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RESEARCH AND DEVELOPMENT OF POTENTIAL ADAPTATIONS OF A CONDUCTIVE PRINTED CODE ON CARDBOARD PACKAGING

Short Term Scientific Mission Report

COST Action FP1405 - ActInPak

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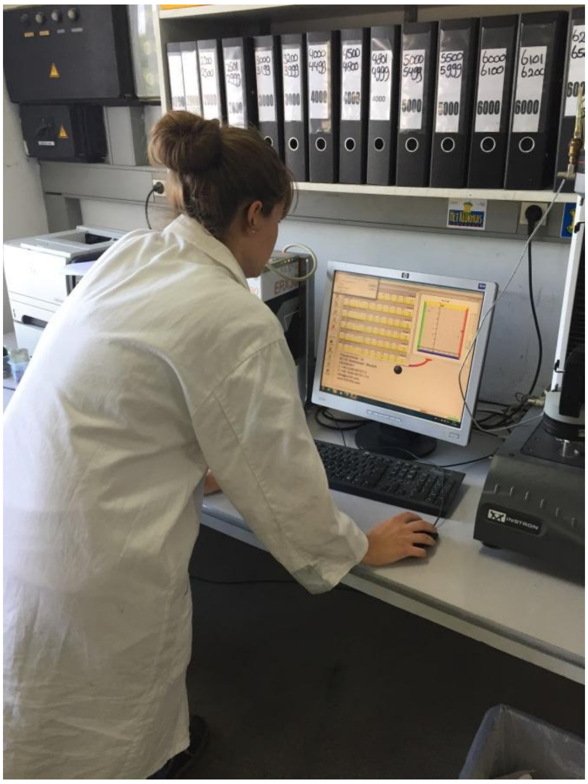

SUMMARY

INTRODUCTION

Bumaga BV and its partner Bergman Media Group are developing Papercode. Currently, the Papercode technology is based on paper cards printed with conductive ink that need to be held between two fingers and touched against a touch-screen of smartphone or tablet in order to enable specific app-content (Figure 1). For some applications, however, it might be desirable for the codes to be printed directly on the packaging or use product. Since it is crucial for the technology to work properly that contact is being made between the body and the conductive ink, some research and development work needs to be done to figure out in which ways the Papercode technology can be embedded in packaging while still remaining functional. The assignment focused on this topic combines printed electronics and packaging to develop smart packaging and includes researching and developing the potential adaptations to the printed codes and developing concepts on how to inform the consumer about how to use the code.

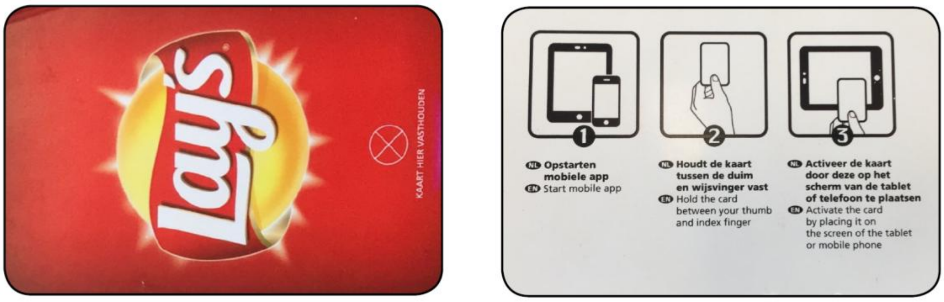

Figure 1: Example of Papercode card, front and back sides

To well understand how Papercode works, it's important to know first, how touch screens of smartphones and tablets work. There are many touch screen technologies like the resistive or the infrared grid technologies. The most use in smartphones/tablets is the **capacitive technology** (Figure 2). A capacitive touchscreen panel consists of an insulator, such as glass, coated with a transparent conductor, such as indium tin oxide. As the human body is also an electrical conductor, touching the surface of the screen results in a distortion of the screen's electrostatic field, measurable as a change in capacitance. Different technologies may be used to determine the location of the touch. The location is then sent to the controller for processing. [2]

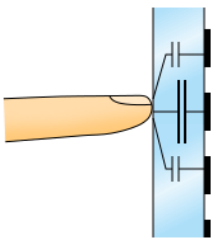

Figure 2: capacitive touch screen [2]

Current smartphone and tablet screens are **multi-touch** screens, which mean that they can recognize the presence of more than one point of contact. For example, to zoom or to make a rotation, two fingers are required (Figure 3). [3][4]

Figure 3: multi-touch screen [4]

When the card is held between fingers, the conductive code becomes a finger extension because it conducts the electrical impulses of the body to activate the touch screen through the code. It uses the multi-touch technology to identify the unique code.

Papercode is currently embedded in a paper card as seen previously, now the challenge is to embed Papercode in packaging or use products while still remaining functional.

I. HOW PAPERCODE COULD BE EMBEDDED IN PACKAGING

A. MAIN ISSUES

1) Regarding substrate

There are a lot of substrates dedicated to packaging but many of them are not supposed to be good **substrates** regarding conductivity. This study will only focus on biomaterials, especially cartons. Corrugated board is widely used in secondary tertiary packaging but also in primary packaging. So far, flutes are full of air so it seems difficult to print Papercode on one side and then to hold it between the thumb and a finger still remaining functional. Folding cartons are more likely to wear Papercode but, it will depend on its **thickness**, **roughness** and **porosity**.

Most of packaging cannot be taken between two fingers, could the Papercode still work when **touching only in one of its sides**? This is maybe one of the most important questions that must be answered. When Papercode is applied to paper card, it is a two dimension reasoning but now with packaging it is a three dimensional problem. Which means substrate is printed when flat and it is then converted. So another question is, could the code be **creased** and **folded**?

Furthermore, packaging is exposed to shocking and rubbing. Care has to be taken about it.

2) Regarding printing

Papercode is currently printed on a paper sheet and then laminated with another paper layer. Advantages of this technique of manufacturing are that the code is invisible, protected and does not interfere with decorative printing layer. With packaging, lamination could not be used in most of case so printing should be reconsidered.

The code could be printed in one side and the decorative ink in the other. The code would not be visible and the decorative ink would not be affected. However this means that the substrate has to be printed twice and the thickness of the substrates could prevent the transit of electricity to the screen.

To promote the system conductivity, the code could be printed before the decorative layer. This makes the code totally invisible. Which would be preferable was to print the conductive ink with the first printing unit and then in the same pass, print the conventional inks. But this is not currently feasible because the silver ink needs to be cured after printing. It would also mean that conventional inks would be printed with waterless offset, that may not be desirable.

So what could be done is printing the conductive ink, curing it, then with a second pass, printing decorative ink. Silver ink is grey; printing conventional ink above it could give color management troubles. In this case, a white layer could be printed before CMYK.

B. CONCEPTS PROPOSAL

Two kind of Papercode integration in packaging could be considered. The first one could be when the code is directly usable, no need to purchase the product and open it (direct code). The second type could be when the code is usable only when opening the packaging or shaping it (indirect code).

1) Direct code

The first idea when thinking about code printed on packaging is to stay in two dimensions because it seems easy to implement.

Starting from the definition of Papercode, the first condition for the code to works is that a physical link takes place between the screen, the code and the body, so the simplest way to create this connection seems to embed a virtual button. The code would be printed and extended by an area dedicated to a finger; it would act as a virtual button to activate the code. One hand holds the smartphone and press the screen to the package. A finger from the other hand would press the button (Figure 4).

Figure 4: "button" – 1 finger

A more intuitive option could be to only use the hand which holds the smartphone. While pressing the screen against the code, some of the fingers could also touch the code (Figure 5). If this option couldn't work, adding the second hand could increase the electricity passing through the code (Figure 6).

Figure 5: "intuitive" – 1 hand

Figure 6: "twins" – 2 hands

Currently, the main condition for the code to work is to be held between two fingers (the thumb and the index finger) because it requires a minimum energy threshold which is ensured by those two fingers.

The solution which seems to be the most reliable because the package and the code would be held by a hand is to print Papercode in several sides of the packaging so the consumer could take the product into its hand and touch the smartphone screen with it (Figure 7). In this case, the code would be creased and folded (Figure 8).

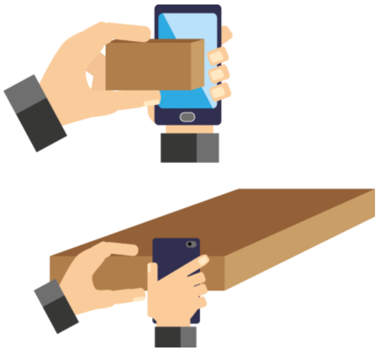

Figure 7: How to use "3D code"

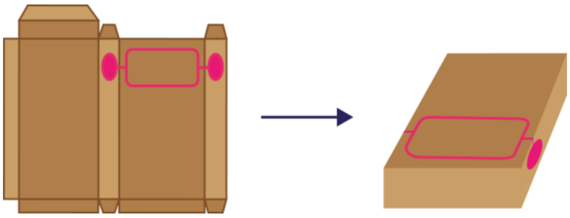

Figure 8: "3D code"

2) Indirect code

In case the previous options could not work, it would be preferable to stay close to the Papercode card concept. Namely, hold a thin code between two fingers.

When opening a box, flat surfaces become accessible so Papercode could be held between the thumb and a finger (Figure 9).

Another way to hold the code between two fingers could be to add perforations so that consumers can punch out a Papercode card (Figure 10).

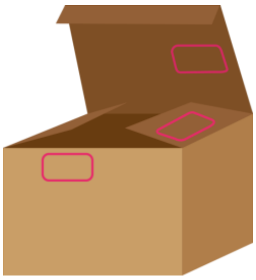

Figure 9: "after opening"

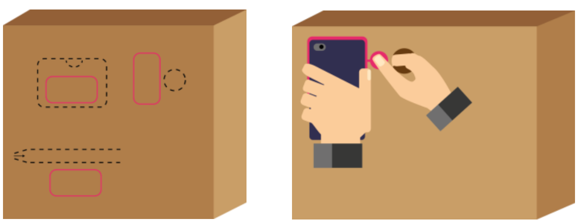

Figure 10: dots-cutting

From these concepts, numerous prototypes and tests could be imagined.

II. EXPERIMENTATION

A. TESTING PLAN

After imagining different concepts, relevant parameters to analyze have been identified.

Different **substrates** with different properties (thickness, porosity, roughness, …) should be printed with conductive ink and then tested to understand in what type of packaging Papercode could be embedded.

Furthermore, different **fingers areas** designs should be printed to evaluate which could be applied to packaging.

Code performance has to be checked after **creasing** and **folding** to know if Papercode could work in three dimensions.

Optical properties of printing layer could be analyzed to prevent color management issues caused by the code. In fact, the printing of the code underneath the decorative layer could be visible so if it is not desired, printing of a white layer between the code and the decorative print could resolve the problem.

Finally, **abrasive tests** should be done to analyze scratches that can be resulted from transport of packaging box because it could break the conductive pattern. To prevent scratches, trying out several ways of applying a **protective layer** could be relevant.

This plan has been sent to Bergman Media Group, the company which prints Papercode. From this, they created designs to print.

B. TESTING DESIGNS

Papercode is printed by offset waterless printing. Waterless printing is an alternative printing system that runs on standard offset presses. The key to waterless printing is a plate that uses an ink-resistant silicone coating to eliminate the need for dampening solution. This process takes time and is more expensive than digital printing. A designs sheet has been created and printed by Bergman Media Group, the company which develops Papercode in collaboration with KCPK/Bumaga. This sheet allowed doing most of the tests explained in the previous part. It has been printed on five different paper or board substrates (170 g/m^2, 200 g/m^2, 300 g/m^2, 400 g/m^2 and a 350 g/m^2 sulphate board) in a 450x320 mm format. Conductive ink pattern is based on a previously used unique pattern with 5 dots.

C. TESTS AND RESULTS

1) Code performance

In order to evaluate code performance regarding different parameters, the first idea was to measure resistance from either side. To do so, a multimeter has been used (Figure 20). But not any value could be measured, ohmmeter acted like if resistance was too high to be measured.

Another way to measure codes performance has been found. It consists of watching how a multi-touch screen reacts when in contact with a code. To do so, smartphone application *MultiTouch Visualizer* developed by Schenzhen Goodix Technology Co. has been downloaded. This application provides multi-touch test, which includes multi-touch drawing (Figure 11-a) and multi-touch position tracking (Figure 11-b) with different colors. The app is also able to show apparition order of dots. [11]

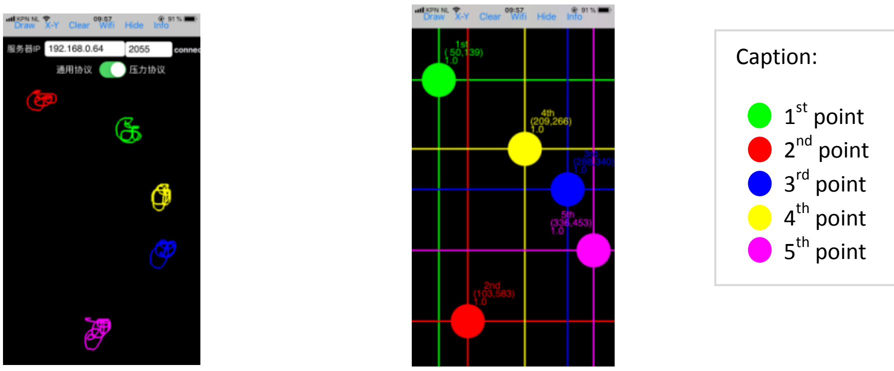

Figure 11-a: multi touch drawing *Figure 11-b: multi touch position tracking*

Figure 11: App overview when five fingers are touching the screen

a) Performance regarding substrate

Each substrate has been tested in a normal use of Papercode. The code was held between the thumb and the index finger and the printed side was rub on a screen. Figure 12 shows how the screen reacted.

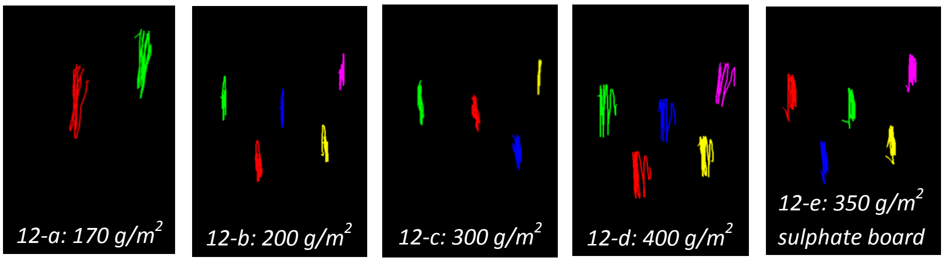

Figure 12: Screen reaction to Papercode printed on different substrates

Papercode printed on a 170 g/m^2 paper does not react well, only 2 dots are recognized by the screen (Figure 12-a). This could be explained by the fact that we cannot put enough pressure on it to establish a good contact with the screen because the paper is not stiff enough.

Other substrates show good performance, code is functional in most of cases. With the 300 g/m^2 paper, only four dots have been detected (Figure 12-c) so the code is not functional but it does not mean that this paper is not good to carry a code, it only shows that sometimes the code does not work due to printed issues or other reasons. Another sample has been tested and was totally functional.

Codes have also been tested with the other side, the non-printed side was placed on the screen instead of the printed side. In this case, the substrate is a barrier between the code and the screen. With all substrates seen above, the code was still functional so it might be feasible to print the conductive code on the inside of a packaging. This test has been done with a corrugated board but as said before, there is too much air is the flutes to enable the passage of electricity.

b) Performance regarding contact method

As seen above, some codes have been tested the same way as the classic Papercode card and it works. So now, different contact methods must be tested to know what could be feasible with packaging.

The first proposal of Papercode embedded in packaging was the one where the consumer places its smartphone on the product and presses a virtual button with the free hand. That means there is only one point of contact between the code and the body (Figure 13). Two types of code have been tested. The first one, code 1, is a code designed exclusively for this application, looking like a button. The second one, code 2, is the classic Papercode pattern.

Figure 13: One finger option

The number of dots detected by the multi-touch app has been counted for twenty three copies of each pattern (Figure 14) and only a thumb was touching the code.

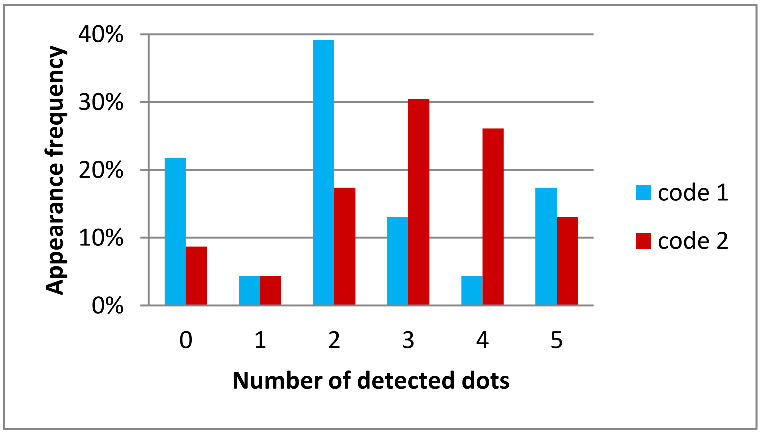

*Figure 14: Frequency of number of dots detected for twenty three **code 1** and **code 2***

Histogram above shows that on 22% of cases, code 1 does not work at all, in most cases it detects 2 dots (39%) and sometimes the code is functional, it detects 5 dots (17%). Code 2 is more stable, usually it detects 3 or 4 dots (56%) but surprisingly, code 1 has been more correctly detected than code 2 (13%).

Both codes are not reliable because screen rarely detects 5 dots, which is the condition for the code to work. Classic Papercode pattern seems to be best option but required improvement. Results may also confirm the hypothesis that a code too long decreases its performance.

A more intuitive option could be to only use the hand which holds the smartphone. While pressing the screen against the code, some of the fingers could also touch the code (Figure 15). This application has been tested with an adapted pattern.

Figure 15: "intuitive" – 1 hand

Nineteen of the twenty codes tested were totally functional which represents 95% of codes. This result is very encouraging considering using the code without being held between fingers.

c) Performance regarding creasing and folding

Embedded in packaging, Papercode might be creased and/or folded but it could break the conductive ink film. This is why some tests have been done to see if Papercode remains functional when folded.

Boxes have been creased and cut with a laser and then assembled. Two kinds of pattern have been tested. One with one fingers area and another with two fingers areas. The first one is folded once whereas the other is folded twice. Code performance has been controlled for several parameters: substrates, box filling (Figure 16), fingers areas and fingers used (Figure 17). The multi-touch app has been used to collect the detected dots.

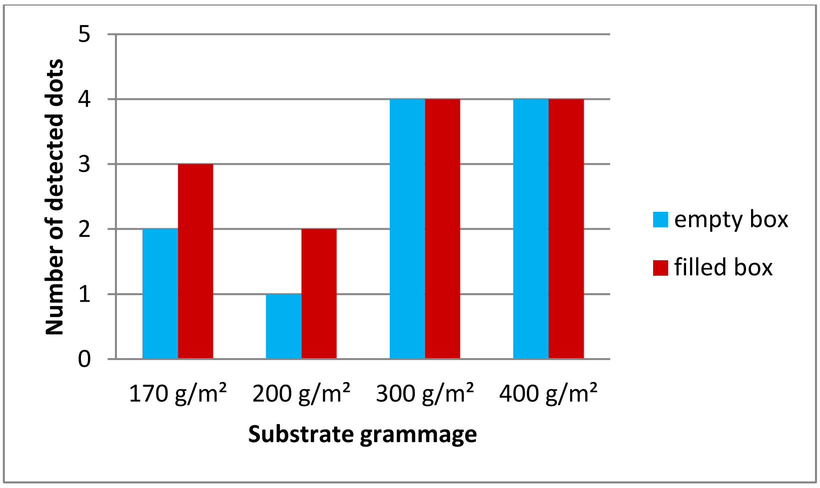

Figure 16: Number of detected dots according different substrates and box filling (Fixed operating conditions: 2 fingers areas)

Figure 16 shows two facts:

- The higher the grammage, the more the code is functional. This corresponds to what was previously seen, boards are more stiff than paper, so they are better to establish a contact area between the screen and the code.
- Boxes with low grammage are more functional when filled than empty because the content keeps the material flat so they can make a better contact area with a screen.

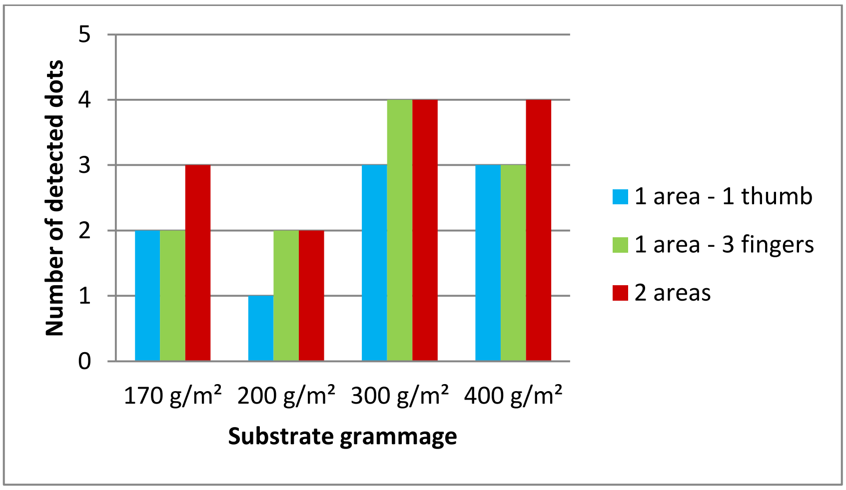

Figure 17: Number of detected dots according different substrates and different body contact (Fixed operating conditions: filled boxes)

Figure 17 shows two facts:
- Boxes with 2 fingers areas give better results than only 1 fingers area boxes.
- When the box has only one fingers area, using 3 fingers seems to be better than only 1 thumb.

Even if a board with two fingers areas seems to be the best options, none of the boxes tested were functional; screen never detected five dots. Four dots out of five were detected, it is enough to say that folding the code is conceivable.

2) Optic and physic properties
   a) Color management

When classic Papercode is printed on a sheet and then laminated with another sheet, the code is totally invisible because it is between two sheets. When applied to packaging or to the use product, there is no lamination possible. Conductive code will be printed on the front or back side of the packaging. Conductive ink is silver based so it is kind of grey and very shiny, it is almost a mirror. This could cause color management issues regarding the other inks used and if the code is expected to be invisible.

There are two different cases to get an invisible code, the first one is to print the conductive code on the inside of the packaging and the second one is to print the code in the front side and cover it with decorative inks. In the first case, packaging is printed both sides (code in the back side and decorative inks in the front side), that could be a restraint because it may increase production time. Board should not be too thick because the code will not be functional (corrugated board for example). To conclude about the second case, tests have been done.

Magenta ink is printed on a white sheet, it is the reference, the goal to reach since we want the code to be invisible (Figure 18-d)

First try: Conductive code is printed then the magenta pattern is printed. Code is still visible and shiny (Figure 18-b).

Second try: A white ink layer is printed between the code and the magenta decorative layer. Shiny aspect has almost disappeared, code is less visible but still (Figure 18-c).

18-a: code *18-b : code+magenta* *18-c : code+white+magenta* *18-d : magenta*

Figure 18: different printing

To go further, spectrophotometer measurements (with a X-Rite ERX30) have been done to calculate L*a*b* values of the three printing. Magenta pattern is composed of many little triangles with different ink coverage so several measures have been done to calculate magenta mean L*a*b*.

Results shown on Table 1 and Figure 19 confirm the previous comments. When the code is covered with a single decorative layer, ΔE is 51 which is very high. When the code is covered by a white layer then a decorative layer, ΔE decreases to 14, it is better but still too high for the code to be invisible.

	L*	a*	b*	c	h	**ΔE**
Magenta	68	38	-13	41	341	ref
Code + magenta	21	22	1	22	352	**51**
Code + white + magenta	58	31	-7	31	344	**14**

Table 1: Colorimetric coordinates of three printing

Remark : ΔE is a standard calculation measure of human visual perception of two-color differences. ΔE =1 is the limit value below which the differences are no longer perceptible, in general , ΔE lower than 3 is acceptable.

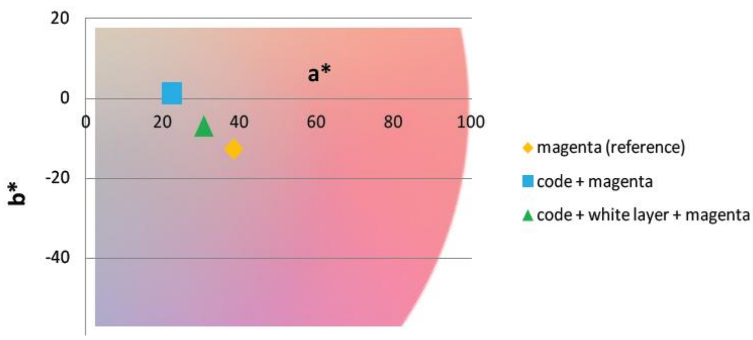

Figure 19: (a, b*) diagram of the three printing*

At the end of this evaluation, it seems that we need to go further. We could try to print two layers of white, very good results are expected but it adds a passage in the press (or two white groups) which adds a cost and time. Or it should be careful to print only very dark hues on the code.

b) Abrasive resistance

Something relevant also in the scope of the packaging focus might be to look at the protection of the Papercode using lacquers/varnishes, while still maintaining the functionality of the Papercode. Scratches that result from use of the cards or for example transport of the packaging boxes might cause scratches in the ink, and when scratches go too deep, they may break the conductive pattern that is necessary for the Papercode to work.

A conventional offset varnish has been applied on a few codes with a rod coater in order to make comparison between code with varnish and code without varnish regarding abrasive resistance. After drying, varnished codes were tested on a smartphone screen and it turned out that code is still functional.

Abrasive resistance measurements have been done with a Taber Type Abrasion Tester (Figure 20). A characteristic rub-wear action is produced by contact of the test specimen against the sliding rotation of two abrading wheels. As the turntable rotates, the wheels are driven by the sample in opposite directions about a horizontal axis displaced tangentially from the axis of the sample. One abrading wheel rubs the specimen outward toward the periphery and the other, inward toward the center while a vacuum system removes loose debris during the test. The wheels traverse a complete circle on the specimen surface, revealing abrasion resistance at all angles relative to the weave or grain of the material. [12]

Figure 20: Taber Type Abrasion Tester

The technique used to interpret results generated with the Taber abrader is the Taber Wear Index (TWI). It indicates rate of wear, and is calculated by measuring the loss in weight (in milligrams) per thousand cycles of abrasion. The lower the wear index, the better the abrasion resistance.

$$TWI = \frac{(A - B) \times 1000}{C}$$

A = mass (mg) of specimen before abrasion
B = mass (mg) of specimen after abrasion
C = number of test cycles

Before test with the Taber abrader, it has been noticed that the white and magenta inks stick poorly to the code surface. After a few uses of a box, ink comes off and lets the silver layer appear. It has been confirm with the use of the abrader, decorative inks are totally removed after a few test cycles.

Two substrates have been tested, the 170 g/m^2 paper, used for the Papercode card and the 350 g/m^2 sulfate board more suitable for a packaging use. Figure 21 shows that the Taber Wear Index of the 170 g/m^2 paper increases earlier than the 350 g/m^2 sulphate board TWI. It means that more scratches are required to totally abrade the conductive ink on the board because the lowest TWI (around 30) correspond to the silver ink layer while the bigger TWI (around 75) correspond to the substrate.

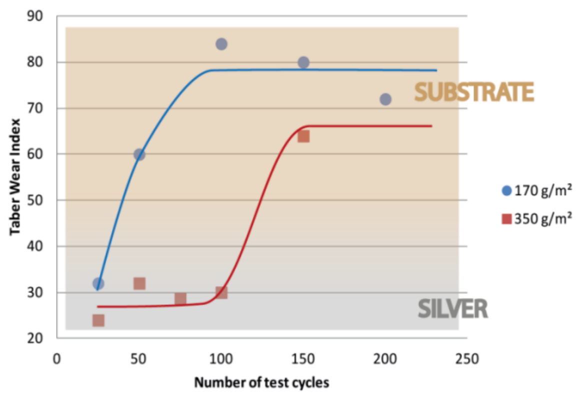

Figure 21: Taber Wear Index according number of test cycles for two substrates
(Fixed operating conditions: no decorative ink, no varnish)

Then varnished and non-varnished codes have been tested. Results show that the TWI of the varnich is very high (arround 250) which could be seen as a fail because the lower the wear index, the better the abrasion resistance but actually it is not that has to be seen.

Figure 22 shows the TWI according to the number of test cycles for a varnished code and a non-varnished code. While the conductive ink is totally removed after 100 test cycles for the non-varnished code, the varnished code has still its conductive layer unbroken. There are three main steps for the varnished code; the first one is the abrasion of the varnish which has required about 100 test cycles. Then the conductive layer is abraded in about 150 cycles and finally there is no more than the board. In the experience, 100 cycles are much in comparison with the use of a box.

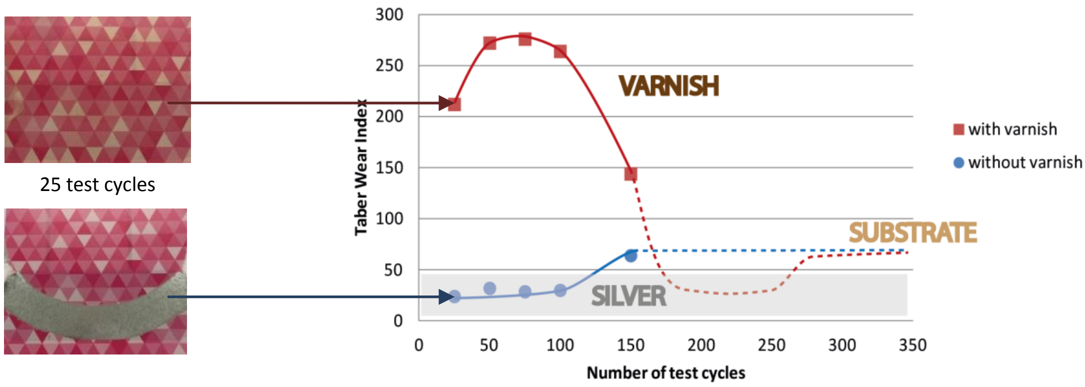

Figure 22: Taber Wear Index according number of test cycles for varnished and non-varnished codes
(Fixed operating conditions: 350 g/m^2 sulfate board, white+magenta layers)

To conclude, silver ink is quite resistant to scratches, normal use of a box could not scratch it until the code breaks. But decorative inks stick poorly to the conductive surface so varnishing it seems to be a good way to protect the decorative layers and the code in the same time.

CONCLUSION

To sum up, substrates with high grammage were the best and they were thin enough for the code to work both sides. The concept for which consumer has to touch a virtual button with one finger seems not to be an option to follow because the code was rarely completely detected. But the concept in which user touches the packaging while he holds its smartphone is intuitive and gave good results. Creasing and folding do not break codes, folded box show good results but it was not totally functional.

If the code has to be invisible, it could be printed inside packaging or outside and cover with several ink layer. In fact printed a decorative layer on top of a code is not enough to hide it. Adding a withe layer improves it but is still not enough to completely hide the code. Silver pattern is highly resistant to scratches but decorative layers printed on code stick poorly so are removed when a finger rub the surface. A varnish should be coated at last to protect printing.

BIBLIOGRAPHY

[1] Anonym. Packaging Machine.2017 [online]. Available on :< http://www.teknologiprima.com/products/packaging-machine/> (accessed 11/06/2018)

[2] Anonym. Capacitive sensing.2018 [online]. Available on :<https://en.wikipedia.org/wiki/Capacitive_sensing> (accessed 05/06/2018)

[3] Anonym. Multi-touch technology how it works.2018 [online]. Available on :< http://www.sky-technology.eu/en/blog/article/item/multi-touch-technology-how-it-works.html> (accessed 05/06/2018)

[4] Anonym. Multi-touch.2018 [online]. Available on :< https://en.wikipedia.org/wiki/Multi-touch> (accessed 06/06/2018)

[5] Anonym. Unlock the potential of paper.2016 [online]. Available on :< http://www.t-ink.com/products/touchcode/> (accessed 06/06/2018)

[6] Anonym. T+Sun.2018 [online]. Available on :< http://www.sunchemical.com/product/t-sun/> (accessed 06/06/2018)

[7] Rick Lingle. Touchcode ink technology customizes consumer, package interaction. 10/12/2014 [online]. Available on :< http://www.packagingdigest.com/smart-packaging/touchcode-conductive-ink-technology141210> (accessed 06/06/2018)

[8] Charbax. Jones Packaging anti-counterfeiting using T+Sun Touchcode touchscreen sensitive coding.Youtube. 07/02/2016 [online]. Available on :<https://www.youtube.com/watch?v=OuiOdrXa7sw&t=239s> (accessed 05/06/2018)

[9] Anonyme. Interactive Product Solutions. 2017 [online]. Available on :< https://interactiveproductsolutions.co.uk/touch-transfer-technology/> (accessed 08/06/2018)

[10] Anonyme. ESMA Driving Print Excellence. Functional Printing: Touch Transfer-Interactive Packaging. Youtube. 23/02/2017 [online]. Available on :< https://www.youtube.com/watch?v=U5ZWHd4196Q> (accessed 08/06/2018)

[11] Anonym. App Store Preview. MultiTouch Visualizer. 2018 [online]. Available on :<https://itunes.apple.com/us/app/multitouch-visualizer/id376335100?mt=8> (accessed 09/07/2018)

[12] Anonym. Taber Industries.Taber Abraser (Abrader). 2018 [online]. Available on:< https://www.taberindustries.com/taber-rotary-abraser> (accessed 18/07/2018)