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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-knifes, 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 of 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 accidently, 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-micro-flora, infected-food, animals, and human-excreta. Ball *et al.* (2013) outlines

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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 of 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.

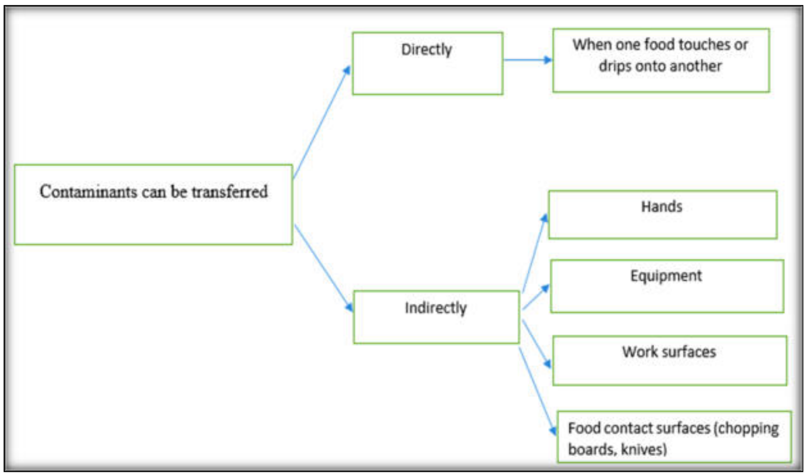

Figure 1: Cross-contamination-channels.

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/cm^2 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-

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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 (eFORS), that out of the 7,998 outbreaks, with a-known-etiology, 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), cholera, hepatitis A, and acute-aflatoxicosis, have occurred in-a-number of African-countries, relatively-recently. For-example, outbreaks of cholera, 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), afflatoxin-poisoning (323 cases), brucellosis (198 cases), and cholera (56 cases). One of the-most-devastating water- and food-born-diseases is considered to-be a-cholera, 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 cholera, and possess documented-epidemic-potential. The-main-symptom of cholera is a-profuse-diarrhoea, resulting-in dehydration, which, if untreated, leads-to death, within-hours. The-most-rapid-growth of *V. cholerae* Ol 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-resent-report on Kenya, by WHO (2017): ”The country experiences cholera 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-cholera-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).

1.1.4. Food-born disease-causing-agents.

Food-born-pathogens cross-contamination, from-surfaces-to-food, can contribute-to food-borne-diseases (Miranda & Schaffner, 2016). These-diseases are caused by a-variety of etiological-agents, including: (i) Pathogenic-bacteria (e.g., *Salmonell*a, *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 *Listeria monocytogenes*, *Salmonella typhimurium*, *MRSA, corynebacteria, Escherichia coli*, *Helicobacter pylori,* and *Neisseria gonorrhoeae,* among-others.

Most-viruses, such-as *corona*, *coxsackie*, *influenza*, *SARS,* or *rhino*-virus, can persist on surfaces for a-few-days. Other-viruses, such-as astro-virus, *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-borne-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; Kusumaningrum *et al.,* 2004). A-finding from a-resent-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-associate 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-6^{th} most-common-contributing-factor (out of 32) for food-borne-diseases (CDC, 2013; Gould *et al.,* 2013; 2010). The-next-sub-section introduces this-food-contamination-route.

Cooking-utensils, including cutting-boards and knifes, 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).

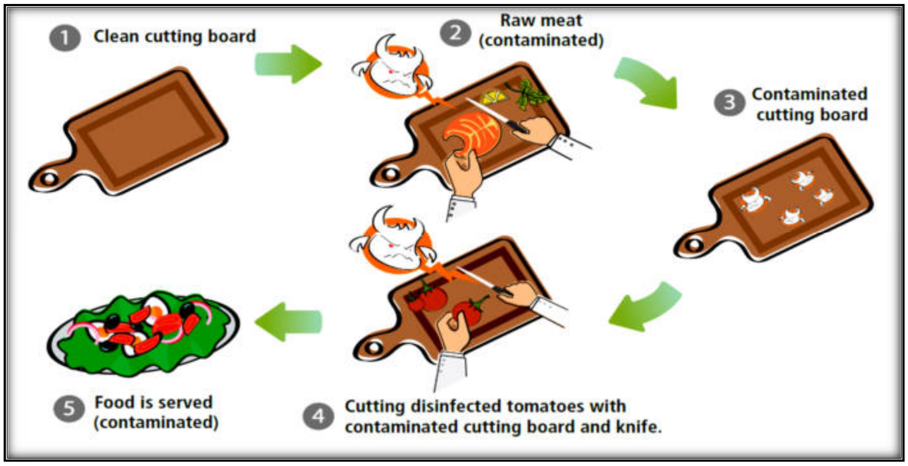

Figure 2: Example of cross-contamination (FAO, 2017).

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 de-contamination (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-born-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., Guillan-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 knifes, 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).

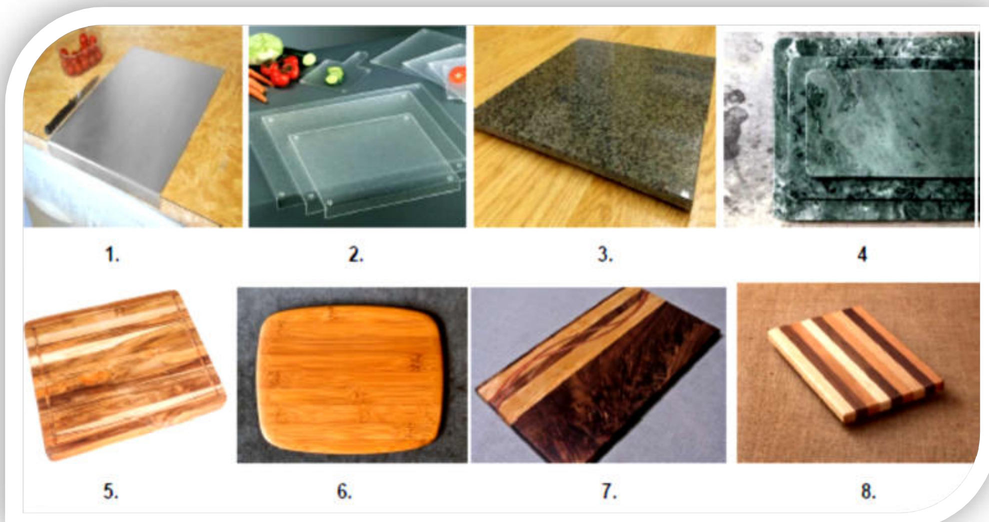

Figure 3: Selected-examples of the-Materials used for chopping-boards.
Keys: 1 - Stainless-steel; 2 - Acrylic; 3 - Granite; 4 - Marble;
5 - Teak; 6 – Bamboo; 7 - Walnut; 8 – Acacia.

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-knifes, 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 polyethene; 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-extent-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 & Ostroff (*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 as 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-Trichromacy* (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 8.0% 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 a-disability; universal-design-approach, to-be-used, to-consider the-condition, by incorporating easy-recognizable-symbols, since colors of the-chopping-boards and cutting-knifes, *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,

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performed during this-study.

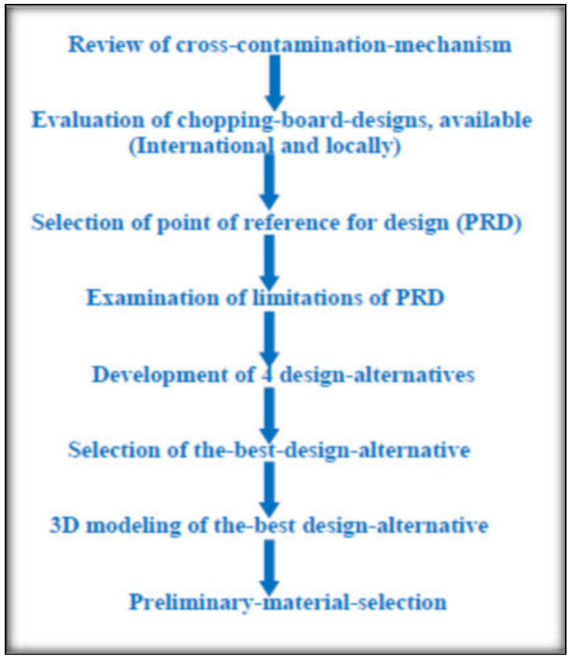

Figure 4: The-chronological-steps, performed during this-study.

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) AutoCADsoftware, 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 Asbhy (1999), and the-interaction of use, function, materials, and shape, from Roozenburg & Eekels (1995).

3. Results.

3.1. Examination of available-designs.

A-number of relevant-International-patents (developed by individuals, as-well-as design-companies) were reviewed; examples included: US 9,155.427 B1 (2015); US D655,939 S (2012); US 8.220,789 B2 (2012); US D638,265 S 5 (2011); US 8,070,148 B2 (2011); US 7,681,871 B2 (2010); US14814 A1 (2010); US 2007 23 A1 8 (2009); US 0146353 A1 (2009); US 0080487 A1 (2007); US 0001359 A1 (2007); US 19221 A1 (2004); US 0046301 A1 (2004); and US 0195763 Al (2002).

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

Figure 5: Most-common food-cutting-boards, available at-selected-local-supermarkets.
Keys: 1 - wooden; 2 - plastic; 3 - bamboo.

Figure 6: Selected-examples of boards, available for purchase, on-line.
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 knifes; (ii) Local-supermarkets, mostly-offered individual-food-chopping-boards (*no* sets), besides, none had knife-provision; and (iii) Selected-products, available on-line, were pricy, 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 knifes, 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-remove 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, knifes, 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-compartment-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-born-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, gnerated by the-design-team, are shown in **Figure 8**.

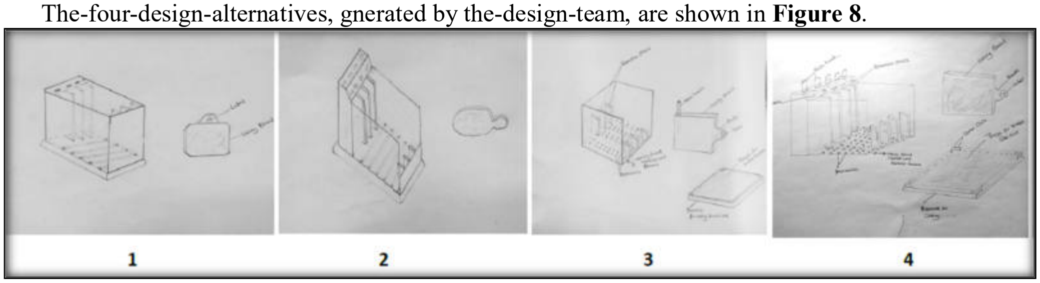

Figure 8: Hand-sketched four-design-alternatives.

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 30cm × 20cm × 10mm 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-corded-boards and the-position of labels; **Figure 12** and **Figure 13** show labels/symbols and dimensions of the-set-components, respectively.

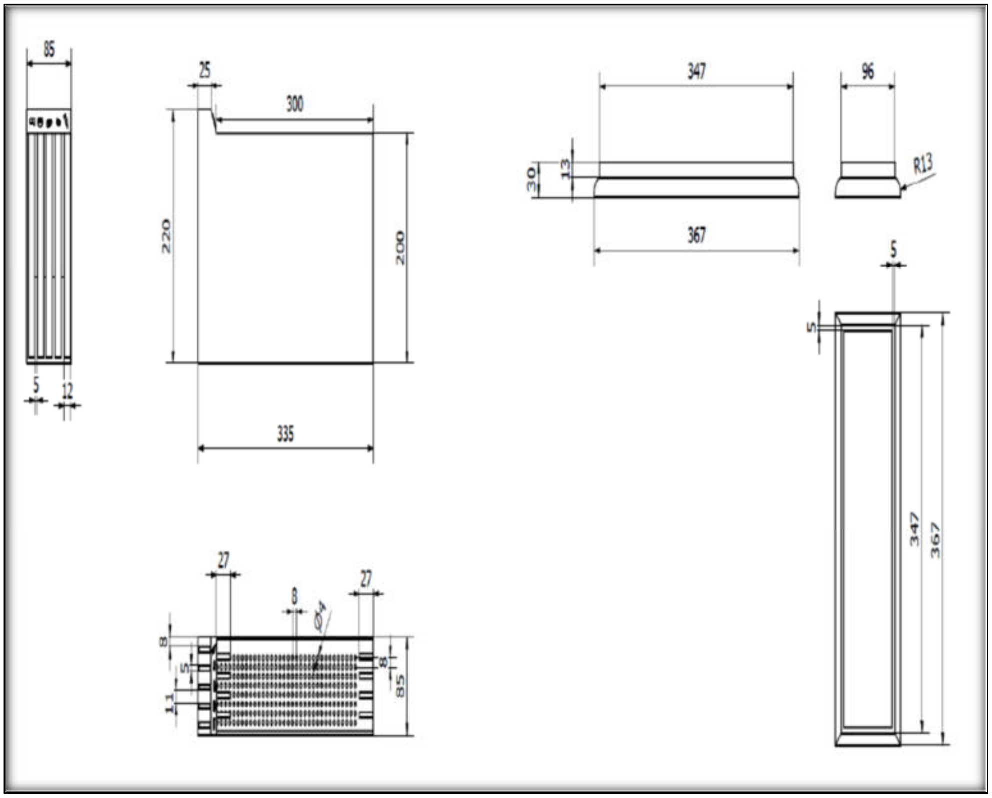

Figure 9: 2D drawings of the-main-elements of the-design-set.

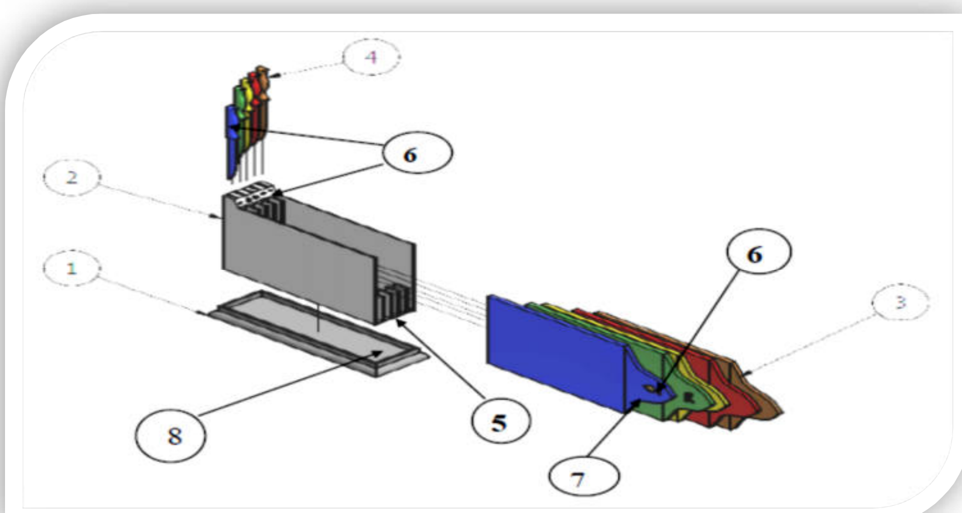

Figure 10: Set-assembly of the-best-alternative-design.
Keys: 1 - Basement**; 2 -** Stand**; 3 –** Boards (five)**; 4 –** Knifes (five);
5 – Separation-plates**; 6 –** Labels/symbols**; 7 –** Handle of the-board**;**
8 –Perforations (see **Figure 13** for details)

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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).

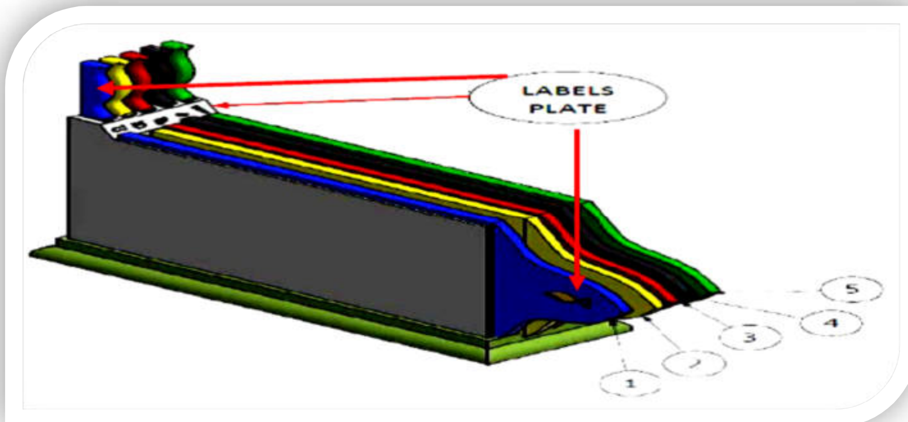

Figure 11: Color-corded-boards and the-position of labels.
1 – Blue (raw sea-food); **2** – Green (raw fruits and vegetables); **3** – Yellow (raw-poultry);
4 – Red (raw meat); **5** – Brawn (cooked food).

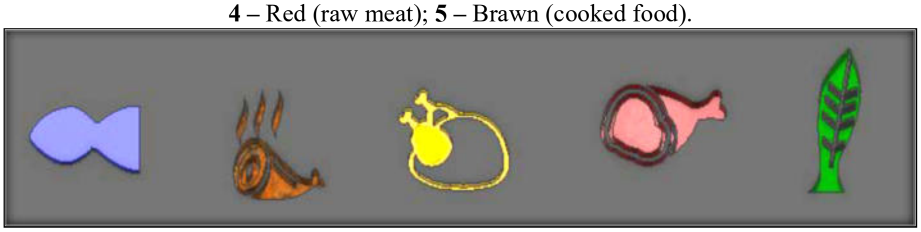

Figure 12: Labels/symbols.
Keys (*left to right*): Blue (for Raw-Fish); Brown (for Cooked-food); Yellow (for Raw-poultry);
Red (for Raw-meat); and Green (for Raw-fruits and vegetables).

3.7. Materials-selection.

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) *Hybrids* (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-able 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.

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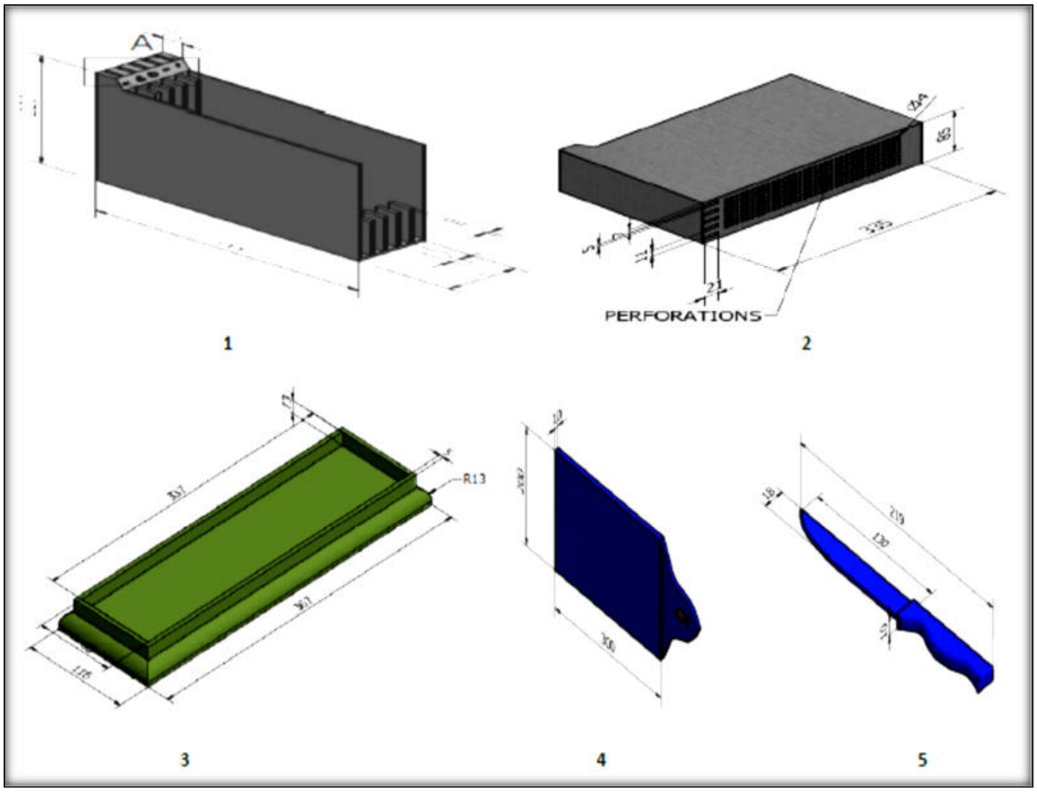

Figure 13: Dimensions of the-set-components.
Keys: 1 – Stand; **2 –** Perforations in the-basement**;**
3 – Basement; **4 –** Board; **5 –** Knife.

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).

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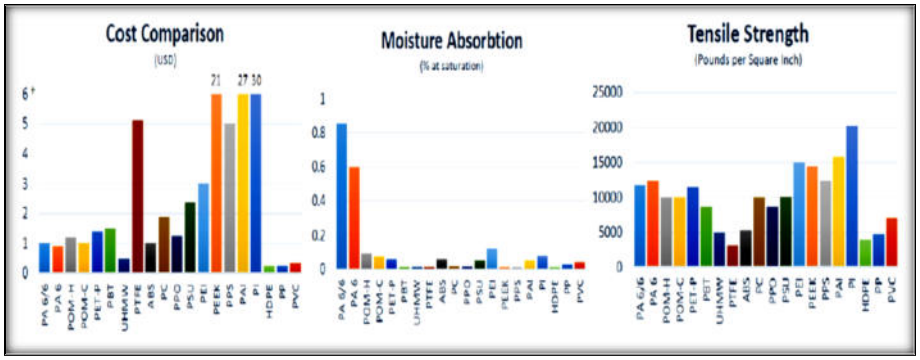

Figure 14: Plastics-polymers
(Precision Punch & Plastics manufacturing-company, U.S.A.)

Keys:

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-crystalinity 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: (i) *powder-coatings*, which can be electro-statically-layered to various-surfaces, and (ii) *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-sterile-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 of 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-polyethyleneimines.

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

Hydrogels 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 (Bahram *et al., nd;* Wichterle & Lím, 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; Villalán *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-modeling CAD-programs, such-as SolidWorks. Additionally, according to Ui *et al.* (2002), the-emphasis of the-design-decisions, unavoidably shifts-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) additional-methods, such-as: PuCC; AHP (Analytic-Hierarchy-Process); and TRIZ (Theory of Inventive-Problem-Solving) should-be-applied (see Starovoytova, 2019a; 2019b; Renzi *et al.,* 2017; Starovoytova, 2016; 2015; Starovoytova *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) *Casting* (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, hip); (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-matrixes 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 is 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 matrixes); (3) choose a-mode of fabrication of the-set; (4) examine the-possibility of incorporating of 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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