observed when the intent of the user was to close a drawer.

Close smoothly

The most common strategy was to close the drawer smoothly. The drawers were then guided through the motion or given a gentle push causing them to close with a slow velocity. The test persons used different parts of their body to close the drawer ranging from their hands, feet, legs, knees or hips. Whichever body part was used they all had the same result to the motion of the drawer.

Slam shut

In the slam strategy the drawer was given a forceful push resulting in a swift motion and a straining crash at the end. The test persons used different parts of their body to close the drawer ranging from their hands, feet, legs, knees or hips. This strategy was not as common as closing the drawer smoothly but one of the test persons only used the slam shut strategy during the observation.

Close while pulling down

This strategy was performed by a child closing a drawer over her head was to pull the drawer down as well as pushing it in.

Close interior drawer with exterior drawer front

The last strategy for closing a drawer was observed in all the test persons with a kitchen containing interior drawers behind exterior drawer fronts. If the interior drawer was opened it was later closed by pushing it close with the exterior drawer front causing the drawers to slam into each other, Appendix E, Figure 1.
Support

With the intent to support oneself on a drawer front two different strategies with a similar effect on the drawer were observed.

Support oneself on drawer front

The first strategy was performed by adults who positioned one hand on top of the drawer front and used this for support while reaching for things either inside of the drawer or in front of it, Appendix E, Figure 2.

Appendix E, Figure 1. The interior drawer is closed by colliding with the exterior drawer front.

Appendix E, Figure 2. A vertical force is applied when the user supports himself on the drawer front.
Pull oneself up using drawer front

The second strategy for supporting oneself was used by a child who reached for the inside of an open top drawer positioned above her head, by holding onto the handle or top of the drawer and pulling herself up.

Play

An activity with the only intent to play with a drawer was observed in a child who stood with her back to a drawer and held onto the handle behind her back. While playing she pulled the drawer back and forth behind her back, leaned on the open drawer and sat down in it without putting her whole weight in it.

Activities and strategies affecting doors

Open door

Three strategies were observed in the contextual interviews with the intent to open a cabinet door.

Open smoothly

The first strategy was to open a cabinet door smoothly by guiding it throughout the motion.

Open while pulling down

The second and most common strategy mostly occurred on wall cabinet doors. In this strategy the door was opened smoothly by pulling the handle or knob down as well as out, Appendix E, Figure 3.
Appendix E, Figure 3. Some of the test persons pulled the handle down while opening and closing wall cabinet doors.

Open further than intended

The last strategy for opening a door was to open it more than the intended opening angle by leaning on the door. Three children in one of the observations were sitting in front of an open cabinet with double doors, two of them with their backs or shoulders against the doors. One of the children leaned against the door with her back and pushed it open past 125° repeatedly. One of the children later stood up and again leaned on the door pushing it open more than 125, Appendix E, Figure 4. The force she used seemed less than the force used in the horizontal force test conducted by IKEA.

Appendix E, Figure 4. The door of a cabinet is force open further than intended when a child leans on the open door.
Close door
When the intent was to close a cabinet door three strategies were observed.

Close smoothly
The most common strategy was to close the door smoothly by guiding it shut with a hand, knee, leg or a foot or by giving the door a gentle push.

Close while pulling down
Some of the test persons used a strategy where the handle or knob of the door was pulled down while the door was closed, Appendix E, Figure 3.

Slam shut
The last strategy was to slamming the door shut by giving it a swift push using hand, knee, leg or foot.

Support
Two different strategies were observed of the intent to support oneself on a cabinet door.

Support oneself on knob, handle or edge of base cabinet door
The first strategy occurred when the test persons supported themselves on base cabinet doors. They rested their hands on the top of the door or held onto the handle or knob while reaching either up or down. In some cases the test persons were reaching for something on a shelf above. In other cases they bent down reaching for something on the floor or for the garbage disposal and used the door for support when straithening up, Appendix E, Figure 5. These situations mostly occurred by the cabinet containing the garbage disposal.
Appendix E, Figure 5. The user supports itself on the knob of the door while bending down.

Hanging on to handle or knob on wall cabinet door

The other strategy was used on wall cabinet doors while reaching for a high shelf. The test persons usually held on to the handle or knob for support when they reached into a cabinet, which resulted in pulling the handle or knob down, Appendix E, Figure 6.

Appendix E, Figure 6. The handle or knob of the door is used for support while reaching for a high shelf.

Play

One child with the intent to play with a door opened a base cabinet and hung onto the door with her hands on the top edge of the door and swung back and forth.
Activities and strategies affecting knobs or handles

Most activities that effects knobs or handles also affects drawers or doors and are presented above.

Open and close drawer or door while pulling down

When the intent was to open or close a drawer there was a strategy conducted by a child that affected the handles or knobs of the drawer. It was a situation where a child pulled a drawer down by the handle while she closed and opened the drawer.

Support

When the intent was to support oneself on a drawer one child held on to a handle above her head and pulled it down to reach inside the drawer. Many test persons pulled the handle or knob of a door down during the motion when their intent was to open or close the door. The two strategies with the intent to support oneself on a cabinet door both affect knobs and handles since the test persons applied a vertical force onto the knobs or handles.

Using handles or knobs as foothold

There were two activities that can be considered to only affect knobs or handles. The first of those was with the intent for a child to reach the counter top. One of the children climbed up to the counter top using the handles of a cabinet with closed drawers as a ladder, Appendix E, Figure 7. She was around four years old and her weight was approximated to 24kg by the mother.

Appendix E, Figure 7. A child uses the handles of the drawers as a ladder when climbing to the worktop.
Pulling handle or knob when using attached towel

The other activity that affected only the handle or knob was when a towel hung from a handle or knob was used. The towel was attached to a knob or handle and pulled down or out when it was used.
Appendix F.
Alternative fasteners

Without socket

The experiments indicated that higher SWR loads could be obtained by using particle board screws instead of plastic sockets with smaller screws, thus also possibly performing better in an over-opening test (which is not tested at this point, but could be another interesting future test). As stated before, the function of a plastic socket is not only holding the hinge in place, but also making the assembly easy for the customer, why such alternative should be evaluated from a wider viewpoint. In any case, the concept of a version of the regular particle board screws can be seen in Appendix F, Figure 1.

Redesigned socket

Another alternative is to keep the plastic socket, but with slight alterations that might give it a better holding performance. This could be achieved by decreasing the space for the screw, especially at the tip of the socket, thus making it expand more when tightening the screw into place. A sketch of such socket can be seen in Appendix F, Figure 2.
Appendix F, Figure 2. A redesigned plastic socket intended to expand more, especially at the tip, than a regular plastic socket.

The socket could also be designed more like a wall anchor with the ability to expand more at the middle. This would possibly give the socket some extra grip in the lower density middle layer of the particle board, Appendix F, Figure 3.

Appendix F, Figure 3. A redesigned plastic socket designed like a wall anchor with the ability to expand more at the middle of the board where the density is lower.

Without particle board screws

Yet another alternative to particle board fasteners could be to integrate rails within the structure of the cabinet. This would allow to securing the hinges and drawers without interfering with the particle board at all, thus being able to use a completely different quality of particle board. In order to prevent the rails from being bent under high horizontal loads at the hinges, the rails would need to be fixated at the middle, e.g. with a couple of fasteners running through the frame to avoid particle board screws. Appendix F, Figure 4 shows a very general sketch of the concept.

Appendix F, Figure 4. A general sketch of a rail concept where no particle board screws have to be used and therefore the quality of the board is of less importance, which means it could be cheaper to produce.