

# Doctoral thesis

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## Doctoral thesis – Textiles

Development of model for predicting ultraviolet protective properties of woven fabrics+

**Author: Kostajnshek Klara**

Mentor: Dimitrovski Krste

The aim of the doctoral dissertation was to develop a fast and efficient method for predicting the UV protective properties of fabrics already in the stage of planning and designing. We established a mathematical model to calculate and predict the UV-protective properties of fabrics, using transmittance (KT), reflection (KR) and absorption (KA) coefficients of ultraviolet (UV) radiation. The model is based on our extended cover factor theory by using the geometrical properties of monofilament polyester fabrics. The model was first validated on monofilament polyester fabrics by comparing the theoretical values calculated according to the model with previously measured values of the UV radiation parameters. The results show high correlations ( $r > 0.98$ ) and small differences between the theoretical and measured values, indicating the high model efficiency. Moreover, the results confirm the theoretical assumption that the coefficient of UV transmission of the fabric area covered with two yarns ( $K_{2T}$ ) is approximately equal to the power function of the coefficient of UV transmission of the fabric area covered with one yarn ( $K_{1T}^2$ ), and that the coefficient of UV absorption of the fabric area covered with two yarns ( $K_{2A}$ ) is approximately equal to the square root of the coefficient of UV absorption of the fabric area covered with one yarn ( $\sqrt{K_{1A}}$ ). Apart from developing a new model, we also defined a new method to determine maximum density, which is also based on the extended version of the cover factor theory. This method was used to determine the constructional parameters and parameters of UV radiations that are necessary for using the model. For its broader use, the model was also validated on a series of single- and double-layer thread systems, using uncoloured raw polyester (PES) rotor yarn and coloured cotton (CO) ring yarns in two different counts. For that purpose, the method for preparing single-layer or double-layered thread systems with uniform density was developed. PES samples differed in the number of twist yarn and thread density, while CO samples differed in colour and density of the thread. Open area and yarn diameters were determined using image analysis. In both cases, the results show high correlations ( $r > 0.94$ ), small differences between theoretical and measured values, and confirm the before mentioned theoretical assumption. Taken together, the results clearly show high efficiency of our model and practical importance, since it can be used to develop and produce protective clothing.

Tailoring of smart textiles using temperature and pH responsive hydrogel as a carrier of antimicrobial substances+

**Author: Štular Danaja**

Mentor: Tomšič Brigita

The aim of the research was to develop new temperature and pH responsive smart textile materials with

simultaneous controlled porosity, moisture management and pro-active antimicrobial protection, provided by controlled release of antimicrobial substances and bio-barrier formation. Hydrogels based on poly-N(isopropylacrylamide) and chitosan with micro-(PNCS\_M) and nano-size (PNCS\_N) particles were synthesized using dispersion polymerisation. The particle size of PNCS hydrogels influenced their responsive properties. On the fibre surface, PNCS\_M hydrogel showed better pro-active porosity and moisture management properties and greater temperature sensitivity, while PNCS\_N hydrogel showed superior moisture release and greater pH responsiveness. The 30-second oxygen plasma treatment of fibres improved adsorption and distribution of the PNCS\_N hydrogel on fibre surface, which improved the desired temperature and pH responsive properties of functionalised samples. In order to achieve the proactive antimicrobial activity, different antimicrobials, i.e. AgCl, colloidal silver and savory (*Satureja montana*) essential oil (EO) with the working mechanism based on controlled release, or 3-(trimethoxysilyl) propyl-dimethyltetecyl ammonium chloride (Si-QAC) and (3-aminopropyl) triethoxysilane (APTES) with the working mechanism based on the formation of a bio-barrier, were incorporated into the PNCS hydrogel particles. An excellent antimicrobial activity and temperature related controlled release of silver was achieved, although the presence of silver compounds repressed the temperature and pH-related moisture management of samples. For the embedment of the hydrophobic savory EO into hydrogel particles, PNCS hydrogel with incorporated  $\beta$ -cyclodextrins (PNCS/CD) was synthesized. The latter improved the temperature responsive properties of the hydrogel and allowed an increase in the chitosan concentration, which resulted in the synergistic antimicrobial activity provided by the bio-barrier formed by chitosan and a pro-active release of the savory EO. When combining PNCS hydrogel and Si-QAC or APTES, the application procedure, concentration and the chemical composition of polysiloxane matrix greatly influenced the responsive and protective properties, as well as the cytotoxicity of functionalised samples. The two-step application procedure, including the application of first PNCS\_M hydrogel and then 0.5 % Si-QAC, ensured an excellent antimicrobial activity, although the sample showed high cytotoxicity. When Si-QAC was replaced with a 4% concentration of APTES, an excellent antimicrobial activity, noncytotoxicity and preserved responsiveness were obtained. The electrospinning procedure was used for the formation of composite PNCS\_M hydrogel and PLA fibres with stimuli responsive properties and pro-active release of the ultraviolet (UV) dye.

Development and transformation of the textile industry in slovenia in the second half of the 20th century+

**Author: Cerar Estera**

Mentor: Stankovič Elesini Urška

The aim of the doctoral thesis is to investigate factors that influenced the development of the textile industry in the territory of Slovenia from the end of WWII until Slovenia's independence. Researching the history of the textile sector in relation to the activities and various political interests and pertinent decisions contributes to a better understanding of the conditions that resulted in the decline of this formerly prosperous industry. The research illustrates the importance of the textile industry, both for Slovenian as well as for the Yugoslav economy, highlights the relation of politics to the industry and the reasons for its downturn. Moreover, it demonstrates that the quality of products was anything but inferior to that of the more developed "West". The research is based on archive materials, periodicals and other written sources. The methods applied, including

analysis, synthesis, description and compilation, helped us support three hypotheses. Individual chapters give insight into political and general economic conditions in the second Yugoslavia, planning policy, currency exchange policy, import-export policy and the operation of the textile industry in the individual planning period, the main products, employees, ways of working, equipment and machinery, investments, the degree and rate of modernisation and the basic problems in the industry (low education structure, low wages, night shifts for women, slow rate of modernisation). In addition, it illuminates the relations among various industries as well as relations between individual republics and federal authorities. The central part of the general overview concludes with a timeline illustrating the most relevant influences, which had either a positive or a negative impact on the development of the textile industry in Slovenia. The hypothesis that the textile industry was a very successful sector in the second half of the 20th century but hindered by the outflow of money into other sectors was confirmed. We also confirmed the second hypothesis, that the textile industry could have been preserved on a larger scale under different economic and political circumstances. However, the third hypothesis, that by timely restructuring more companies and posts could have been saved, was only confirmed in part because the final verdict would require additional information.

Applicable properties of textiles with integrated aerogel composites+

**Author: Kraner Zrim Polona**

Mentor: Rijavec Tatjana

The present thesis describes the applicable properties of a newly developed laminate of commercially-produced silica aerogel composite called Pyrogel@2250 and a nonporous membrane called SympaTex®, which is reinforced with polyester warp knitted fabric. The silica aerogel composite turns to dust when crushed during flexing and was thus laminated on both sides to prevent direct skin contact and the spreading of aerogel dust into the environment. The laminate was characterized for its morphological structure, thickness, mass per unit area, stiffness, tensile properties, delamination, water vapor permeability, thermal conductivity and thermal resistance. The newly developed laminate was compared to other materials which are usually used as isolative materials in footwear. The thermal conductivity of the laminate amounted to 16 mW/m·K. and the water vapor permeability to 1.31 mg/cm<sup>2</sup>·h. The laminated silica aerogel composite was subjected to 30,000 cycles of flexing. It was discovered that flexing had no significant effect on the thermal resistance and water vapor permeability, but it increased the tendency of delamination and deteriorated its tensile properties. Because of the high stiffness a sectional construction of the laminate was introduced to make it suitable for the use in footwear. To study the influence of sections, samples of laminated silica aerogel composites with different proportion and distribution of sections inside of the aerogel composite were prepared. Sections did not have an impact on the water vapor permeability, but they lower the thermal resistance. In the final part of the research different samples of laminated aerogel composites were prepared in a three dimensional form as an insulative layer in footwear. The thermal resistance and water vapor permeability of the new laminate and reference samples as well as on reference footwear were measured on a foot manikin. The thesis confirms that the newly developed laminate is suitable for introduction in protective footwear designed for use in environments with extremely low temperatures.

Preparation of functional polyamide textiles with increased thermal stability+

**Author: Šehić Alisa**

Mentor: Barbara Simončič

In the doctoral dissertation, functional polyamide textiles with increased thermal stability were prepared by three processes of chemical modification of polyamide 6

(PA6) fibers, by sol-gel application of combination of flame retardants 9,10-dihydro-9-ox-10-phosphaphenanthrene-10-oxide-modified vinyl trialkoxysilane (DOPO-VTS) and tetraethoxysilane (TEOS) onto flat textiles, with melt spinning process of filament yarn samples with incorporated flame retardant (FR) additives melamine cyanurate (MeCy), aluminium diethylphosphinate (ALPi), sodium aluminosilicate (SASi), carbon nanotubes (CNT) and carbon black (CB), and melt spinning of the newly synthesized PA6 copolymer with a directly included flame retardant group DOPO (PA/DCA) on the polyamide chain. The results indicate that the presence of the sol-gel finishing DOPO-TEOS reduced PA6 decomposition rate and favored char formation, which confirms an increase in thermo-oxidative (TO) stability. The presence of the coating reinforce the fibre structure, stopped melt dripping but did not prevent the burning of PA6. FR additive MeCy had the biggest flame retardant influence on the PA6

filament yarns by decreasing the onset temperature of thermo-oxidative and increasing char stability at 800 °C. The presence of MeCy completely stopped the flaming combustion of the filament. While SASi and CB interacted with MeCy, the addition of ALPi and CNT in a mixture with MeCy inhibit flame retardant properties of MeCy and only slightly improve TO stability of composite filament yarn samples. The presence of DOPO in copolymer caused a decrease of the onset temperature of the TO-decomposition of PA/DCA, a decrease of the decomposition temperature of the first step of degradation, and a slight increase of the temperature of the decomposition of the second step compared to PA6 and influence in the reduction of amount of residue. This indicates the operation of DOPO in the gas phase. The burning time of the PA/DCA copolymer yarn sample was significantly reduced compared to the burning of PA6 yarn, but the dripping melt of the copolymer was not self-extinguishing. These results were not as good as on films prepared from PA/DCA, where the dripping melt of the copolymer did not burn. The addition of all FR additives increased the degree of crystallinity of the yarn and slightly reduced its tensile properties.

Tailoring the multifunctional protective properties of textiles with plasma and sol-gel technology+

**Author: Vasiljević Jelena**

Mentor: Barbara Simončič

The aim of this doctoral dissertation research was to use the nanotechnology processes of plasma surface pre-treatment and sol-gel finishing to impart long-lasting novel multifunctionalities, i.e., low-adhesion super-hydrophobicity, oleophobicity, self-cleaning properties, flame-retardancy and antibacterial properties, to textiles. The plasma surface activation and etching of cotton and polyester fibres by low-pressure water vapour and oxygen plasmas were used as a pre-treatment to improve the water- and oil-repellent performance as well as the durability of the sol-gel coatings. The used sol-gel treatments were (i) the surface deposition of Stöber silica particles followed by their in situ growth of the TEOS-based particle-containing polysiloxane layer to create the rough, bumpy surface topography of the fibre surface, and (ii) the fabrication of the organo-functionalized hybrid coatings using fluoroalkyl-functional oligosiloxane (FAS) and 1H,1H,2H,2H-perfluorooctyltriethoxysilane (SiF) for water- and oil-repellency, P,P-diphenyl-N-(3-(trimethoxysilyl)propyl) phosphinic amide (SiP) and 10-(-

-trimethoxysilyl-ethyl)-9-hydro-9-oxa-10-phosphaphenanthrene-10-oxide (Si-DOPO) for flame retardancy and 3-(trimethoxysilyl)-propyldimethyloctadecyl ammonium chloride (SiQ) for antibacterial properties. Furthermore, organocyclotetrasiloxane 2,4,6,8-tetrakis(2-(diethoxy(methyl)silyl)ethyl)-2,4,6,8-tetramethyl-cyclotetrasiloxane(T4) was used to increase the coating's orientation and adhesion. The water vapour and oxygen plasma pre-treatments improved the water- and oil-repellency performance of the FAS and SiF coatings formed on the cotton fibre surface, respectively; however, they did not markedly influence the coating's adhesion ability, thus not improving the washing fastness of the coatings. In contrast, in the case of polyester fibres, although the water vapour plasma pre-treatment did not influence the water and oil repellency of the FAS coating, the washing fastness of the coating was markedly improved. Both Si-DOPO and SiP increased the thermo-oxidative stability of the cotton fibres and retarded glowing combustion. Compared to Si-DOPO, SiP provided an approximately two-fold higher total quantity of dry solid add-on at the same concentration of the applied sols and provided very high hydrophobicity. Therefore, an approximate 2-fold lower concentration of SiP compared to that of the Si-DOPO provided a comparable thermo-oxidative stability. The water- and oil-repellent, antibacterial, and flame-retardant properties of the SiF, SiQ and SiP precursors were successfully associated in the multifunctional two-(SiF-SiP and SiF-SiQ) and three-component (SiF-SiQ-SiP) organofunctionalized polysilsequioxane coatings formed on the cotton fibre surface. The cooperative action of the SiF, SiQ and SiP components in the three-component coating provided the cotton fabric with exceptional and novel multifunctional properties, including simultaneous high hydrophobicity (water static contact angle of 135°), oleophobicity (n-hexadecane static contact angle of 117°), antibacterial activity (bacterial reduction of 100 % for both *E. coli* and *S. aureus*), enhanced thermo-oxidative stability and "glow" retardancy. Creation of the roughened, bumpy surface topography by the surface deposition of Stöber silica particles followed by the in situ growth of the TEOS-based particle-containing polysiloxane layer was a highly efficient pre-treatment for improving the water- and oil-repellency performance and washing fastness of the FAS coating. This procedure enabled the fabrication of the long-lasting "Lotus effect" accompanied by an exceptionally high oleophobicity. The structure of the multifunctional three-component water- and oil-repellent, antibacterial, and flame-retardant hybrid polysilsequioxane coating was optimised to increase its washing fastness to cotton fibres. By including T4 as the fourth component in the multifunctional SiF-SiQ-SiP coating, the washing fastness of the coating was increased, and this was even more pronounced if silica particles followed by the in situ growth of the TEOS-based particle-containing polysiloxane layer were deposited on the cotton fibre surface in the pre-treatment process. The structural optimisation also led to the improvement of the functional properties of the coating, which exhibited the "Lotus effect" (water static contact angle of 161° and water roll-off angle of 4°) and simultaneously demonstrated high antibacterial activity (the R values for *E. coli* and *S. aureus* were 81.6 and 100 %, respectively), enhanced thermo-oxidative stability and "glow" retardancy. The only weakness of the optimised coating is the impairment of its oleophobicity.

Enzymatically assisted bleaching of textiles+

**Author: Špička Nina**

Mentor: Forte Tavčer Petra Eva

The research of the present doctoral thesis is divided in three parts. In the first part a complete enzymatic pretreatment of cotton fabric was developed which functions on the basis of simultaneous application of different enzymes which are compatible with each other. A mixture of  $\alpha$ -amylases, amyloglucosidases and pullulanases enzymes catalyses the degradation of a sizing agent that is made from starch into glucose. The

GOD enzymes catalyse the oxidation of gained glucose. During this enzymatic reaction hydrogen peroxide is generated. With the addition of pectinases enzymes simultaneous scouring is carried out. The bleaching is performed with bleach activator TAED. When TAED reacts with hydrogen peroxide peracetic acid is formed to bleach the present fabric. The whole pretreatment is carried out for 2 hours at a temperature 50 °C in a slightly acidic and neutral bath. The advantages of a such pretreatment lie in the short process time and in the reduced water and energy consumption. Cotton fabrics of adequate absorbency, high tenacity and high DP are obtained while the achieved whiteness is medium. In the second part of the research it was found out that the new enzymatically assisted bleaching process with arylesterase enzymes has a powerful bleaching ability in mild process conditions i.e. in neutral bath and at temperature 65 °C. After bleaching a higher whiteness is obtained on the alkaline scoured fabric compared to the enzymatically scoured one. Enzymatic scouring and bleaching with arylesterase enzymes can be effectively combined in a one-bath process. A short final treatment at 85 °C contributes to a higher whiteness. Enzymatically scoured and/or bleached cotton fabrics retain high strength and are adequately absorbent. The disadvantage of using this process represent high TOC-values of the baths, while the benefits are in the small amount of consumed water and energy. In the third part of the research it was confirmed, that the textiles from cotton and synthetic fibres derived from natural renewable sources can be efficiently pretreated through enzymatic scouring and different peracetic acid bleaching processes. Such special fibres are regenerated bamboo fibres, soyabean protein fibres and fibres from polylactic acid and they are thermally and alkali sensitive. During scouring the noncellulose and other impurities are not completely removed from the surface of cotton and regenerated bamboo fibres. The surface of fibres from poly(lactic acid) slightly depolymerises while the soyabean proteins on the surface of soya bean protein fibres slightly denaturate. Nevertheless, the enzymatically scoured textiles are satisfactory absorbent and retain high tenacity. For bleaching the peracetic acid was added to the bleaching bath in form of a commercial solution or was produced directly in the bath in the presence of hydrogen peroxide with the addition of a bleach activator TAED, or arylesterase enzymes. The bleaching processes with peracetic acid have a powerful bleaching ability in mild pretreatment conditions. The whiteness obtained increases in following order: hydrogen peroxide in combination with TAED > hydrogen peroxide in combination with arylesterase enzymes > an equilibrium solution with peracetic acid > an equilibrium solution with peracetic acid in combination with TAED. During bleaching the noncellulose and other impurities are additionally removed. They are more efficiently removed during the conventional bleaching. Textiles bleached with peracetic acid retain high tenacity and are adequately absorbent. Among the differently pre-bleached textiles no significant colour differences are observed.

Preparation of masterbatch with micro-and nanocapsules for melt spinning of fibres+

**Author: Leskovšek Mirjam**

Mentor: Stankovič Elesini Urška

In the manufacture of synthetic fibers with the addition of active particles which are formed by melt spinning, the preparation phase of input raw materials is crucial. In the case of manufacture of polypropylene fibers with the addition of the melamine-formaldehyde microencapsulated particles (microcapsules and microspheres–nanocapsules), it was found that the particles are in dry form, prone to undesirable aggregation of clusters. Although the phenomenon can not be totally avoided, the size of the clusters can be reduced by drying the suspension of particles in a dryer that operates according to the principle of co-current flow spray dryer, while the dosage rate of the suspension in the dryer and the mass content of the particles in the suspension should be minimized. The temperature of the drying does not affect the size of clusters. Unreacted

reactive methylol groups of the melamine-formaldehyde resin also have no effect on aggregation of particles, not even with a longer synthetic reaction, which only increases the stability of the cross-linking of the resin. The mechanical indivisibility of clusters is mainly affected by emulsifier –modifier, which is involved in the synthesis reaction of particles. During the drying process of the suspension of particles, emulsifier can envelop clusters with an inseparable layer. The aforementioned facts were confirmed by the Fourier transform infrared spectroscopy, thermogravimetry and differential scanning calorimetry. Despite the fact that most of the structural, mechanical and thermal properties of spun polypropylene fibers deteriorate with melamine-formaldehyde particles, some show a positive trend. The spatial distribution of the particles in the fibers can be identified by confocal microscopy, while particle susceptibility to deformation during preparation of input raw materials and spinning of fibers is proved by images of scanning electron microscope.

Antimicrobial protection of textiles with the use of nanosilver+

**Author: Danijela Klemenčič**

Mentor: Barbara Simončič

The doctoral thesis covers the research area of textile finishing and includes new processes of chemical modification of textiles with the aim of creating functional textile products with high added value. The study is interdisciplinary in which the research fields of textiles, chemistry, materials and microbiology are involved and interacted.

The main part of the research represents the development of a new universal procedure for the preparation of textile composites with antimicrobial, protective properties; this involved a coating containing silver (Ag). Chemical modification of cotton (CO), wool (WO), silk (SE), viscose (CV), polyamide (PA) and polyester (PES) fabrics as well as CO/PES and WO/PES fabric blends was performed in two steps, where a silica matrix was first created on the fibre surface by means of the application of an inorganic-organic binder (RB), silver chloride (AgCl) particles then being synthesised in situ. Properties of the coating were determined by SEM, EDS and ICP-MS analyses and microbiological tests. The results of the study show that the new procedure is suitable for the chemical modification of natural and synthetic fibres. The presence of the matrix increased the capacity of the fibres for AgCl adsorption, reduced the size of AgCl particles and enabled their physical embedding while not inhibiting their release from the fibres. Therefore, a higher concentration of the adsorbed AgCl in the silica matrix increased the antimicrobial activity of the coating even after repeated washing cycles.

The originality and contemporary nature of the doctoral thesis is proved by 8 scientific papers that Danijela Klemenčič and co-authors have published in internationally recognised journals, among them 5 in journals with an impact factor in the category of 1A1, which is recognised as scientific excellence.

Textile functionalisation by applying microcapsules+

**Author: Barbara Golja**

Mentor: Petra Eva Forte Tavčer

Cotton fabrics were printed with microcapsules with a fragrance (essential oil), antimicrobial agent (triclosan) and flame-retarding agent (triphenylphosphate). Flame-retarding microcapsules were also printed onto PES nonwoven fabric. Impregnation and exhaustion processes were also used for fabrics treatment. The properties

of treated fabrics and microcapsules were analysed before and after application and also after washing. The result of the research was a system for textile functionalisation with microcapsules for improvement of quality, functionality and usefulness of textile products.

## Doctoral thesis – Graphic arts

Development of combined method for analysis of facial images using eye tracking system+

**Author: Iskra Andrej**

Mentor: Gabrijelčič Tomc Helena

The use of facial images is widespread today. Popularization of the use of eye tracking systems, the field of observing facial images has become the subject of many researchers. The purpose of our research was development a new combined method for the analysis of facial images, which would further verify the results of the analysis of facial images obtained by other methods. The first step was selection and preparation of facial images from chosen facial databases. Due to the variety of tests we have chosen two facial image bases: Minear & Park and Stirling. At the beginning we performed time-spatial analyses with four different times and three different dimensions of the frontal facial images. The results of observing facial images in relation to recognition success were presented by combined method which consist previously known time-spatial method and the newly designed area method. Additional results we obtained with facial features method and method of measuring response times in recognition process. All the results showed us the turning point in observing face images at four seconds observation time and indicated potential problems of use of eye tracking systems for small dimensions of facial images. These results were used for the preparation of profile facial image tests, where we used only two different dimensions of facial images (medium and large). Comparison of the recognition of front and profile facial images showed us a significant difference in results between frontal and profile facial images only in false recognition. The use of the combined method and the facial features method revealed a different way of observing profile facial images, where observing of whole face happened in a shorter time than that of the frontal facial images. Next testing was done on faces presented at different view angles, where the results of combined method showed us different perception of those facial images. The combined method was also tested in emotion recognition, where we found a great compliance of the area method and the facial features method. Since the facial features method has mainly confirmed the results of emotion recognition, we can also use the new surface method for emotion recognition. The result of our research work is a combined method, part of which is a newly developed area method, which results supported the methods used so far in the analysis of facial images with eye tracking systems.

Analysis of Factors Influencing Photodegradation of Ink Jet Prints+

**Author: Blaznik Barbara**

Mentor: Bračko Sabina

The photodegradation of inkjet prints is a multi-layer process. It includes several factors, such as ink as a complex mixture of colorants and various accompanying substances, paper, which in addition to various fibres also contains other components (e.g. optical bleaching agents), and external factors (e.g. temperature, humidity, and the strength and spectral composition of the radiation from a light source). The aim of the doctoral dissertation was a systematic analysis of the complex process of degradation of prints made with an



inkjet printer. Selected types of paper and printers with dye-based inks were included in the research. In the initial phase, the analysis of basic chemical and optical paper properties was performed. The TLC, GC/MS, FTIR methods enabled a systematic analysis of the printing ink and identification of components involved in the process of degradation in the solution and on the print. The influence of medium-wave UV radiation on the stability of printing ink solutions in an inert atmosphere and an atmosphere of oxygen was analysed. Moreover, the influence of light, medium-wave and short-wave UV radiation on inkjet prints, and individual components were studied. To monitor the dynamics of the degradation of paper, ink and prints, colorimetric parameters were used. The results showed that the changes in paper properties were mainly caused by short-wave UV radiation. The analysis of ink revealed that they contained 2–4 colourants and a considerable number of accompanying substances. The photodegradation of ink in an aqueous solution occurred most rapidly in the presence of light with higher short-wave UV radiation. Furthermore, the presence of oxygen increased the rate of ink degradation in the solution. In most cases, the degradation of prints was faster under the influence of light with higher short-wave UV radiation. As it turned out, the influence of the spectral composition of light depends on the type of ink as well as on paper, especially on the presence of optical brightening agents in it. Consequently, the prints on paper containing optical brightening agents had inferior fastness. The analytic methods used in this study enabled a thorough analysis of the degradation of individual components of prints. However, for the interpretation of the results, it was necessary to take into account that the degradation of prints represents an interaction of many internal as well as external factors. Therefore, the use of colourimetry proved to be an effective method to monitor the photodegradation process and accurately describe it with regard to the changes in the optical properties of prints. The results enabled a comparison of the rate of degradation of individual systems under different conditions, leading to the description of changes on prints, paper and ink.

Application of uniform color appearance model to color rendering in static three-dimensional computer-generated graphics+

**Author: Bratuž Nika**

Mentor: Javoršek Dejana

Despite several technological advancements in the last few decades, we are still encountering issues regarding the reproduction of colors on different media and the achievement of color constancy. A possible option of ensuring constant color appearance are color appearance models, namely, the current color appearance model CIECAM02, which, despite having a great potential, is still not fully applied to practical workflows, especially in 3D computer generated graphics we come across on a daily basis. The purpose of this dissertation was to examine advanced color metrics and the CIECAM02 color appearance model to the point where it could have been implemented to 3D computer generated graphics. It was assumed that the CIECAM02 color appearance model can be used in 3D space, but it turned out that different setup parameters and settings influence the rendering calculations and algorithms which can, in turn, affect the rendering of color, too. Test setups were rendered with Blender software and three different rendering engines, namely, Blender Render, Cycles and the plug-in rendering software YafaRay. It was determined that rendering engines do not render color equally, that the CIECAM02 color appearance model can be applied to 3D computer generated graphics, and that by using the CIECAM02 color appearance model, we can significantly improve color matching when changing the lightness of the background. The CIECAM02 color appearance model can be successfully implemented on colors in 3D setups, or can be applied to already rendered 2D visualizations.

The correlation between objective and subjective digital photography quality assessment and its communication value+

**Author: Ahtik Jure**

Mentor: Starešinič Marica

Photography is involved in modern communication more than ever and good communication value of photography has a deciding influence on successful communication. In our research we determined communication value with the help of image quality assessment, that was based on subjective method (web application, crowd sourcing), objective method of eye tracking, mathematical objective measures (RMSE, PSNR, SSIM) and colour differences. Assessment was based on a testing image database that we developed for this purpose. Database includes 30 photographs with 28 different manipulations that are based on different visual quality parameters. We determined that higher sharpness, lower contrast and lower saturation have little influence on image quality and on the other hand, higher contrast, change of lightness and lower sharpness have big influence on it. We calculated strong correlation between results gathered with subjective method and ones gathered with an eye tracking method, but the correlation with other objective methods is less significant. In our research we also developed two new methods, one is for subjective quality assessment and the other for analysing data gathered with the method of eye tracking.

Viscoelastic properties of graphic papers+

**Author: Možina Klemen**

Mentor: Praček Stanislav

Viscoelasticity is the property of a material, which responds to deformation as a viscous and as an elastic material. A viscous material, e.g. honey, is capable of resisting tension and shear forces and responds linearly to the external deformation, while an elastic material, after removal of the external load, immediately returns to its starting position. Viscoelastic materials have elements of both listed types of responses, the viscous and elastic. It is a time-dependent response to tension. Elasticity is usually a consequence of the ability of intermolecular bonds to expand along the crystalline structure of the polymer, while the viscosity is the result of scattered atoms or molecules within the amorphous stage of the polymer. The purpose of the Ph.D. thesis "Viscoelastic properties of graphic papers" was based on an examination of the following: a) the impact of the fiber composition, b) technological parameters of manufacturing, c) structural characteristics, d) physical-mechanical properties and e) the interdependence of "conventional" and "new" analytical methods in investigation of the viscoelastic properties of the paper. The survey included classical and new methods of investigation of paper, which was divided into five sections, i.e. basic physical, physical-mechanical, surface and structural-chemical composition, uniformity of the paper, and the deformation under load composition and viscoelastic properties. The 12 test samples (V1-V12), were distinguished according to material composition (primary or secondary cellulose fibers), technological production (produced on three paper machines) and finishing (coating, calendering), whereas for all of the 12 samples the printing technique was common, i.e. web printing of roll on roll/sheet. Application of secondary cellulose fibers for newspapers, V1-V3, and graphic papers, V4-V6, is a long-established practice, while manufacturers still solely use virgin cellulose fibers in production of specialty papers such as papers for flexible packaging, V7-V9, or label papers, V10-V12. The results of the survey have shown that papers produced from secondary, V1-V6, and primary, V7-V12, cellulose

fibers are substantially similar, which overall suggests the possibility of reducing the proportion of the primary cellulose fibers and replacing them in part with appropriate deinked pulp, i.e. secondary cellulose fibers. In spite of the weakened physical-mechanical properties, they are still sufficiently "strong" to withstand the stresses which occur during the wet and drying part of the paper machine, coating, calendering, winding, rewinding, and a web printing process.

Legibility of information on lcd displays in different light conditions+

**Author: Franken Gregor**

Mentor: Možina Klementina

An increasing amount of content is now read on screen and both the form and the size of the typeface determine the legibility of the text. Reading is a complex cognitive process involving the recognition and decoding of symbols for reading comprehension. The reading speed depends on a number of factors, including font type and size. The aim of the PhD thesis was to determine the legibility of screen typefaces in different sizes and contrasts on an LCD screen using an eye-tracking device under various ISO standard lighting conditions. In preliminary measurements, 50 participants read 50 texts of approximately the same length and difficulty on an LCD screen. Based on the preliminary measurements of an eye-tracking device, texts suitable for further testing were selected from median reading times. The main study comprised five experiments used to test how the font type, font size, line spacing, positive/negative imaging, display contrast and typefaces and viewing conditions impact the reading speed. The results show that the reading speed increases with font size and that Verdana is the typeface that is processed most quickly. Negative imaging and increased line spacing improve the reading speed. Reduced viewing conditions resulted in a minimal increase of the reading speed.

The impact of colour and typography on perception of titles for conventional and mobile television+

**Author: Pušnik Nace**

Mentor: Možina Klementina

The purpose of the study was to determine which typefaces, lettercases (lower-, upper- or sentence case), positions and colour combinations of words are processed the fastest when they are briefly displayed in a larger (e.g. television) and smaller (e.g. mobile) central part of the screen. The set of typefaces which are commonly used in modern media has extremely expanded in the period of digitalisation. It should be stressed out that all typefaces are not suitable to be presented on the screen in a limited time interval since their design features do not contribute to the fast processing of inscriptions. Typefaces that were included in the study should be more suitable for the on-screen presentation and often represent an integral part of the corporate identity of various television shows. The Ph.D. thesis is based on the analysis of the results which were gained with the help of three experiments. In each experiment, it was examined how the typeface, lettercase, position of the inscription and colour combination affect the speed of processing the verbal information. The first experiment was performed on a larger, and the second and third on a smaller central part of the screen. The experiment on a larger central part of the screen was performed under standard lighting conditions and on a small central position of the screen once in the standard and once in the recommended lighting conditions. In order to limit the complexity of information, the inscriptions consisted of generally known three-letter words taken from the

Slovenian language dictionary. To measure the effect of the studied variables, the threshold to recognize words in different experimental conditions was measured (i.e. the minimum time of word presentation needed for the correct recall). A total of 360 people participated in the experiments. Typefaces, position of the stimulus, lettercase (lower-, upper-, sentence case) and colour combination affect the speed of information processing. Individual typefaces showed good (Georgia, Calibri, Verdana, Trebuchet) or poor (swiss 721) performance in all experiments, regardless of the size of the central part of the screen. The position of titles (regardless the size of the central part of the screen) proved as important, while when presented in top positions, faster processing was noticed. It turned out that for the displaying of short inscriptions, upper-case letters are more suitable. The use of colours affects the speed of information processing at different sizes of the central part of the screen. Those findings may help in the planning of the optimal on-screen presentation of short word information.

Printed smart packaging with functional elements+

**Author: Kavčič Urška**

Mentor: Muck Deja

My doctoral dissertation is divided into three parts, where in each part independently or in connection with other parts forms smart packaging. The purpose of the dissertation was to get to know with the production and operation of different functional elements that are printed on packaging and consequently increase its value, interactivity and traceability. The first part deals with monochromatic, dichromatic and multi-coloured 2D codes printed in process printing inks. Readability of coloured codes printed in different printing techniques and different raster tone values A (%) was tested. Different code readers, accelerated ageing and lightfastness were used for testing the readability of codes. Codes printed in black printing ink reach readability already at 15 % A, codes printed in cyan and magenta at 30 % A, codes printed in yellow are poorly readable. Light fastness influences negatively on readability of codes while accelerated ageing at high temperature and moisture does not influence on them at all. Dichromatic codes printed in black and cyan ink and codes printed in black and magenta ink are readable, while codes printed in black and yellow ink are not readable. Reasons for unreadability could be, besides a colour, also in optical density, whiteness of printing material, a used reader and light in the room where codes are read. The operation of UHF RFID antennas is analysed in the second part. Here were determined the power and working distance of different commercially available tags on packaging with different content (1), different printing and electrical properties of a self-designed antenna (2), and comparison of function between commercially available and printed tag with the same design on cardboard packaging with different content. Tags on empty cardboard packaging work perfectly, but response gets worse when packaging contains a product with a high amount of liquid or metal. When the UHF RFID tag is in the direct contact with metal, it does not work. It was established that printing of UHF RFID tags on paper and cardboard was possible and successful. Design as well as used conductive ink and its heating have great influence on readability of tags. Comparison of readability of commercially available and printed tags of the same design revealed that on empty packaging the reading distance is comparable. A better function was defined at vertically oriented tags in comparison with horizontally oriented ones. On the packaging with tablets in aluminium blister inside, the power and reading distance were diminished. They were improved with inserting an additional cardboard between the antenna and aluminium blister. In the case of packaging with syrup in glass vial, the dielectric separator was the vial itself. In the third part the thermochromic displays are printed. The influence of cardboard thickness, layers of thermochromic ink, varnish, different electric power, time of heating, abrasion resistance, light fastness, and temperature ageing on final performance were determined. It

was found out that rubbing negatively affects on visual appearance of display. Small differences in colour ( $\Delta E < 4$ ) were caused by temperature ageing, where longer heating time, higher ageing temperature and a double layer of thermochromic ink cause higher colour difference. On the other hand, the light fastness caused high colour difference. One hour of exposure to 35 °C caused  $\Delta E > 2$ , while two hours  $\Delta E > 4$ . A higher colour difference was caused by longer exposure time and higher temperature, whereas a double layer of thermochromic ink and varnish protected the display against higher colour differences. The response of displays was analysed with determination of mean grey value at different times of power connection on electrical power of 4.8 W or 6 W. It was proven that the thickness of printing material crucially influences on the time of display response. At power of 4.8 W the thicker sample EXT (0,700 mm) reaches mean grey value of 70 in 13 seconds, while the sample AVP (0,400 mm) 140. Higher mean grey value means higher discoloration. Exposing displays to light fastness for 4 hours at 65 °C caused a delay of display discoloration – samples exposed to light fastness started to respond with 1 to 2 seconds delay in comparison with samples that were not exposed to light fastness. Oppositely, increasing of electrical power from 4.8 W to 6 W accelerated respond for at least 2 seconds.

Evaluation of user experience in mobile advertising+

**Author: Sedovšek Robert**

Mentor: Hladnik Aleš

Due to the increase in use of mobile devices –e.g. smart phones, tablets –and their enhanced functions, requirements for advertisers have been also set higher in terms of creating improved online advertisements, including rich media mobile advertisements. Namely, advertisers allocate increasingly larger budgets to online advertising, which also affects the general interest and the quantity of studies focusing on advertising campaigns –that is, how well ads work, how they are perceived by users and how high the returns on investments are. The aim of this doctoral thesis is to evaluate the usability, user experience and engagement in interaction with mobile ads. More specifically, the aim is to analyse the various types of user interfaces within the mobile photo gallery, which is one of the most common elements of rich media mobile advertisements. It was a challenging task to use a simple, fast, cost-efficient and flexible method of examining the influences of various structural concepts of a user interface on the use of mobile contents by a larger group of users in their everyday environment, without these users knowing that they were participating in a study. A so-called tracker was developed –a software library capable of recording and saving information into data logs used in analyses. A tracker is a flexible piece of software which can be built into random web contents (in this case, into a mobile photo gallery which was presented to the subjects in the form of advertisements). In the first study, users' intuition was observed based on the data logs analysis –that is their preferred gestures for horizontal navigation through the photo gallery, the effects of their gestures on engagement in viewing the gallery (number of photos viewed) as well as the impact of either the presence or absence of instructions on the decrease in the number of incorrect gestures (user gestures not used in navigation). The data acquired from data logs was statistically evaluated using the two-way analysis of variance (ANOVA) at a 95% confidence level. It was established that users use the swipe gesture more naturally than the tap gesture. These findings were also substantiated by the survey, while a high correlation between the survey results and the analysis of data logs was established. Likewise, with a more intuitive version of a user interface (Swipey UI, which uses swipe gestures for navigating the gallery), a significantly higher average number of photo views per session (5.8) was reached vis-à-vis the alternative interface (2.9). As expected, the presence of instructions caused a decrease in

the average number of incorrect gestures. However, it can be assumed based on the value of the F-ratio (70.6 for user interface type and 7.1 for the presence/absence of instructions) that the influence of the user interface on the number of incorrect gestures is 10-times higher than the influence of the presence of instructions. As a result, the second study was aimed at the function of different instruction designs. Using a non-standard type of user interface (vertical navigation through the photo gallery), four different instruction designs were looked into: iconic instructions, icon animation in the direction of swipes, constantly displayed text instructions, and text instructions in an interstitial format. It was demonstrated that there exist statistically significant differences between different structural types of instructions. The lowest number of incorrect gestures (in this case tap and swipe to the left/right) was noted when the instructions were presented in the form of text always displayed on the bottom of the screen (no. of incorrect gestures: 2.8), while the number was highest when instructions were presented as icons (4.7). Also confirmed was the hypothesis that the average number of incorrect gestures is inversely proportional to the average number of photos viewed. On the other hand, the hypothesis stating that instructions presented in the interstitial format result in an increase in the number of users who immediately close down the content, i.e. they close advertisements with no interaction at all, was rejected.

Preparation, printing and characterization of tungsten (vi) oxide thin layers for applications in optoelectronic devices+

**Author: Vidmar Tjaša**

Mentor: Hladnik Aleš

PhD thesis examines the potential of WO<sub>3</sub>sol-gel material to be used as functional ink for inkjet printing and integration of WO<sub>3</sub>printouts in printed optoelectronic systems. The research evaluates the correlation of the complex composition of functional WO<sub>3</sub>sol-gel material to its physico-chemical and rheological properties and evaluates the printability of the material with inkjet printing technique. The main focus of the research was the modification of the sol-gel synthesis and the composition of WO<sub>3</sub>sol, which enabled the development of functional inks for inkjet printing on unconventional and complex surfaces, such as glass and transparent conductive oxide (TCO). The challenge was very complex as the starting WO<sub>3</sub>sol was tailored for dip-coating technique and has never been used before in inkjet printing. The replacement of highly volatile solvent -ethanol, with of 2-propanol and 2-propoxy ethanol was needed in synthesis of WO<sub>3</sub>sol. Rheological properties of the modified WO<sub>3</sub>sols were also suitable for analogue flexographic technology, as demonstrated with precise lines and homogeneous surfaces on glass substrate made with flexographic printing. In addition, incorporation of additives in the WO<sub>3</sub>sol enabled production of test viscous WO<sub>3</sub>paste, which allowed the deposition of thick layers with screen printing and doctor blading technique. An important contribution to the understanding and usefulness of sol-gel materials for inkjet printing represents the study of time and thermal stability of sol-gel materials associated with the transition of sol to gel, which evaluates the applicability of the material to be used in printing industry and mass production. The results of rheological and micro-rheological properties of sol in connection with structural changes have described the effect of temperature and aging on the process of gelation, which is strongly affected also by storage conditions, sol concentration and the type of the solvent used, therefore the stability of sols varies from few days up to 10 months. Useful information about the drop formation process of WO<sub>3</sub>sols were given with Reynolds, Weber, Ohnesorge and Z dimensionless numbers. Adhesion, optical properties, topology and the spectrophotometric characteristics of WO<sub>3</sub>printouts were evaluated. The functionality of printed WO<sub>3</sub>layers was tested in simple photochromic (PC) and hybrid electrochromic systems (EC) and organic solar cell prototype (OPV). Realized EC system enabled optical

modulation in the visible part of the spectrum ( $T_{vis}$ ) between 50 % and 6%, while PCsystem between 85 % and 42 % under one-hour exposure to the sunlight (standard test conditions; 1000 W /m<sup>2</sup>, AM 1.5, T = 25 °C). We were faced with numerous problems in the development of OPV system, like surface interactions and interactions between the layers, which have a negative impact on the homogeneity and functionality of the individual layer, therefore the response of OPV system was insufficient. In overall, we believe, that the study made a significant contribution to a better understanding of the sol-gel materials and their applicability in inkjet printing and moreover in the broad spectrum of graphic technologies. We answered to many complex questions in the field of physico-chemical properties of WO<sub>3</sub>sol-gel materials, and demonstrated that the modification of sol-gel synthesis route enabled the preparation of printable WO<sub>3</sub>material. We have shown that inkjet printing is a useful technique in the research of printing unconventional materials on complex substrates, due to its fast and easy adaptability to the user and contact-less and precise transfer, required by optoelectronic systems.

Printed electronics on polimer foils+

**Author: Đokić Miloje**

Mentor: Muck Deja

Doctoral dissertation is divided into three sections. In the first we dealt with UHF RFID smart card technology, in the second Near Field Communication (NFC) we have developed an NFC tag that contains a temperature sensor. The third set was dedicated to verifying the commercially available conductive adhesives. First the UHF RFID tag was designed, simulated and made by screen printing. While testing UHF dipole antennas for RFID applications, we studied the impact of three conductive inks, reading distances and deformation cards on the strength of the return signal. Three-way analysis of variance (ANOVA) was used to aid in the interpretation of the results of measurements of laminated and non-laminated cards. This was followed by research and feature comparison of UHF RFID antennas that were printed with industrial screen and flexography printing. After printing we optimized the drying process specifically for each print technology to achieve the best antenna performance. Properties of the antenna were analyzed by measuring a large number of parameters, such as resistivity, the power of the backscattered signal, the characteristic impedance and the returning loss signal. We also analyzed in details the impact of the final lamination on readability and operation of the card. The possibility of producing RFID antennas with different printing technologies were studied in relation to the production speed and repeatability of the printing. The second section presents the process of making NFC tag with integrated temperature sensor. We displayed and presented the design process and simulation of antenna and the whole process of making NFC tags using screen printing. Created tags were tested with two devices, the conventional reader and mobile device – tablet. That was followed by analysis of working tags with network analyzer, where we checked the resonant frequency of NFC tags, real and imaginary resistance and their capacitive or inductive nature. In the third section various conductive adhesives were studied, because we had problems in the making process of the tags related to the process of contacting the chip. The aim was to find out what kind of glue is the most convenient for manually assembling chips on printed antennas. For testing, we prepared 5 different adhesives (2 isotropic, 3 anisotropic). Adhesives were tested in two ways: with the method of measuring the contact resistance with a multimeter and measuring the voltage drops. For the first method we used multimeter FLUKE 289, but for the second method we used KEITHLEY 2401 SourceMeter instrument. The purpose of measurement of the voltage drop was to confirm the results of previous measurements and to obtain more precise results. For this reason, measurements were performed in two

ways, first by the electric current 3 mA and the second with a current of 30 mA. In doctoral thesis, we have shown that it is possible to make smart UHF RFID card with a screen printing technique with the described optimization of the design of the UHF antenna, which enables easy reading of cards. While comparing two different printing techniques for printing electronics we have proved that the industrial screen and flexography printing can be used for the production of RFID smart cards. In a study in this area, we found that the flexography proved to be a faster solution for printing, but screen printing allows better repeatability. Results obtained in the research of NFC tags helped us to figure out the properties of printed NFC tags and to be aware of their strengths and weaknesses. Using both classical reader and mobile de-vice for testing NFC tags gave us the perspective to see the extent to which mobile devices can replace conventional reader. From the test results of the conductive adhesive we can see that the adhesive "Epo-Tek E2101" shows the best results, and the lowest resistance. Glue "Bison ELECTRO glue" had good results, but it is very fragile and inflexible.

Properties and print quality of recycled papers+

**Author: König Silva**

Mentor: Diana Gregor Svetec

The work of the doctoral student, Silva König, is in the field of paper and graphic technology. In doctoral dissertation, the properties and durability of recycled papers were determined, their suitability for printing with conventional and digital printing techniques was investigated, and the quality and durability of prints were assessed. The results of the research have shown that characteristics of recycled papers are similar to characteristics of classic printing papers made from virgin fibers. The good printing properties of recycled papers enable their use in conventional and digital printing techniques, more precisely in offset and electrophotographic printing. Also, the durability of prints exposed to the various factors (such as light, moisture, heat) is similar, for both type of papers. The main message of the research was: recycled papers can replace conventional wood-free papers in everyday office use and various graphic products. As part of the dissertation, newer methods for evaluating the quality of prints were presented. On electrographic prints made with the dry ink, the image capture and image analysis proved to be more suitable for determining the raster tonal value than the generally used densitometric method. A new method of image processing in printing, with which we can evaluate the light fastness of the print is based on the assessment of the chrominance histogram. Its main advantage is that the change in the print can be evaluated as a numerical value, using a highly saturated color image for evaluation, which can be small enough for any chamber intended for accelerated aging.

Properties, printing and eco design of packaging from recycled polypropylene and polyethylene+

**Author: Tišler Barbara**

Mentor: Diana Gregor Svetec

The use of polymeric materials for packaging applications is constantly growing, therefore reuse and recycling of these materials is important from economical as well as ecological viewpoint. The goal of research was to assess the usability of products made from the recycled polyolefins and to make classification of them according to ecological criteria. Polyolefins that were included in the research were polypropylene (PP), low-density polyethylene (LDPE) and high-density polyethylene (HDPE) obtained from mechanical recycling of the separately collected waste packaging in Slovenia. From these polymers different products were produced;



monofilaments and foils in the melt extrusion processes and plates with injection moulding and thermoforming. For printing on foils and plates flexographic and digital printing techniques were used. The research has shown that the addition of recycled polymer to virgin polymer in melt spinning deteriorates mechanical properties, which limits the usability of monofilaments, nevertheless, they could be used as fillers in the composite materials. Mechanical and surface properties of foils made from the recycled polymer are not so good comparatively to foils made from the virgin polymer, but they give better UV protection and can replace the foils made from the virgin polymer in many applications. Thinner plates made from the recycled polymer have higher tenacity, extensibility and are tougher comparatively to the plates of the same thickness made from the virgin polymer, whereas at thicker plates made from the recycled polymer mechanical properties deteriorate. Results have shown, that print quality of prints made with the UV inkjet printing is lower, because the dark color of plates and its non-uniformity influence the color of print. Prints of higher quality could be obtained only when printing was performed onto the previously printed white color. In conclusion the guidelines for eco-design of flexible and rigid polymeric packaging are given. The assessment includes the quantity of material used, the source of material and the quantity of recycled polymer, printing technique and assessment of product as a waste.

Printing and analysis of passive electronic components+

**Author: Horvat Maša**

Mentor: Klanjšek Gunde Marta

The thesis is dedicated to analysis of passive electronic elements which were prepared by screen printing. Commercially available printing inks were applied, including three types of silver-based conductive inks and one dielectric ink. The feasibility of four papers intended for conventional printing was analysed and compared with the results obtained for the samples prepared on the paper dedicated for printed electronics. The print forms were prepared for single- and three-layered elements. For preparation of samples screen printing technology was applied on the five selected substrate materials. Special attention was devoted to the properties of printing inks as a result of printing and drying processes and their influence on the electrical properties of final samples, especially the multi-layered ones. The electrical, thermal and chemical properties of the printed passive electronic components were analysed in details. The profiles and shapes of lines used in single-layered elements were evaluated together with the adhesion of the functional ink on the applied papers. The electrical resistivity of the conductive inks was studied as a function of screen density, type of paper substrate and drying conditions. The results confirm that the electrical conductivity depends on the examined printing parameters. The resistivity increases with the screen density and diminishes with drying temperature. The influence of surface roughness of the used paper substrates on electrical resistivity of prints was also evaluated. The preparation of the prints was optimized by proper selection of mesh density and drying conditions. The print quality of three-layered elements prepared as parallel-plate capacitors was also evaluated. Their electrical properties were thoroughly analysed with special attention on the material properties of the dielectric layer. The electrical functionality of capacitors was studied in terms of the state of polymerization of UV-curable dielectric layer, varied by the energy applied for curing. The boundary between the dielectric and conductor layers was analysed in dependence on the curing energy applied for dielectric layer in conditions of single- and double printed dielectric layer. It was shown that parallel-plate capacitors are feasible using single-printed dielectric layer only if the dielectric is completely polymerized. This way the thinnest possible dielectric is assured, thus the largest capacitance of the capacitor.

## Doctoral thesis – Textile Design

Clothes as Visual Symbol in Contemporary Arts and Practices of Former Yugoslavia+

**Author: Todorović Tijana**

Mentor: Toporišič Tomaž

My doctoral dissertation focuses on the research of non-verbal, i.e. visual language of clothes. While researching the system of dressing and individual articles of clothing as a visual sign in contemporary performative arts and practices, I ascertained that their visual style provides social, cultural and sociological information. Clothing is thus becoming an artistic and aesthetic manner of expression that reveals a part of a character or situation. When everyday clothes are included into the research, the basic function of clothing remains the same from its very beginnings to today. I have focused on clothing within the territory of former Yugoslavia because this territory was socially and politically specific and complex from the end of World War II to its disintegration. By researching the history of clothes and the system of communication with them, linguistics and visual art theory, I have gained new knowledge that provides me with a better insight into the non-verbal, i.e. visual language. If we translate the visual language into the language of clothing and link this to performative arts, we can learn about rituals, culture and cultural heritage, social status, taste, aesthetics, the individual's attitude towards the environment, etc. The research ascertained the importance of artistic expression with the use of various articles of clothing (personal expression in relation to culture and society) and with this provided a broader frame for the understanding of history and the organisation of the state. The research also ascertained the importance of design, costume design and the textile industry for Slovene and Yugoslav societies as well as revealed the attitude of politics towards creativity, creative arts, industry, theatre... It is because of this that the dissertation is important also for the understanding of the social and cultural visual discourse in today's world. The research also reveals the importance and the development of society through visual codes and follows the advancements and changes in relation to political and cultural changes. In my research I focused on clothing between 1945 and 1991, from the beginning of the second Yugoslavia to its final disintegration. I believe Yugoslavia presented an appropriate and interesting case due to its differences in the socialist system. I wanted to know how much freedom and what sort of interpretation can be obtained as a response to the limitation or freedom within such society. In the part of the research in which I discuss clothing and the textile industry in Yugoslavia and Yugoslav theatre, I have ascertained that the Yugoslav system did not lag behind the developed West as regards quality and development. I have used methods of analysis, synthesis, description and compilation, with the aid of which I responded to the four hypotheses:

- 1.) Clothing, seen in the cultural-social and historic context, represents a visual sign aimed at communication.
- 2.) Clothing as a visual sign can function as non-verbal language with similar characteristics to verbal language.
- 3.) Clothing (wearing clothes, costumes) makes it possible for us to follow the changes in society while the visual language of clothes indicates the reasons behind the social-cultural state as well as the consequences of changes.
- 4.) The system of fashion, culture and theatre are social additions that are reflected in each other, depend on each other and can be followed through the visual language of clothing on the example of former Yugoslavia.

Uses of Fashion Language and Clothes in Contemporary Art+

**Author: Končić Jasminka**

Mentor: Zgonik Nadja

Nowadays, when on a daily basis the fashion of clothing is used to shape one's identity and to determine one's social status, the language of fashion and clothing is becoming an increasingly efficient medium through which powerful artistic, sociological and ideological messages can be transferred. On the one hand the fashion of clothing demands its artistic recognition; on the other hand the language of fashion and clothing is more frequently used in contemporary visual art. The study of the phenomenon of continuous use of clothing and the language of fashion in the works of visual art is seen as the ever more intense presence in contemporary times. This work is a complete historical review of the use of fashion and anti-fashion garments and also the language of fashion of clothing in the works of visual art from the beginning of the 20th century to contemporary art. Although this phenomenon has become more common, so far there have not been any systematized reviews of how the garment sign has been used in artworks.

In the work, we can observe how the fashion system elements such as catwalk, fashion show, fashion magazine and clothing items are increasingly used in contemporary art. Particular attention is dedicated to the phenomenon of sculptural clothing, a sculpture as a garment without a body (empty dress). The focus is also put onto the role of clothing as a ready-made, such as the one in the avant-garde artistic movements at the beginning of the 20th century, which is replaced by the sample shaping principle in the post-production artwork.

Mathematical approaches in the design of textile surfaces+

**Author: Puc Sabina**

Mentor: Škrekovski Riste

This research focuses on the creative interdisciplinary process of designing repetitive patterns stemming from periodic functions with two variables. By using Wolfram Mathematica, a computer algebra system, we generated 3D-graphs based on pre-set mathematical functions with linear combination of powers of sinusoidal functions. The latter were then cut by a selected number  $k$  on the horizontal  $xy$  plane on equal or unequal levels. The cuts were projected onto plane  $z = 0$ , where contour maps appeared. With a digital translation of abstract mathematical values onto a visual media, a visual image based on aesthetic concepts was created. The creative criteria were based on the artistic potential of periodic configurations, expressive properties of structural units and the congruence of various compositions. Colour combinations and contour lines were then applied to corresponding contour maps by means of optional parameters, thus creating one-layered repetitive patterns. An even greater diversity of composition was achieved by layering and combining planes into multi-layered configurations. Since the result of this research was to design a mathematical collection with one- and multi-layered repetitive digital patterns, a systematic structural analysis allowed us to define wallpaper groups based on planar distribution, disposition of modular structure units and symmetric operations. A digital collection of periodical patterns based on seventeen wallpaper groups was also created, in which symmetric operations were applied onto an asymmetric cell of a selected repetitive pattern in accordance with the characteristics of the various wallpaper groups. The symmetric unit of one motif which repeats itself in regular intervals was then applied in parallel rows within the elementary grid. Finally, we put up an exhibition at Zeta Gallery, where we focused on the artistic impact which the repetitive patterns, devoid of mathematical groundwork, had on visitors.

Interpretation of Slovenian Heritage into Contemporary Clothing Product Collection+

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**Author: Vilman Proje Jana**

Mentor: Bogataj Janez

The objectives of the Ph. D Thesis refer to the question of how to design a modern clothing image that will reflect modern times and the contemporary recognition of Slovenia.

Theoretical standpoints provide us with the understanding of cultural heritage and how it is related to national affiliation and the creation of new identities, and they offer an insight into the importance of clothing and into the development of affiliated costume clothing.

The analysis of clothing practices in tourism and for tourism in Slovenia has shown that most tourism workers wear their own clothes. On the basis of a case study and our own participation, has been developed a model for designing affiliation clothing arising from cultural heritage for tourism needs, which has been checked in the experimental part of the dissertation.

The research performed has provided the definitions about our clothing image and what elements are considered or recognised by the Slovenian public as Slovenian affiliation costume and what textile motifs are identified as Slovenian.

The carnation has been identified as a Slovenian motif and transformed into three modern motif compositions, and their identification has again repeatedly been verified by checking the opinion of the wider public. The modern carnation motif, identified as Slovenian, has been incorporated in the proposals for garments used to show affiliation to Slovenehood with the clothing image and we have studied the possibilities of applying it on other products.

The dissertation has proven that the selection of the original story and the design of the symbol, recognised as such by the members of a community, are very important for designing affiliated clothing.

The influence of digital media on creative process in fine arts+

**Author: Golob Urška**

Mentor: Berlot Pompe Uršula

The thesis presents an interdisciplinary research that combines the field of fine arts, digital technology, and phenomenology. The research was a multiple case study that investigated the experiential and artistic processes of six Slovenian artists of younger generation. In the foreground, I investigated their experiential dynamics within two-dimensional creation, where I was interested in the eminent role of the digital media in comparison with analog media. The research question that guided the investigation was: How do artists experience interaction with digital media (compared to analog)? What is the experiential role of digital media in artistic creation? In the process of detecting differences, I was interested in the points of experiential shifts, which was more thoroughly observed in the second investigation phase, where I combined experiential process with the artistic analysis. For the purpose of investigation, I used an experimental approach – a multi-layered methodology that matches new post-humanistic approaches within qualitative research. This consisted of a qualitative phenomenological method of research and artistic analysis. Gathering data was supported with the development of an application prototype, which was installed on the smart devices that artist used during the research. The results of the survey highlighted changes on the different level of experience in the agency and its related constituents; control, media benefits, awareness of the body, the presence and (semantic) use of the language. Parallel observation of the dynamics of the experience and the process of creation has brought a more comprehensive insight into (contemporary Slovenian) fine art practice and at the same time presents new

ways of exploring the complex creative process. In conclusion, I offer suggestions and new strategies for further observation and development of artistic practices.

Development of multifunctional 3D knitted structures with auxetic potential+

**Author: Rant Darja**

Mentor: Pavko Čuden Alenka

Nature provides us with many examples of effective and environmentally friendly solutions to the various problems that plague humanity. The study of applying designs from nature to solve problems in engineering, materials science, medicine and other fields is called biomimetics. Biomimetic design guidelines are the basis for the development of knitted fabrics for multifunctional packaging, which do not represent an additional environmental burden, but are often useful and visually appealing. Preserving the freshness of food is an important contribution to healthy nutrition and reducing the amount of discarded food. Food conservation including packaging is important for preserving the freshness of food. For household storage of foods, a variety of materials are used in modern times, of which textiles represent a smaller share. Textiles have multifunctional food storage potential. They can mechanically protect food against impact, they are air-permeable, thus preventing the formation of molds, they are washable and therefore repeatedly usable, biodegradable and thus sustainable, foldable, pleasant to the touch and decorative, i.e. suitable for production in different colors, sizes and shapes. Among the textiles, knitted fabrics are distinguished by their stretchability and flexibility, the possibility of seamless production, high efficiency of production, possible self-folding and the possibility of complex functionalization. The purpose of this research was to formulate based on theoretical and experimental starting points-inspirations, design, produce on an industrial knitting machine and test visually interesting, aesthetic and multifunctional knitted fabrics with auxetic potential – the potential ability of lateral expansion under axial strain. In the area of packaging performance the purpose was to design and develop knitted structures with several functions for food storage, while in the area of multi-purpose use the objective was to anticipate the use of these knitted structures in other clothing and non-clothing areas. The main objective of the study was to analysis the influence of the structural parameters of links-links knitted fabrics on the folding potential, which leads to a greater auxetic and protective effect. Experimental work in design was based on the systematic development of 3D, textured and foldable structures with auxetic potential, from various materials and in different densities. The technological experimental work consisted of testing the multifunctional properties of selected, newly designed, knitted structures for: foldability, compression, antibacterial and biodegradable properties, and the ability to preserve the freshness of food. Finally, a visual analysis of the manufactured multifunctional knitted structures, which are suitable for the production of aesthetically interesting clothing and other textiles, as well as for the production of visually attractive and functionally useful packaging material for household storage of baked goods / breads was performed. Multicriterial decision making of the development process for corporate clothing and uniform+

**Author: Šterman Sonja**

Mentor: Kljajić Miroljub

The multi-criteria decision making process during development of corporate clothing and uniform. This dissertation explores multi-criteria decision making in the development process of corporate clothing and uniforms, introducing the approach of systems engineering development models. This includes a multi-criteria decision making model, which involves the fundamental criteria of quality and properties, functionality, communication power of clothing, suppliers and economic aspects, as well as a series of sub-criteria. In

practice, these factors are often not precisely determined, what causes problems for the end user, who can be supplied with uniforms that lack functionality and are aesthetically unsuitable. We have considered the end-user feedback, which was collected on the base of realised project of corporate uniforms. By integrating end-user feedback obtained through surveys, this dissertation defines the relevant important criteria. These were identified using an expert focus group for decision making supported by Think Tank. The results were divided into hierarchical matrices, which were then considered using the AHP method of paired comparisons. We got the base matrix and used it to evaluate alternatives. Considering the sensitivity of the evaluation criteria with paired comparison, the AHP method represents the most appropriate approach to assessing the importance of criteria, sub-criteria and alternatives. As an example, looking at the evaluation of alternatives, we selected the old and the new customs wind jacket, which shows relevant results and confirms the possibility of the introduction of process systems in the engineering of areal model for the design and purchase of uniforms. On the basis of systems engineering, the integrated model takes into account the elements of the user (knowledge and experience) and scenario (criteria). The result of the process of searching the optimal way of introducing uniforms is the introduction of the complex model, supported by end-user feedback and contemporary information of the science: when uniforms are produced in adherence to this model, they meet the requirements of the end-user.

Research on waste textiles in Slovenia+

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Waste textiles are according to its source generally divided into industrial textile waste, that is generated before consumer's use and post-consumer textile waste, which is generated after consumer's use. Post-consumer textile waste is composed of waste apparel and home textiles. In the first part of the dissertation the quantity, type and further treatment of post-consumer textile waste, collected in assembly centres across Slovenia in 2013 was examined, while in the second part its quality and recyclability was assessed. In the third part environmentally conscious consumers behaviours in the field of purchase and disposal were examined. With the use of qualitative descriptive method was in the first part of dissertation found that most of 136 assembly centres collects waste textiles. The assembly centres are in Slovenia operating in accordance with legal regulations; nevertheless the utilization of post-consumer textile waste could be more efficient. Textile waste could be more effectively used through better management and consumer's cooperation. Waste textiles is not properly sorted and is exposed to weather conditions, also there is a lack of contractors. In assembly centres that collects apparel and textiles the largest share of apparel was sent for recycling (24 %), while the largest share of collected textiles was passed on or sold (56 %). In assembly centres that collects apparel only the largest share of collected apparel sent for recycling (50 %). In both types of collection centres the waste textiles were visually evaluated by administrators. It was found that more than half of the collected apparel is suitable for reuse, while the collected textiles were evaluated as less preserved. With an objective to determine the possibilities of recycling post-consumer textile waste, in the second part its quality was assessed. Quality evaluation of textile waste was performed by quantitative analysis of the fibre composition and measurement of tensile strength and elongation. Single-component apparel and textiles represented the largest share of waste textiles(63 %)and this facilitates recycling processes. The possibility of recycling these based on their fibre composition and quality was presented. Because consumers are primarily responsible for effective utilization of post-consumer textile waste, in the third part environmentally conscious consumer behaviours

considering purchase and disposal of apparel and textiles were examined. Data were collected from a sample of 535 consumers with the use of structured online questionnaire. A socio-demographic profile of environmentally conscious Slovenian consumer was conducted. It was found that age and gender influenced apparel disposal patterns. Older and female consumers were more likely to donate waste apparel to others in comparison with other participants. The most widespread environmentally conscious consumer behaviour among Slovenian consumers is »purchase of classically styled apparel«. It was found that the frequency of apparel recycling is dependent on the consumer's gender and attitude towards convenience but it does not depend on the consumer's age, status, education and attitude towards responsibility. Furthermore, dependence between gender and the amount of apparel thrown into municipal solid waste stream was not found. In the context of environmentally conscious behaviour in the third part the recognition of four eco-labels present in Slovenia was examined. In Slovenia the majority of consumers are not familiar with the meanings of studied eco-labels. It was found that Slovenian consumers are most familiar with the meaning of Oeko-Tex Standard 100 label, which they also trust the most. The meanings of eco-labels are most familiar to highly educated female consumers in the age range 21-40 years, living in a house located in the city.

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