Universal Design to Limit Food Cross-Contamination: Incased Set of Kitchen Utensils with Five Color-Coded Food Chopping Boards and Knifes

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Abstract
This study is focused on a conceptual design of a kitchen appliances/utensils set, comprising of five color-coded food chopping boards and five matching color-coded knives, to reduce cross-contamination at private homes, as well as at food establishments. Selected relevant Patents, as well as products, available locally and internationally, were analyzed. The Joseph Joseph Index™ Color-Coded Chopping-Boards set (of four), was chosen as a point of reference for the current design; its seven identified limitations have directed the scope of the current design. Target specifications/objectives, of the set, were formulated from the document analysis, while Pair-wise Comparison Charts were used, to rank the importance of the objectives, in the different levels. The best-ranked design (out of the four alternatives made) was chosen, via standard Engineering-Design Weighted Decision Matrix (EDWDM) and ‘Drop and Re-vote’ (D&R) method. 2D drawings, of the best design alternative, were created via computer-aided-design (CAD) AutoCAD software 2018, while 3D modeling, of the set and all its components, was produced by Autodesk-Inventor Version: 2016 (Build 200138000, 138). Designed labels (positioned on each board and each knife, as well as on the set itself, as an inclined panel) were introduced, to cater for the people with color-blindness (according to the fundamental principles of the Universal design), and also to avoid confusion (as a reminder which board is which) for all users. The study adopted ‘analysis’ method of materials selection. The main objectives, of the intended set, was used as a guide, in preliminary materials selection. This concise study has focused on conceptual design only; and, hence, it is further recommends to: (i) carry out a detailed design; (ii) select a specific material (out of the group, identified by this study); (iii) choose a mode of fabrication of the set; (iv) examine the possibility of incorporating anti-microbial agent(s) and/or coating(s); (v) fabricate the prototype(s); (vi) conduct explorative-use-ability-trials; and (vii) analyze the marketing aspect of the final set. This work is potentially beneficial to engineering product design students and faculty, as well as to households and food establishments (subject to successful implementation).

Keywords: Color blindness; Materials selection; Food safety; Joseph Joseph Index™ Color Coded Chopping Boards set.

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1.0. Introduction.

1.1. Food-safety and food-contamination.

1.1.1. Food-safety.

FAO & UN (1999) states, that: “It is important to differentiate between food-safety and food-quality”; Safety refers to hazards to human health in food, while Quality refers to all attributes, and, thus, might include safety. In particular, Food-safety encompasses actions, aimed at ensuring that all food is as safe as possible (World Bank, 2000). According to Velusamy et al. (2010), food-safety is a global health goal, while food-borne diseases are a major health issue, worldwide. The latter, in general, can be attributed by several factors, such as: the nature of food and its preparation, under-cooking of the food, dirty equipments and cutting surfaces, and the food-handlers themselves, among others.

The risks to food-safety, according to the World Bank report of 2000, fall into four broad categories, namely: (i) microbes, through improper handling; (ii) parasites, through improper cooking; (iii) physical agents, which may be intentionally or accidentally added into the food; and (iv) chemicals, which occur naturally in food, and those which are present in the environment (World Bank, 2000).

All countries share similar concerns about food-safety hazards, but the relative importance of risks differs with climate, food-eating and cooking habits, levels of income, and public infrastructure. Some risks are greater, in developing countries, due to poor sanitation and inadequate water supplies (World Bank, 2000).

1.1.2. Food-contamination.

WHO (2008) defines food-contamination as “the introduction or occurrence of a contaminant in food environment which causes food to be unsafe”. WHO (1999) developed a framework, that outlines the various sources of food contaminations, to include: food-handlers, flies and pests, polluted water, dirty pots and cooking utensils, domestic animals, indigenous microflora, infected food, animals, and human excreta. Ball et al. (2013) outlines
the following factors to be the major causes of food contamination: (i) Preparation of food, several hours prior to consumption; (ii) Insufficient-cooking or reheating; (iii) Cross-contamination; and (iv) Serving of food using dirty utensils.

This study is focused on the food cross-contamination and its reduction.

According to WHO (2008), food contamination transfer is dependent on the: (i) surface; (ii) food-type (the moisture of the food); (iii) contact-time; and (iv) inoculums-matrix. Epidemiological data indicate that cross-contamination during food preparation in the home contributes noticeably to the occurrence of food-borne diseases (Sampers et al., 2010). To help prevent such occurrences, the inclusion of a cross-contamination model in exposure assessments would aid in the development and evaluation of interventions, used to control the spread of pathogenic bacteria (Sampers et al., 2010).

**Figure 1** shows the simplified model of food cross-contamination.

![Figure 1: Cross-contamination channels.](image)

Household, and other food establishment types, have been the focus of numerous food cross-contamination studies; the surfaces studied include: ceramic tile (Jensen et al., 2013; Dawson et al., 2007; Wendt et al., 1997); stainless-steel (Jensen et al., 2013; Kusumaningrum et al., 2004; Moore et al., 2003; Midelet & Carpentier, 2002; Wendt et al., 1997); wood (Dawson et al., 2007), glass (Jensen et al., 2013); and plastic (Jensen et al., 2013; Chen et al., 2001; Zhao et al., 1998). Studies involving transfer from similar surfaces to foods have come to various conclusions (Jensen et al., 2013; Dawson et al., 2007). These differences may be due to the range of experimental procedures, among published studies. Differences include: (i) the times of contact between surfaces (Jensen et al., 2013; Dawson et al., 2007; Moore et al., 2003); (ii) the organisms used (Jensen et al., 2013; Dawson et al., 2007; Moore et al., 2003; Kusumaningrum et al., 2003); (iii) the foods and contact surfaces (type and wet/dry condition) used (Miranda & Schaffner, 2016; Jensen et al., 2013; Dawson et al., 2007; Moore et al., 2003; Kusumaningrum et al., 2003); and (iv) drying times (Jensen et al., 2013; Dawson et al., 2007; Ryu & Beuchat, 2005; Donlan, 2002); each of which can result in different outcomes. On the other hand, a research by D’Souza et al. showed that pressure changes, ranging from 1 to 100 g/cm² had no effect on the contamination transfer (D’Souza et al., 2006).

Besides, only limited data is available to quantify precisely, the food cross-contamination (Mylius et al., 2007; Nauta et al., 2007). For example, for Camp. jejuni only data on board-transfer were found (see Luber et al., 2009; Kusumaningrum et al., 2004; Moore et al., 2003), and limited data on knife-transfer (see Luber et al. 2009). For hand-transfer and hand washing, only data on *Enterobacter aerogenes* are present, which is used as surrogate-organism for *Salmonella* (Montville et al., 2001; Chen et al., 2000).

1.1.3. Food-borne diseases and their impacts.

Food-borne diseases are regarded as acute illnesses, associated with the recent consumption of food, having normally a short incubation period, and symptoms, with gastrointestinal features, including: vomiting, diarrhea, and abdominal cramps. In some cases, there may be neurological and other symptoms, connected with the alimentary tract (WHO, 2008). According to Mukhola (2000), WHO regards illness, due to contaminated food, as one of the most widespread health problems, in the contemporary world.

Although proper food handling, preparation, storage, and feeding practices may prevent many food-
borne-diseases, each-year, millions of people become ill, and thousands die, from these-diseases (Kumiko et al., 2009). The-Centers for Disease-Control and Prevention (CDC, 2015; 2014) estimates, that each-year there are more-than 9 million-episodes of food-borne-illness, over 55,000 hospitalizations, and at-least 1,351 deaths, that can be attributed-to foods-consumed, in the-United-States (Scallan et al., 2011), while FSWSG (2008) indicates much-higher-fatality of 3,000 people, while WHO (2008) estimates even-higher-number of deaths (5,000), to-occur each-year, in the-U.S.A., alone. In-particular, during 1998-2008 periods, reporting was made, through-the-electronic Food-borne Outbreak-Reporting-System (eFOR), that out of the 7,998 outbreaks, with a-known-etiolo-gy, 3,633 (45%) were caused by viruses; 3,613 (45%) - by bacteria; 685 (5%) - by chemical and toxic-agents; and 67 (1%) - by parasites (see Gould et al., 2010 for more-details).

The-Health-Canada and the-Public-Health-Agency of Canada also-estimate that every-year, between 11 and 13 million Canadians suffer from illnesses, caused by food-borne-contamination-agents (FSWSG, 2008). In 2005 there were 1,545 incidents of food-poisonings, reported in-Japan, and 86% of those were caused by bacteria or viruses (WHO, 2014). Besides, Campylobacter jejuni is identified as the-top-five of pathogens, causing most-food-related-infections, worldwide (Zwietering & van Asselt, 2005). In-the-Netherlands, for-instance, there are an-estimated 65, 000 campylobacteriosis-cases, per-year (Kemmeren et al., 2006).

Several-devastating-outbreaks of food-borne-diseases, such-as: salmonellosis, entero-haemorrhagic Escherichia coli (EHEC), choler, hepatitis A, and acute-aflatoxicosis, have occurred in-a-number of African-countries, relatively-recently. For-example, outbreaks of choler, in 2004, in 28 countries resulted in 85,807 cases, and 2,221 deaths. In 2005, reports from 30 countries indicated that 33,934 cases were recorded, and 1,161 deaths have occurred. During the 2004, an-outbreak of acute-aflatoxicosis, in-Kenya, reported 317 cases and 125 deaths. Another-outbreak, reported a-further 74 reported-cases and 28 deaths, in 2005 (FAO & WHO, 2005).

In-Kenya, food-poisoning, or food-borne-illness, is quite-prevalent. A-report by FAO & WHO (2005) indicates, that in 2004, the-following-incidences were observed, in-Kenya: gastroenteritis (722,275 cases), typhoid (643,151 cases), dysentery (600,660 cases), aflatoxin-poisoning (323 cases), dysentery (600,660 cases), brucellosis (198 cases), and cholera (56 cases). One of the-most-devastating water- and food-born-diseases is considered to-be a-choler, caused by one of the Vibrio cholerae species. Seven-global-pandemics, of this-contagious-disease, have been recorded, during-the last 200-years (Popovic et al., 1993). Over 100 serotypes of Vibrio cholerae exist, but generally the-toxigenic-strains of the-sero-group 01 cause choler, and possess documented-epidemic-potential. The-main-symptom of choler is a-profuse-diarrhoea, resulting-in dehydration, which, if untreated, leads-to death, within-hours. The-most-rapid-growth of V. cholerae 01 occurs in-moist and alkaline-foods. On-most-food, V. cholerae 01 can survive from 2 to 14 days, better at 5-10°C than at 30-31°C. V. cholerae 01 also-seems to-survive-better on cooked-rather-than on raw-food (Kolvin & Roberts, 1982).

According-to a-recent-report on Kenya, by WHO (2017): "The country experiences choler outbreaks every year; however, large cyclical epidemics occur approximately every five to seven years and last for two to three years". For-example, from 1st January through 29th November, 2017, 20 of 47 counties (43%) in-Kenya have reported-cases. As of 29th November, seven-counties (Embu, Garissa, Kirinyaga, Mombasa, Nairobi, Turkana, and Wajir) continue to-have active-choler-outbreaks. During-the-same-period, a-total of 3967 laboratory-confirmed and probable-cases, including 76 deaths (case-fatality-rate = 1.9%) were reported by the-Ministry of Health, Kenya to WHO. Of the-cases reported, 596 were laboratory-confirmed.

Up to 70% of diarrhea-cases, in-developing-countries, is said-to-be-caused, by pathogens, transmitted, through-food (Kumiko et al., 2009). In-Kenya, in-particular, approximately 88% of diarrhea-associated-deaths is attributable-to unsafe-water, inadequate-sanitation, and unsatisfactory-hygiene, during food-preparation and consumption (Abuga et al., 2017). However, according to Gachuki (2012) the-incidences of food-borne-diseases are not easy to-estimate, in-Kenya, as most of them are unreported or under-reported. In-the-same-line, Gould et al. (2013) points-out, that "food-borne-diseases are possibly 300-350 times more-frequent, than what is reported".

Although most-individuals fully-recover, food-borne-illnesses can result in-chronic-health-problems, in 2 - 3 % of cases. Illnesses, such-as chronic-arthritis, and hemolytic-uremic-syndrome (HUS) leading to kidney-failure, have long-term-consequences for the-affected-individual, and for the-economy, and the-society, as a-whole. For-example, Health-Canada estimates that the-annual-cost, related to these-illnesses, and related-deaths, is between 12 and 14 billion dollars (FSWSG, 2008).


Food-born-pathogens cross-contamination, from-surfaces-to-food, can contribute-to food-born-diseases (Miranda & Schaffner, 2016). These-diseases are caused by a-variety of etiological-agents, including: (i) Pathogenic-bacteria (e.g., Salmonella, Escherichia coli, or Shigella); (ii) Parasites (e.g., Cyclospora); (iii) Viruses (e.g., Norovirus); (iv) Fungi, protozoa, trematodes, and cestodes group; (v) natural-toxins (e.g., toxin-producing-organisms (i.e., Staphylococcus aureus or Bacillus cereus), and poisonous-plants); (vi) Chemicals (including heavy-metals), and (vii) Nematodes, among-others. Comprehensive-directory, of the-examples, of each-of the-listed-agents, can be-found-in WHO (2008).
Moreover, transfer of pathogens, around the kitchen-environment, has been shown in many previous domestic-based-studies (see, for example, Kennedy et al., 2005; Gorman et al., 2002; Hilton & Austin, 2000).

1.1.5. Survival-rates and multiplication of food-born-pathogens. According to Kramer et al. (2006), most gram-positive-bacteria, such as: *Enterococcus spp.*, (including VRE), *Staphylococcus aureus* (including MRSA), or *Streptococcus pyogenes*, survive for months on dry-surfaces. Many gram-negative-species, such as *Acinetobacter spp.*, *Escherichia coli*, *Klebsiella spp.*, *Pseudomonas aeruginosa*, *Serratia marcescens*, or *Shigella spp.*, can also survive for months. A-few others, such as *Bordetella pertussis*, *Haemophilus influenzae*, *Proteus vulgaris*, or *Vibrio cholerae*, however, persist only for days. Mycobacteria, including *Mycobacterium tuberculosis*, and spore-forming-bacteria, including *Clostridium difficile*, can also survive for months on surfaces. *Candida albicans* as the most-important fungal-pathogen can survive up to 4 months on surfaces. Persistence of other yeasts, such as *Torulopsis glabrata*, was described to be similar (5 months) or shorter (*Candida parapsilosis* 14 days). In general, gram-negative-bacteria have been described to persist longer, than gram-positive-bacteria. Humid-conditions enhanced persistence, for most-types of bacteria, such as *Chlamydia trachomatis*, *Listeria monocytogenes*, *Salmonella typhimurium*, *Pseudomonas aeruginosa*, *Escherichia coli*, or other-relevant-pathogens. Low-temperatures, e.g., 4°C - 6°C, also improved persistence of most-types of bacteria, such as *Listeria monocytogenes*, *Salmonella typhimurium*, *MRSA*, corynebacteria, *Escherichia coli*, *Helicobacter pylori*, and *Neisseria gonorhooeae*, among others.

Most-viruses, such as *corona*, *coxackie*, *influenza*, *SARS*, or *rhino-virus*, can persist on surfaces for a few-days. Other-viruses, such as astrovirus, *HAV*, *polio* or *rota* virus, persist for approximately 2 months. Blood-borne-viruses, such as HBV or HIV, can persist for more than one-week. Herpes-viruses, such as CMV or HSV type 1 and 2, have been shown to persist from only a-few-hours up to 7 days. The most-common-pathogens may well survive, or persist on surfaces, for months, and can, thereby be a-continuous-source of transmission, if no regular-surface-disinfection is performed (Kramer et al., 2006). A-low-temperature, such as 4°C - 6°C, was associated with longer-persistence for most-bacteria, fungi, and viruses. High-humidity (e.g., >70%) was also associated with longer-persistence for most-bacteria, fungi, and viruses (see Hayden et al., 2006; Noyce et al., 2006; Williams et al., 2006; Wilks et al., 2005; Neely & Maley, 2000; Maule, 2000).

On-the-other-hand, food-safety is a scientific-discipline, describing handling, preparation, and storage of food, in-ways, that prevent food-born-illness (Abuga et al., 2017). According to the discipline, bacteria are the most-common-cause of food-borne-outbreaks, since bacteria are microorganisms with high-reproductive-capacity. According to WHO (2014), bacteria multiply by a-method, called ‘binary-fission’, where one-bacterium becomes 2, and 2 bacteria become 4, etc. For example, *Vibrio parahemolytica* carries-out fission very quickly, and in conditions, which are good for the-bacteria-growth, it can undergo fission once every-eight-minutes. If each-bacteria splits-in-two, every-eight-minutes, after 3 hours there will be 4,200,000 bacteria and 68,919,470,000 bacteria after 5 hours!

From the above-information, it can be put-forward, that pathogens do not only survive, for a-long-time, on-the-surfaces, but they are also able to multiply, rapidly, while conducive-environment, such as temperature, moisture, pH, and oxygen, can speed-up the-growth of the-pathogens.

1.1.6. Poor-hygiene-practices, during food-preparation and consumption. World-Health-Organization (2008) estimates 40% of food-borne-disease-cases originate in the-home, either directly or indirectly, through-avenues, such cutting-board and knives (Gordon, 2018; Bloomfield & Nath, 2013). Analogous, most-countries report, that between 10% and 50% of food-born-diseases, are associated with private-home-environment (see Bloomfield & Nath, 2013; Redmond & Griffith, 2003; Medeiros et al., 2001), via a-range of contamination-routes (ADPHID, 2017), such as: cutting-boards; utensils (e.g., knives); counter-tops; surfaces (e.g., refrigerator-handles); food; and food-handler-hands.

According to van Asselt et al. (2008), up to 87% of the-sites, where food-born-diseases-outbreaks occur, are associated with foodstuffs, prepared or consumed in households, where about 40 - 60% of the cases of food-borne-diseases are caused by inadequate-food and -utensils handling-practices (de Jong et al., 2008), such as cross-contamination from cutting/chopping boards (Ravishankar et al., 2010; Luber, 2009; van Asselt et al., 2009; Parry et al., 2005; Kusumamangrum et al., 2004). A-finding from a-recent-study, reported by Abuga et al. (2017), states that consumer-food-hygiene and safety-kitchen-practices were as-low-as 42.9%. Additionally, failure to-acquire the-home as a-potential-location to-acquire food-borne-diseases may be a-serious-barrier, for implementation of safe-food-handling-practices (Abuga et al., 2017).

Surface-cross-contamination (for example via cutting/chopping boards) is the 6th most-common-contributing-factor (out of 32) for food-born-diseases (CDC, 2013; Gould et al., 2013; 2010). The next-subsection introduces this-food-contamination-route.

Cooking-utensils, including cutting-boards and knives, washed in-contaminated-water, or food, contaminated, during or after preparation, e.g., moist-foods, contaminated, during or after cooking or preparation,
and allowed to remain, at room-temperature, for several hours, provide an excellent environment for the growth of pathogens, e.g., *Vibrio cholerae* (World Health Organization, 2008). It is well-established that a high percentage of food-borne illness is caused by failure of consumers to prepare food in a hygienic manner. Indeed, a common practice in households is to use the same kitchen equipment and surfaces, for both, raw meat and fresh produce (Gkana et al., 2016). Microorganisms, attached to processing equipment and surfaces, may escape cleaning and sanitizing procedures, and proceed to contaminate processed product. Pathogens, originating with raw products can attach to food-preparation surfaces, which, if not adequately cleaned, before reuse, can serve to re-contaminate cooked foods (Frank, 2001). Figure 2 shows an example of indirect cross-contamination, where the same board and knife were used for raw meat and for raw vegetables (served as salad).

![Figure 2: Example of cross-contamination (FAO, 2017).](image)

Cleaning with cold-water and dish-soap, followed by vigorous scrubbing and rinsing, practices commonly followed in household kitchens, to clean cutting boards, may reduce, but not eliminate the risk of exposure to the pathogens (Soares et al., 2012). Hypochlorite disinfection, of cutting-board surfaces, is considered as the safest and most efficient method (Soares et al., 2012), however, many, if not all, households, are basically not aware of the dangers of inadequate cleaning and food cross-contamination. When utensils were not cleaned properly, after they were used, the transfer rate was 1.25% from poultry to plastic board surface and 45.62% from plastic and knives to lettuce.

From the common methods, used in cleaning of surfaces, at homes, studies have shown that water and soap, alone, are not enough, to ensure decontamination (Barker et al., 2003; Cogan et al., 2002; 1999; Scott & Bloomfield, 1990; 1993). To eliminate the cross-contamination route, it is important to use separate surfaces, or to properly wash the surfaces, during the preparation of raw and cooked foods, or ready-to-eat foods (Sampers et al., 2010; Cogan et al., 1999); therefore, in the context of this study, separate chopping boards, for raw and for cooked food, are preferable.

1.2. Research purpose and selected relevant issues.

1.2.1. Research purpose.

Poor hygiene, during preparation and/or consumption of food, in conjunction with the ability of food-borne pathogens to survive (for a long time), and also to multiply rapidly, can lead to food cross-contamination. Food cross-contamination, in turn, can lead to food-borne diseases, resulting in some cases, in: (i) severe sickness, or even death (either immediately, or shortly, after food consumption), or (ii) in increased risk of chronic diseases (e.g., Guillain-Barre syndrome, or rheumatoid arthritis (CAST)).

Food safety issues are receiving growing attention, worldwide, due to ever increasing incidence of food-borne diseases and their negative impacts on the public health, economy, and on the society, at large. Moreover, Luber (2009) points out that: “There is a focus in many countries to reduce the level of human illness from food-borne pathogens”. In the same spirit, this study is focused on a conceptual design of a kitchen utensils set of color-coded chopping boards and knives, to reduce food cross-contamination at private homes, as well as at food establishments. Universal design approach was applied, to design a food chopping boards set, with particular emphasis on the people with color blindness condition; the next sub-sections provide the background details.
1.2.2. Selected-relevant-issues.

1.2.2.1. Chopping-boards and materials, used in their-fabrication.

A-cutting, or chopping-board, is a-durable flat-board, on which to-place a-product/material, for cutting. The kitchen-cutting-board is commonly used in-preparing-food, and it-is also-called food-chopping or food-cutting-board, is an-indispensable kitchen-utensil. Such-boards are often made-of different-materials (see selected-examples in Figure 3), and come in-various-shapes and sizes.

With-regard-to materials, stainless-steel has often-been-considered the-optimal-material-choice for commercial-food-preparation-surfaces, because of its-resistance-to corrosion and chemical-degradation, mechanical-strength, and ease of cleaning (Wilks et al., 2006), although stainless-steel may have higher-bacterial-transfer-rates than other-surfaces (Wilks et al., 2005; Robine et al., 2002). A-study by Soares et al. evaluated four-types of materials, used-as cutting-surfaces, for food-handling: pine-wood; triclosan-treated- plastic; tempered-glass, and stainless-steel. Among the-surfaces analyzed, wood was considered to-be the-most-difficult to-clean, while stainless-steel was the-easiest (Soares et al., 2012).

Figure 3: Selected-examples of the-Materials used for chopping-boards.

Keys: 1 - Stainless-steel; 2 - Acrylic; 3 - Granite; 4 - Marble; 5 - Teak; 6 – Bamboo; 7 - Walnut; 8 – Acacia.

In-particular:

(i) Wood is, somewhat, self-healing; shallow-cuts in-the-wood will close-up, on-their-own. Wood also has natural-anti-septic-properties. On-the-other-hand, wood is intrinsically-porous, which allows food-juices and bacteria, to-penetrate the-body of the-wood; the-moisture is drawn inside, in-by-the-capillary-action, until there is no more free-fluid on the-surface, at which-point immigration ceases. Bacteria, in the-wood-pores, are not killed instantly, but neither do they return to the-surface (Cliver, 2006; Abrishami et al., 1994). Hard-woods, with tightly-grained-wood and small-pores, are best for wooden-cutting-boards, which help to-reduce absorption of liquid and dirt, into-the-surface. There are different-types/species of wood, which are used for cutting-boards (Aviat et al., 2016; Xi et al., 2013; Milling et al., 2013), for-example:

Acacia cutting-board is often-labeled as the-top-choice for this-kitchen-item; usual-maintenance (oiling), however, is required, to-prevent them from splitting. Acacia is a-highly-sustainable-wood; it has the-appeal of bamboo, but without the-need for international-export.

Walnut cutting-board is the-most-expensive of the-wood-cutting-boards, walnut is a-strong and durable-material, however it needs maintenance with oil, regularly, otherwise, they can develop very-deep-cracks, making it unhygienic.

Teak cutting-board; Teak, a-tropical-wood, contains tecto-quinones-components of natural-oily-resins, which repel moisture, fungi, warping, rot, and microbes. Teak is also-known for being a-very-durable and water-resistant-form of wood, and for this-reason, it is a-popular-choice for cutting-boards. Although little-pricy, due-to-its-density, there is minimal-scarring and scratching done, to-it, when used for food-chopping. Besides, teak-cutting-board does not require oiling; Teak-wood’s tight-grains and natural-coloration make it a-highly-attractive cutting-board-material, both; for aesthetic and durability-purposes. It is important to-note, however, that there are
cutting-boards, made from African-Teak or Rhodesian-Teak, which despite the-name, are not made from the-same-species of wood.

Cherry cutting-board has softer-texture, which, on-one-hand, will be helpful in-protecting knives from damage, but it may also-cause more-damage to the-wood, itself. These-boards should never be submerged in-water, or placed in a-dishwasher, just like the-other-wood-varieties. Another-issue is that the-board should be at-least 2 inches, in-thickness, as it can crack easily; regular oiling, proper-washing, and disinfection are needed.

(ii) Bamboo, although commonly-listed under ‘wood’, strictly-speaking is not a-wood; the-distinguishing-features is that bamboo grows very-fast, while wood not, also these-materials have fundamentally-different internal-structure. Bamboo-cutting-boards are considered to-be-naturally-anti-microbial; they can be produced, from multiple-pieces, by lamination. Bamboo has long been a-popular-alternative for wood, in-many-areas, not just with cutting-boards. The-biggest-concern, however, is the-sustainability of the-material. Compared to most-woods, bamboo has a-very-fast re-growth-rate, making it ideal for a-range of products. As most-bamboo is sourced in-China, there is an-issue of questionable-labor-practices, and the-energy-spent, to-transport the-product, cancelling-out the-sustainable-factor. In-terms of cutting-board-quality, bamboo will require some-maintenance, as it can be quite-hard-to-the-touch, and is prone-to splitting and cracking.

(iii) Plastic-boards are usually-called PE (polyethylene) cutting-boards, or HDPE (high-density-polyethylene-plastic), can be made from injection-molded-plastic, or from an-extrusion-line. Polyethylene-cutting-boards have-been-around, for many-years; and proven to-be the-cheapest and effective-types. Most-HDPE-boards are specifically-designed not to-dull the-edge of a-knife. High-density-polyethylene, which is the-most-used in commercial-applications, has been shown to-delaminate, in-response-to knife-scarring (Gkana et al., 2016; Cliver, 2006).

(iv) Marble cutting-boards are known for being one of the-most-hygienic-forms, due-to their-non-porous nature, and ease of cleaning; however, they can do some-damage to the-knives, because of their-tough-surface.

(v) Granite is another visually-pleasing-material-choice for cutting-boards, however such a-board will dull the-knives, and it can be noisy, during food-chopping.

(vi) Maple cutting-board is considered to-be the-most-expensive, on-the-other-hand it will not damage the-knives, and will help to-prolong its-life significantly. Cleaning a-maple-cutting-board is relatively-simple, and is it non-porous-material, hence fewer-bacteria and less-water can seep through.

(vii) Stainless-steel cutting-boards are not as-common-as the-previously-mentioned-types. Steel-boards are durable and easy to-clean; they do not warp or swell, like some-wood varieties can, and there is no need to-oil them, or perform any-other-maintenance. However, these-boards can damage the-knives significantly and also cause them to-slip, on the-surface, during use. Besides, the-sound of a-knife, against stainless-steel, particularly when chopping quickly, is not pleasant.

(viii) Acrylic cutting-board is cheap and effective, it is probably be the-second-choice, after polyethylene; such a-board can be submerged in-water, or even washed in-the-dishwasher, hence, it is very-easy to-maintain, however, it should-be sanitized, and replaced every 12 months; making it an-expensive-option.

(ix) Rubber boars are as-expensive-as well-made-wooden-boards, and in-addition they do smell. They can withstand chemical-disinfectants, and they are very-heavy for their-size, so they tend not to-slip. Besides, they exhibit self-healing-properties.

(x) Like-rubber, silicone is soft on the-knife-blade, while being just as self-healing and anti-bacterial, as-wood. Silicone is also heat-resistant, and lacks the-rubbery-smell of rubber-boards, but it is expensive.

(xi) Glass cutting-boards are easily-cleaned and they are more-hygienic, however, they can damage knives, harsh-noises are produced, while in-operation, and due-to their-slick and hard-surface, a-knife can easily-slip, while cutting, and cause a-potential-hazard in-the-kitchen. Also glass-board can be easily broken, especially during washing. In-general, glass-cutting-boards are likely-going-to-do more-harm than good.

Numerous-materials can be used, to-produce chopping-boards; each has its-advantages and limitations. For-example, wood, in-general, is said, to-dull knives, less-than plastic, and plastic is seen as-less-porous, than wood (Cliver, 2006); the-wooden-boards, however, should be-regularly oiled, by edible-mineral-oil, to-avoid warping and splitting. Besides, wooden-cutting-boards do not get cuts, as-deep-as plastic. This means the-bacteria cannot become trapped, and will dry-out, eventually. The USDA’s Food-News for Consumers recommended strongly that plastic, not wooden, cutting-boards be used in consumers’ kitchens. However, a-study by Ak et al. (1994), indicates, that wood had some-sort of antibacterial-effect, which was not found in-plastic.

1.2.2.2. Universal-design concept.
Universal-Design (UD) means the-design of products, environments, programs, and services, to-be usable by all-people, to-the-greatest-extend-possible, without the-need for adaptation or specialized-design (Vanderheiden, 1997). Seventeen-percent of the-U.S.A.-population has some-form of disability (ADA, 2010; Erickson & Lee, 2003), numbers are similar, worldwide; besides, probability of people developing a-disability increases-with-age.
As the population of people with disabilities grows, so does the ethical and economic pressure, to provide that population with products, which offer services and value. Nevertheless, many product designers and companies are unfamiliar with approaches to applying UD (a term, commonly used to describe goods and services, which are usable both by persons with a disability and by typical users (McAdams & Kostovich, 2011)). Universal design is an active research area; nevertheless, formal methods for the design are limited in scope (Danford, 2003; Preiser & Ostrovski (Eds.), 2001; Bowe, 2000). UD is used interchangeably with inclusive design (the term, which mainly used in the United Kingdom (Goodman et al., 2006)), meaning that the design can be used, equally well, by people of any ability: in other words, it does not discriminate against users, based on their ability. In addition, each of the Trans-generational, Rehabilitation-design, and Adaptable-design, do share common elements with UD (Erlandson, 2008; Connell, 1997; Hewer, 1995; Peloquin, 1994).

This study applies UD concepts and principles, with particular emphasis on people with color blindness condition.

### 1.2.2.3. Color blindness condition.

Color blindness, also known as color vision deficiency, is the decreased ability to see color, or to differentiate colors (to a certain degree or completely) (NEI, 2015; Gordon, 1998). Color blindness does not mean, however, that a person can only see black and white. Two major types of color blindness are: (i) difficulty distinguishing between red and green; and (ii) difficulty distinguishing between blue and yellow. Based on clinical appearance, color blindness may be described as total or partial; while total color blindness is much less common, than partial color blindness (Hoffman, 2008; Spring et al., 2007; Neitz, 2007).

According to Blom (2009); Shevell (2003); and Stiles & Wyszecki (2000), total color blindness (‘monochromacy’) is a very rare condition, in which, people only see different tones and brightness levels, with no color, at all. Although the term may refer to acquired disorders, such as cerebral achromatopsia, also known as color agnosia, it typically refers to congenital color vision disorders (i.e., more frequently rod monochromacy, and less frequently cone monochromacy) (EIZO, 2006).

- The various types and characteristics of partial color blindness (Wong, 2011; Simunovic, 2010; McIntyre, 2002) are: (i) Anomalous Trichromat (a mild shift in the sensitivity of the cones); (ii) Protanomaly (shades of red appear weaker in depth and brightness); (iii) Deuteranomaly (shades of green appear weaker); (iv) Tritanomaly (a very rare condition, in which shades of blue appear weaker); (v) Dichromacy (severe deficiency or complete absence of one of the types of cones); (vi) Protanopia (shades of red are greatly reduced in depth and brightness, if they can be seen, at all); (vii) Deuteranopia (shades of green are greatly reduced in depth and brightness, if they can be seen, at all); and (viii) Tritanopia (a very rare condition, in which shades of blue are greatly reduced in depth and brightness, if they can be seen, at all).

Color blindness affects a large number of individuals, with protanopia (red deficient: L cone absent) and deuteranopia (green deficient: M cone absent) being the most common types. In individuals with Northern European ancestry, as many as 8% of men, and 0.4% of women, experience congenital color deficiency (Chan et al., 2014). Likewise, according to the Howard Hughes Medical Institute, in the United States, about 7% of the male population, or about 10.5 million men; and 0.4% of the female population either cannot distinguish red from green, or see red and green, differently from how others do (HHMI, 2006). Color blindness or color vision deficiency also affects about 2.7 million people in Britain. In Australia, around 8% of the male population is color blind, compared to around 0.4% of the female population. The ability to see color also decreases in old age.

Being color blind may make people ineligible for certain jobs, in several countries. This may include being a pilot, train driver, traffic police officer, and working in the armed forces (NEI, 2015; Wong, 2011). Regardless of the types, rights of the color-blind people have been protected, in some states; for example, according to the Decree, issued by president of a republic, ratifying Legislative Decree No. 198, of June 13, which approved the Inter-American Convention/AG/RES. 1608, “A Brazilian court ruled that people with color blindness are protected by the Inter-American Convention on the Elimination of All Forms of Discrimination, against Person with Disabilities”, e.g., the carriers of color blindness have a right of access to wider knowledge, or the full enjoyment of their human condition. In the United States, however, under federal anti-discrimination laws, such as “the Americans with Disabilities Act”, color vision deficiencies have not yet been found to constitute a disability, that triggers protection from workplace discrimination (Larson, 2016; Zhang, 2014).

This study assumes that color blindness is a sort of disability; universal design approach, to be used, to consider the condition, by incorporating easy recognizable symbols, since colors of the chopping boards and cutting knives, cannot be distinguished, by the people with color blindness.

### 2.0. Materials and Methods.

The aim of this research was to design a cost effective, easy producible, user-friendly, and reliable kitchen utensils set, that can be used to reduce food cross contamination. The design followed steps of the fundamental Engineering Product Design (see Starovoytova, 2019a; b; 2018); **Figure 4** shows the chronological steps,
Figure 4: The chronological steps, performed during this study.

In particular:

**Review of cross-contamination mechanism** was done by the examination of the available published literature on the subject matter.

**Evaluation of chopping boards designs** was conducted by the desk study approach and by non-participant observation. Selected relevant patents, as well as similar products, available locally and internationally, were analyzed. In particular, a non-participant observation, across the various local supermarkets, within the locality of Eldoret town, Uasin-Gishu county, and online market platforms such as Jumia and Kilimall, were conducted, to determine the availability of chopping board sets; inclusion of knives in the sets; availability of labels; and different materials, used in their fabrication, among other issues.

**Selection of PRD** was done via comparative analysis of the results, obtained from the previous step, by identification of the most advanced set (at the time of the study), and most suitable (for this unfunded study) design.

**Examination of limitations of PRD** was done by the critical inspection of the PRD, as well as from the available reviews, expressed by some users of the set, at the official cite of the product (see, for example: https://www.josephjoseph.com/en-rw/index).

**Development of four design alternatives** were done by the individual design team members; the end result is four hand sketches. Besides, some preliminary calculations were done, at the same time, which might be required to substantiate ideas and to establish approximate sizes.

**Selection of the best design alternative**; this study used a standard Engineering Design Weighted Decision Matrix (EDWDM), to select the best design alternative. In addition, analogous to Starovoytova (2019 a; b) and Starovoytova & Namango (2016), to confirm the choice, additional method, of selection of best design alternative, was used, namely ‘D & R method’.

**2D drawing** of the best design alternative, was created via computer aided design (CAD) AutoCAD software, while Autodesk Inventor- Version: 2016 (Build 200138000, 138) was used for 3D modeling.

**Preliminary materials selection**; materials selection plays an essential role in the product design process (Doordan, 2003), where 4 elements (function, shape, materials, and manufacturing processes) do interact. Ashby & Johnson (2003; 2002) identify four materials selection methods: (i) Analysis; (ii) Synthesis; (iii) Similarity; and (iv) Inspiration method. This study adopted the analysis method, where a list of product requirements is translated into material objectives and constraints. The main objectives, of the intended set, was used as a guide, in materials selection. Besides, the study adopted the interaction of function, materials, shape, and manufacturing processes, from Ashby (1999), and the interaction of use, function, materials, and shape, from Roozenburg & Eekels (1995).
3. Results.
3.1. Examination of available-designs.

Figure 5 shows selected examples of different food-chopping boards, available in the local supermarkets, while Figure 6 demonstrates the array of products, available online.

![Figure 5: Most common food-cutting boards, available at selected local supermarkets.](image1)

**Keys:** 1 - wooden; 2 - plastic; 3 - bamboo.

![Figure 6: Selected examples of boards, available for purchase, online.](image2)

**Keys:**
- **Upper row** (Left – “Ultra Thin Fruit Vegetable Chopping Board Anti-Bacteria Mat Kitchen Tool” (set of 4); Right – “Wheat Straw Cutting Board Gourmet Chopping with Grinding Garlic Tool” (set of 4).
- **Lower row** (Left – “2 In 1 Creative Foldable Cutting Board with Storage Basket Box for Cooking Tool”; Middle – “Multifunctional Drainage Plastic Chopping Board”; Right – “Expandable Chopping Board”).

The assessment revealed, that: (i) none of the patents, examined, have featured a complete set of color-coded boards and knives; (ii) Local supermarkets, mostly offered individual food-chopping boards (no sets), besides, none had knife-provision; and (iii) Selected products, available on-line, were pricey, especially for people in developing countries, like Kenya.

3.2. Point of Reference for the design (PRD), and its limitations.
Following critical assessment of available designs, this study has chosen Joseph Joseph Index™ Color Coded Chopping Boards set, as a point of reference for the current design (due to its uniqueness and appropriateness, to prevent/limit food cross-contamination. Joseph Joseph Index™ Color Coded Chopping Boards set, designed by
Damian Evans, and since its-launch, in 2008, has been a-worldwide-best-seller (at USD 50); Figure 7 shows the-PRD.

**Figure 7:** Joseph Joseph Index™ Color Coded Chopping Boards (set of 4)

**Keys:** Red – for raw-meats; White - cooked-food; Blue - raw-sea-products; Green - raw vegetables and fruits.

**Figure 7** shows contemporary ABS-storage-case with a-non-slip-base; Boards are stored in-staggered-order, for visual-ease; Illustrated-tabs/labels provide at-a-glance-reminder, which board is which. Besides, the-operational-manual indicates that, boards are dishwasher-safe.

### 3.3. Identified-limitations of the-PRD.

Several-limitations of the-Joseph-Joseph Index™ Color-Coded Chopping-Boards (set of four) were identified (by the-physical-observations and from the-product-users-review-blog), and in-particular: (1) the-boards, inside the-casing, are touching each-other, hence, there could be-cross-contamination from one-board to the-neighboring one(s); (2) no drainage-perforations, at the-bottom of the-set, which could lead-to moisture-accumulation, within the-set; (3) no knife, or knives, included in the-set; (4) protruding-labels tend to-wear-out and become less-visible (as they are used to-get the-boards out of the-casing), hence, losing its-primary-function; (5) according to Ergonomic-design-principles, pinch-grip, used to-get the-boards from the-casing, is much-weaker than the-power-grip (see Starovoytova, 2018), making the-set un-agronomical; (6) There are no board-handles, hence it-is rather-difficult to-removed individual-boards, from the-casing; and (7) no provision for a-separate-board, specifically for raw-poultry-meats (according to the-Oxford-Dictionary (2018), poultry is the-inclusive-term for chicken, turkey, and duck-meat, as-well-as pheasants, and other-less-available-fowl).

### 3.4. Generation of the-design-alternatives.

This-study is based on the-major premise, that according-to Gkana *et al.* (2016): “Separate-cutting-boards and knives, should-be-used, for processing raw-meat and preparing ready-to-eat-foods, in-order-to-enhance food-safety”. In-particular, the-current-design is to-address the-identified-above-limitations, by incorporating: (i) separation-plates, between the-boards, inside the-casing; (ii) perforations, within the-removable-bottom of the-casing; (iii) five-colour-coded-knifes, matching colours of each-of the-five-boards; (iv) a-permanent-labels (engraved) on the-boards, knives, and the-set-casing; and (v) ergonomically-designed-handle for the-board. Where, *Separation-plates* (vertical-plates, running-through opposite-sides of the-casing, whereby on one-side they cover the-whole-surface, while on the-other-side they cover halfway, with the-side-left open); *Perforations* (a-series of small-holes, which cover the-whole-bottom-surface of the-casing); *Basement* (a-separate-block with a-compartment for holding draining-water, which can be attached, or detached, from the-main-casing-interface); *Labels* (well-embossed-symbols on a-slanted-surface on one-side of the-casing, and on every board and knife); *Board withdrawal* ( the-boards are laid in-such a-way, that the-handles protrude the-outside-surface, of one-side of the-casing, and their-withdrawal is in-a-horizontal-manner); and *Knife-inclusion* (the-knives are placed in-incompartment-block, within the-casing, which has small-open-spaces, upon which the-cutting-blades of the-knives can be inserted).

Several-other-issues were also-taken into-account, during the-design-stage, of this-study. First, it was considered, that any-device usually comprises of various-parts. The-utilitarian or functional-part is the-one that truly-performs basic-task, which prompts the-execution of the-segment. The-non-functional-part does not have real-work in-segment-presence, but rather it needs to-do-with support, spreads, examination, and aesthetical-worth,
and therefore, the number of non-functional parts should be reduced, to cut the cost (Juvinall & Marshek, 2012; Budynas-Nisbet, 2008).

Besides, the designed set, should be: (i) manufacture-able/easy-producible (using locally-available equipment and expertise; and being able to be easily and effectively-colored, in five distinct colors); (ii) cost-effective; (iii) soft; and light-weight; (iv) reliable; structurally-sound; and durable. And, as explained above, be functional, hence, components which are not important/functional should be eliminated.

Moreover, the device should be: Efficient (in reducing food cross-contamination); Functional (easily-maintained, user-friendly); Pleasant, in appearance (suitable size and shape, attractive design, good finishing); Durable (not easily broken, stable, and robust-design, strong sound structure); and Safe (harmless to the user, no side-effects, and environmentally-friendly). To achieve these criteria, structurally, all the components should: (a) be symmetrical (and have polar geometry mark), if possible, as this also helps in manufacturing; (b) have consistency, in the dimensions, used for feeding, orientation, and location; and (c) have location points (see Starovoytova, 2019a for more details).

Lastly, the following account will try to justify the decision, made by the design team, that one additional board (for poultry raw meat), is necessary. While numerous potential vehicles of food-borne transmission exist, poultry meat has been identified as one of the most important food vehicles for the food-borne diseases (Silva et al., 2011; FAO & WHO, 2009). Salmonellosis and Campylobacteriosis are among the most frequently reported food-borne diseases, worldwide (Bollaerts et al., 2008), and Enteritidis is the main serotype responsible for human infections (Moore et al., 2007; Pang et al., 2007; Oliveira et al., 2006). According to Shu-Kee et al. (2015), Salmonellosis accounts for 93.8 million food-borne illnesses, and 155,000 deaths, per year. Although only 20–40% of the food-borne diseases cases are associated with chicken meat, consumption of chicken is still the predominating factor for Campylobacteriosis (Humphrey et al., 2007). Illnesses via chicken meat can occur either by undercooking or by cross-contamination.

From the results of a study by Adetunji & Isola (2011), it can be concluded that the cross-contamination, between raw and processed foods, by surface contact is hazardous, because Salmonella can adhere to the surface, and form a bio-film, resulting in a source of contamination. In addition, a relatively recent study revealed that two-thirds of consumers failed to adequately wash hands, after handling raw chicken, nearly 30 percent failed to wash, or change the cutting board, after cutting raw chicken, and one-third failed to wash, or change a knife, used to cut raw chicken meat, before cutting raw vegetables (WHO, 2006; 2002).

Salmonella pathogen is a rod-shaped, Gram-negative facultative anaerobe, which belongs to the family Enterobacteriaceae (Barlow & Hall, 2002). To date, over 2500 Salmonella serotypes have been identified, and more than half of them belong to Salmonella enterica subsp. enterica, which accounts for the majority of Salmonella infections in humans. In human infections, the four different clinical manifestations are: (i) enteric-fever, (ii) gastroenteritis, (iii) bacteraemia, and other extraintestinal complications, and (iv) chronic carrier state (Sheorey & Darby, 2008). Salmonella infection contributes to the economic burden of both; industrialized and developing countries, through the costs, associated with surveillance, prevention, and treatment of the disease (Majowicz et al., 2010; Crump et al. 2004).

The four design alternatives, generated by the design team, are shown in Figure 8.

**Figure 8:** Hand sketched four design alternatives.

### 3.5 Selection of the best design alternative.
Alternative design # 4 was selected, via standard EDWM, with the highest score of 0.82; while Alternative # 1 scored 0.53; Alternative # 2 – 0.47, and Alternative # 3 – 0.65.

### 3.6 Description of the best design alternative, including its 2D drawing and 3D modeling.
Regarding the dimensions of the set, the cutting board size acts as the primary determinant of the sizes of other components of the designed set, board dimensions (L x B x T) of 30 cm × 20 cm × 10 mm were chosen (as one of the most common board sizes, currently used, worldwide).
Figure 9 shows two-dimensional drawing of the main elements of the set, with sizes; Figure 10 demonstrates the set-assembly of the best-alternative-design, while Figure 11 shows colour-coded boards and the position of labels; Figure 12 and Figure 13 show labels/symbols and dimensions of the set-components, respectively.

![Figure 9: 2D drawings of the main elements of the design-set.](image1)

**Figure 10: Set-assembly of the best-alternative-design.**  
**Keys:** 1 - Basement; 2 - Stand; 3 – Boards (five); 4 – Knifes (five); 5 – Separation-plates; 6 – Labels/symbols; 7 – Handle of the board; 8 – Perforations (see Figure 13 for details)
Labels (positioned on each-board and each-knife, as-well-as on the-set itself, as an-inclined-panel) were introduced, to-cater for the-people with color-blindness (according to-the-fundamental-principles of the-Universal-design), and also to-avoid-confusion (as a-reminder which board is which, to all-users).

**Figure 11:** Color-coded-boards and the-position of labels.

1 – Blue (raw sea-food); 2 – Green (raw fruits and vegetables); 3 – Yellow (raw-poultry); 4 – Red (raw meat); 5 – Brawn (cooked food).

**Figure 12:** Labels/symbols.

**Keys (left to right):** Blue (for Raw-Fish); Brown (for Cooked-food); Yellow (for Raw-poultry); Red (for Raw-meat); and Green (for Raw-fruits and vegetables).

The-engineering-materials of mechanical and structural-engineering fall-into the-broad classes/families (Asby, 2010; 2005), such-as: (i) Metals (the-metals and alloys); (ii) Polymers (the-thermoplastics and thermo-sets); (iii) Elastomers (engineering-rubbers, natural and synthetic); (iv) Ceramics, technical-ceramics (Fine-ceramics capable of load-bearing-application), and Ceramics, non-technical (porous-ceramics of construction); (v) Glasses; and (vi) Hybrides (hybrids: composites; hybrids: foams; and hybrids: natural-materials).

According-to Ashby (2004), the-very-first-consideration, in-materials-selection, is on the-functionality of the-material; the-main-goal here is being-able to-produce products that function effectively, safely, and at-acceptable-cost. The-functionality relates three-aspects, namely: (i) the-function of design-component (what it does), (ii) its-objective (intended-achievement), and (iii) constraints (limits to performance). In-this-study, the-function of cutting-board is to-aid in-food-chopping-operations, with main-objective being elimination /reduction of food-cross-contamination. The-most-essential (and hence important)-constraint, in the-initial-consideration of materials-selection, in-this-study, is the-ability of a-material to-be-dyed/colored in five-solid-colors (so-called ‘color-coding’). Besides, a-knife-edge is a-delicate-structure, and can easily-be-blunted by a-surface, which is too-abrasive. A-good-cutting-board-material, hence, should be-relatively-soft, easy to-clean, and non-abrasive, but not fragile, to the-point of being-destroyed. A-good-cutting-board-material should be also less-porous, to-prevent moisture-absorption, which facilitate bacteria thrive and cracks. Other-constraints include manufacturability, cost, porosity, health and safety-issues, etc.
This study adopted so-called ‘screening’ approach to materials-selection, where (Dobrzanski, 2001) elimination of materials starts by comparing their-attributes and limits, set by constraints, hence, if limits are not met, the material is eliminated. Only 2 material-suitable groups of materials were pre-selected, namely: (i) Polymers/plastic; and (ii) Hybrids: Composites. Afterwards, the composites-group was eliminated, due to lack of composites-manufacturing-equipment and expertise, in Kenya, leaving the group of polymer/plastics uncontested.

It is important to note, however, that there are over 60 materials in the ‘polymer/plastic’ group. Figure 14 shows a comparative-property chart, for selected plastic materials. The main properties for comparison, used here, are: cost (should be as minimum as possible), moisture absorption (low), and tensile strength (high).

From the chart, it can be observed that polyethylene materials are superior, based on cost and moisture absorption properties; however, it is not a clear-cut, as they are of lower tensile strength. The polyethylene materials were selected, for further screening; their background information follows.

Polyethylene or polythene (abbreviated PE; IUPAC name polyethene or poly(methylene)) is the most common plastic. As of 2017, over 100 million tons of polyethylene resins are produced annually, accounting for 34% of the total plastics market. Polyethylene is classified by its density and branching. Its mechanical properties depend significantly on variables, such as: the extent and type of branching, the crystal structure, and the molecular weight. There are several types of polyethylene (Kurtz, 2015): (i) Ultra-high molecular weight polyethylene (UHMWPE); (ii) Ultra-low molecular weight polyethylene (ULMWPE or PE-WAX); (iii) High molecular weight polyethylene (HMWPE); (iv) High-density polyethylene (HDPE); (v) High-density cross linked polyethylene (HDXLPE); (vi) Cross linked polyethylene (PEX or XLPE); (vii) Medium density polyethylene (MDPE); (viii) Linear low density polyethylene (LLDPE); (ix) Low density polyethylene (LDPE); (x) Very low density polyethylene (VLDPE); and (xi) Chlorinated polyethylene (CPE).
PE is usually a mixture of similar polymers of ethylene, with various values of \(n\). Polyethylene is a thermoplastic; however, it can become a thermo-set plastic, when modified (such as cross-linked polyethylene). Polyethylene is of low strength, hardness and rigidity, but has a high ductility and impact strength, as well as low friction. It shows strong creep, under persistent force, which can be reduced by addition of short fibers. It feels waxy, when touched. The commercial applicability of polyethylene is limited by its comparably low melting point. Higher crystallinity increases density and mechanical and chemical stability. Polyethylene absorbs almost no water.

The gas and water-vapor-permeability (only polar gases) is lower than for most plastics. In particular, selected data/properties for PE, are:

- Chemical formula: \((C_2H_4)_n\)
- Density: 0.88–0.96 g/cm
- Melting point: 115–135 °C (239–275 °F; 388–408 K)
- \(\log P\): 1.02620 (data are given for materials in their standard state (at 25 °C [77 °F], 100 kPa) (Geyer, 2017; Kurtz, 2015; Batra, 2014).

Considering that there are 11 types of polyethylene; the study recommends to further investigating which polyethylene type is the most appropriate for this particular design set.

4. Discussion.

As mentioned earlier, a substantial proportion of food-borne diseases has been linked to poor food preparation and hygienic practices, in the home (Redmond & Griffith, 2003). Cutting boards are recognized as possible sources of cross-contamination, with pathogens, as well as spoilage bacteria (Cliver, 2006; Carpentier, 1997). Bacteria may grow, or survive, for a long-time on cutting boards, which may subsequently be a source for contamination of ready-to-eat foods (Todd et al., 2009). Surveys show inadequate handling of cutting boards (lack of or insufficient cleaning) for 30–90% of consumers (Redmond & Griffith, 2003). Common cleaning procedures, used by consumers, at home, may not be sufficient to completely remove pathogens from contaminated cutting boards (Cogan et al., 2002). According to the Food Protection Trends (2004), bacteria, on a cutting board, can double, after 10 minutes of use, whether cutting raw meat or vegetables. The discrepancy, between knowledge and practices, shows that consumer education is not enough, to prevent unsafe practices, and has provided a market for products with claimed antimicrobial activity (Aider, 2010; Marambio-Jones & Hoek, 2010; Monteiro et al., 2009; Moretro et al., 2011; 2010; 2006). The global antimicrobial compounds (AMCs) market is estimated to be worth USD 3 billion, and projected to grow to USD 4.5 billion, and 590 kilotons, by 2020 (Grand View Research, 2013). Commercially available AMCs can be divided (Rosenberg et al., 2019) into:

1. Powder coatings, which can be electro statically layered to various surfaces, and
2. Surface modification coatings, that interact with application surface and confer protection against pathogens. They can be applied to surfaces via spraying, draw-down method, thin-film coating, and spin coating (Grand View Research, 2013).

In recent years, antimicrobial polymers and coatings have gained interest, from both academia research and as industrial products, due to their potential to provide higher quality life and safety. Antimicrobial and antibacterial agents are materials, capable of killing pathogenic microorganisms. Surface modification that
effectively kills microbes, on-contact, without releasing a biocide, represents a modern and efficient approach, toward continuous and permanent-solids-materials. The undesirable growth of microorganisms, on-solid-surfaces, that is, bio-fouling, or bio-contamination of surfaces, represents an important threat in diverse surface-settings, for example, medical-implants (Hetrick & Schoenfisch, 2006); water-purification (Nguyen et al., 2012); or food-storage and preparation (Hannon et al., 2017). Substances and food-contact-materials are antimicrobial-materials, if they realize “a reduction of Colony Forming Units (CFU) > 2-log” (Moerman, 2013).

The antimicrobial-compound may be incorporated throughout the-materials, or added, as a-coating, on the-surface of the-material. The antimicrobial-agents can be organic and inorganic-origin.

**Inorganic** antimicrobial-agents, including: (i) Silver - containing antimicrobial-materials (e.g., Silver-ions; Silver-bearing stainless-steel; and Silver-nano-particles); (ii) Copper - containing antimicrobial-materials (e.g., Copper-ions, Metallic-copper, Copper-alloys, Copper-bearing stainless-steel, Copper oxide nano-particles); (iii) Zinc - containing antimicrobial-materials (e.g., Zinc-ions, Zinc-oxide nano-particles); and (iv) Titanium - containing antimicrobial-materials (e.g., Titanium, Titanium-dioxide, Titanium-dioxide nano-particles).

**Organic** antimicrobial-agents include: Triclosan N-halamine containing surfaces; Quaternary ammonium-compounds immobilized on surfaces; Organosilane quaternary ammonium-compounds; and N-alkylated-polyethyleneamines.

For more details, on each, of the-listed-above-agents, see Moerman (2013).

A hydrogel is the most important family of hydrophilic-adhesion-resistant coatings. A hydrogel is a three-dimensional (3D) network of hydrophilic-polymers that can swell in-water, and hold a large amount of water, while maintaining the-structure, due to chemical or physical-cross-linking of individual-polymer-chains. By definition, water must constitute at least 10% of the total-weight (or volume) for a material to be a hydrogel (Bahrami et al., nd; Wichterle & Lim, 1960). There are four major categories of polymers and coatings, such as (Baghdachi et al., 2015): (i) polymeric-coatings, with QA-groups; (ii) polymers with quaternary-phosphonium-groups; (iii) norfloxacin containing-polymers; and (iv) polymeric-N-Halamines-group.

Besides, Triclosan is considered for a polymer-additive, with multiple-properties, to be an antimicrobial, with additional benefits, as a non-polar toughening-agent, and a hydrophobic-wetting-agent (Petersen, 2016). Triclosan, 2, 4, 4′-trichloro-2′-hydroxydiphenyl-ether, has broad-spectrum antimicrobial-effect, acting through multiple mechanisms at high-concentrations, while inhibiting fatty-acid-synthesis at sub-lethal-concentrations (Jones et al., 2000; Levy et al., 1999). It has broad-spectrum activity at low-concentrations, to inhibit both; gram-positive and gram-negative bacteria, and also different virus and fungus (SCCS, 2010; CSC, 2001). Triclosan has been used as an antimicrobial-agent for almost 50 years, clinically and in consumer-products, such as cosmetics, toothpaste, and plastics. Triclosan has multiple bacterial-target-sites for damage, depending on concentrations. Triclosan is bacterio-static to prevent microbes from growing at low-concentrations, by inhibiting an enzyme, involved in fatty-acid-synthesis. On the other-hand, triclosan is bactericidal, to kill microbes, directly, at higher concentrations, by destabilizing bacterial-membranes, and also by introducing intercalating-defects into a bacterial-membrane. It can be incorporated by-mixing into a resin-system, before cure, melt-mixed with thermoplastic-polymers, which set on cooling, into- a-solid, or alternatively applied as a coating, through several different methods (Petersen, 2014; NICNAS, 2009; Villaláñ et al., 2001).

In general, the antibacterial-products are marketed as an improved hygiene barrier. There is growing concern, however, regarding increased use of products, containing antimicrobial-compounds, especially in the domestic-sector. One of the reasons, behind the concern, is fear of development of antimicrobial-resistance (Aiello et al., 2007; Gilbert & McBain, 2001, 2003; Levy, 2001), which is yet to be confirmed.

Furthermore, the results of this unfunded concise study (of preliminary nature), are largely relatively positive, providing a good starting-point, for further and much deeper study, on the same. Next-logical-step, would be a detailed-design, which can be generated, using 3D-solid-modelling CAD-programs, such as SolidWorks. Additionally, according to Ui et al. (2002), the emphasis of the design-decisions, avoids shifting away from technology, towards the user-interaction aspects, to cope with the new appreciations of consumers, for the aesthetic values of materials. Several studies, investigated the relation, between materials and user interaction qualities, of products, and how users appraise materials. Selected studies also try to classify the visual and touch-dimensions of different materials (see Smith et al., 2008) and, even, the sound-dimensions, while in operation (see Ui et al., 2002).

Moreover, the current (conceptual) design is rather uncomplicated, hence, EDWDM was considered to be sufficient, during selection of the best-design-alternative. At a later (detail-design-stage) additionalmethods, such as: PuCC; AHP (Analytic-Hierarchy-Process); and TRIZ (Theory of Inventive Problem Solving) should be applied (see Starovoitova, 2019a; 2019b; Renzi et al., 2017; Starovoitova, 2016; 2015; Starovoitova et al., 2015, Mansor et al., 2014; 2013).

After selecting the most appropriate material, the further studies should also select the appropriate process, to manufacture the final set. A process is a method of shaping, finishing, or joining a material. The manufacturing-processes of Engineering fall into nine broad classes; process classes (Asby, 2010; Ashby &
Cebon, 2007) are: (i) Castig (sand, gravity, pressure, die, etc.); (ii) Pressure molding (direct, transfer, injection, etc.); (iii) Deformation processes (rolling, forging, drawing, etc.); (iv) Powder methods (slip cast, sinter, hot press, hp); (v) Special methods (CVD, electroform, lay-up, etc.); (vi) Machining (cut, turn, drill, mill, grind, etc.); (vii) Heat treatment (quench, temper, solution treat, age, etc.); (viii) Joining (bolt, rivet, weld, braze, adhesives); and (ix) Surface finish (polish, plate, anodize, paint). The following matrices and charts by Asby (2010) can be used, to select most-appropriate-process: (a) The-Process-Material matrix; (b) The-Process-Shape matrix; (c) The-Process-Mass-range chart; (d) The-Process-Section-thickness chart; (e) The-Process-Tolerance chart; (f) The-Process-Surface-roughness chart; and (g) The-Process-Economic-batch-size chart.

5. Conclusion and Recommendations.
Poor hygiene, during preparation and/or consumption of food, in conjunction with the ability of food-borne pathogens to survive (for a long-time), and also to multiply, rapidly, can lead to food cross-contamination. Food cross-contamination, in turn, can lead to food-born diseases, resulting in some cases, in: (a) severe sickness, or even death (either immediately, or shortly, after food-consumption), or (b) in increased-risk of chronic diseases (e.g., Guillan-Barre syndrome, or rheumatoid arthritis (CAST)). This study has accomplished all its objectives, by re-designing the PRD and incorporating six important-upgrading, to reduce food cross-contamination, in the new product-design. The study, however, was purely conceptual in nature; and, hence, it further recommends to: (1) carry out a detailed design (by incorporating the user-interaction-aspects and using more advanced methods, such as PuCC; AHP, and TRIZ, in selection of the best design alternative); (2) select a specific material (out of the group, identified by this study, via Ashby charts and matrices); (3) choose a mode of fabrication of the set; (4) examine the possibility of incorporating AMCs; (5) fabricate the prototype(s); (6) conduct explorative use ability trial(s); and (7) analyze the marketing aspect of the final set.

This work is potentially beneficial to engineering product design students and faculty, as well as to households and food establishments (subject to successful implementation).

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