User Experience Functions (UXFs) and User Interface Functions (UIFs) of Optical Authenticity Features

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ABSTRACT

Banknotes often fail on the design of authenticity features for public usage. Two models are introduced, bringing clarity in the largely unknown domain of human behaviour with banknotes, the Coaster-model and the 4M-model. Third, the perception phenomenon of heuristic quality versus rule-based quality is introduced. These three topics are helpful to understand why banknote design falls short on public authenticity features.

The public attitude towards an authenticity self-check is changing because of two developments in the cash cycle, a controlled issue of banknotes via ATMs and an increase of retailers checking banknotes with devices. As a result confidence in the authenticity of banknotes is on the rise and the need for an authenticity self-check falls. A third cause contributing to the declining public interest in an authenticity self-check is the design of the public authenticity features, which is user-unfriendly. Banknote designers should have more eye for features meeting user requirements, balancing two different user functions of the Coaster-model, respectively 'keeping confidence' and 'checking authenticity'.

In 2013 the first design of the second series of euro banknotes was issued. The promoted features for public usage are mainly optical authenticity features, being a portrait hologram, a colour changing rolling bar and a watermark. Studies carried out in the Netherlands show that the general public does not pick up these features. The cause should be sought in their technology-driven design instead of a use-centered design approach based on user requirements. A review of user requirements for foil features and colour features is provided and, based on these requirements design concepts for foil and colour features are presented.

Keywords: Banknote design, user experience functions, user interface functions, optical authenticity features.

1. INTRODUCTION

Two overarching models are introduced, the Coaster-model (item *i*) and the 4M-model (item *ii*). A third subsection introduces the understanding of a heuristic quality and a rule-based quality (item *iii*). These three topics provide a structure for banknote designers to understand human behaviour with banknotes, including perception issues. Such knowledge is necessary to design optical authenticity features meeting user requirements. The observations and conclusions are mainly based on opinion polls studies carried out in the Netherlands. One has to be reluctant to generalise the findings in just one country to a global scale, although at least one study reported that no major cultural differences were found between six nations of the Eurosystem [15].

i. Coaster-model

Inspiration for a method to organise the user functions of a banknote came from the design of computer screens, like display design for websites, apps, games or other computer applications. Such *interaction design* shows several notable similarities to *banknote design*, explainable as both are a form of graphic design or 2D-design, a design discipline next to industrial design or 3D-design. Two terms are borrowed from this knowledge domain of Human Computer Interaction (HCI), *user experience* (UX) and *user interface* (UI). Especially in shorthand, UX and UI, are compact, simple and straightforward terms. To indicate the banknote's user functions, two novel abbreviations are proposed, UXFs (User Experience Functions) and UIFs (User Interface Functions). This split in user functions provided the basic structure of the *Coaster-model* as shown in figure 1 [17]. The model received this name because it can be explained on the back of a beermat or coaster. The second meaning of a coaster is a coasting ship - especially as used by the Coast Guard - symbolising the guardian function. During the design process the Coaster-

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model may prevent drifting away from the original design targets.
People use banknotes to pay each other, which is its main *economic function*. Saving or hoarding is another economic function of banknotes. During a payment the user has attention for one of the key *user functions*, usually for its value (UIF 1). Attention may also be given to the banknote's authenticity (UIF 3) or to an experience.
Before people will actually use a new banknote design, they have already received a first impression, an impression determined by UX-functions. For example, people qualify a new banknote design as beautiful or ugly. Doing so they are in *aesthetic mode* (UXF 2). As UX-functions are experienced first, these functions are listed in the first column of the Coaster-model and the UI-functions are listed in the second column.
The user interface functions were prioritised by the Dutch in 2013, in the order as given in figure 1 [53]. Together, the UI-functions define the *usability* of the banknote, which may be reported by a *usability score*, which came out for euro banknotes to be 6.4 on a scale from 1 to 10 [18]. The order of the user experience functions is set by the author and is argued as follows. When people receive a foreign banknote, they will show less interest in its design as when they receive a (new) banknote of their own currency area. This assumption is the argument to start with 'recognising identity' (UXF 1). Second, within an instant, people have their judgement ready on the aesthetics, they find the banknote beautiful or ugly (UXF 2). Subsequent UX-functions are 'keeping confidence' (UXF 3) and 'reacting on the main image' (UXF 4). The two upcoming user experience functions received a position at the bottom, 'expecting sustainability' (UXF 5) and 'linking to information technology' (UXF 6).

Key user functions of a banknote	
UXFs **User Experience Functions**	**UIFs** **User Interface Functions**
1. Recognising identity	1. Recognising value
2. Judging aesthetics	2. Handling
3. Keeping confidence	3. Checking authenticity
4. Reacting on main image	4. Receiving the communication message
5. Expecting sustainability	
6. Linking to information technology	

Figure 1.
The Coaster-model, a model of the key user functions of a banknote. User functions are split into User Experience Functions (UXFs) and User Interface Functions (UIFs) [17].

Norman (2013) also introduced the "total experience" of a design, which is the result of emotional satisfaction and usable functions. In terms of the methodology developed, UXFs and UIFs will bring the Total User Functions (TUFs) of a banknote:

UXFs + UIFs = TUFs.

ii. 4M-model
Figure 2 presents the *4M-model*, a model of the 4 Modes of *giving attention* to a banknote [18]. This scheme has been compiled by bringing together the work of Asch [1] and Kahneman [34]. Following the work of Asch, two banknote modes are introduced: *configural mode* and *feature mode*, respectively processing a product as a whole or in parts. Kahneman introduced the two brain modes, the brain is either active in *automatic mode* (fast) or in *controlled mode* (slow). Following Kahneman, a cash transaction is done on autopilot, like driving a car or walking a stair; the human brain processes the sensory information fast, in Kahneman's terms in *System 1*. When the brain is in a controlled mode, giving full attention to a banknote, information is processed slow (or in *System 2*). The 4M-model is created by bringing together the two banknote modes and the two brain modes. Banknote designers will recognise the four typical usage scenarios of the 4M-model. When people are distracted during the payment transaction (M1), they will not give attention to a banknote. This situation is illustrated by Derren Brown with his funny movie "Paying with paper" (2007), demonstrating that in this situation people will actually accept blank paper as a payment. The second mode (M2) represents persons checking a banknote quickly on one or two favourite features, like a check for a thread.

The third mode (M3) concerns the situation that a just received banknote is compared to another, similar banknote, not received at the same moment in time as the first banknote. Finally, any central bank employee will recognise the fourth mode (M4), a proper authenticity self-check by following the instruction leaflet of the central bank.
Mimicked banknotes slip through in M1, not in M2, M3 and M4. People are very well able to detect a counterfeited banknote when they pay attention, as was concluded in two large scale studies done [31, 51]. Key to the detection of counterfeited banknotes is giving attention, which is usually not the case. By far the most common situation is people operating a banknote in *denomination mode* (UIF 1) while they do not pay attention (M1).
With 10 user functions of the Coaster-model and four operating modes of the 4M-model, there are at least 40 situations of how people may perceive a banknote.

Giving attention to a banknote		
Brain mode	Banknote mode Perception of banknote in	
	Configural mode	Feature mode
Automatic mode (fast)	**M1** **No attention** *Paying with blank paper**	**M2** **Attention to single feature** *Thread or watermark*
Controlled mode (slow)	**M3** **Attention to complete banknote** *Compare with other banknote*	**M4** **Dedicated attention** *Following central bank leaflet*

**) Movie by Derren Brown (2007), available on Youtube.*

Figure 2.
The 4M-model, a model of the 4 Modes of giving attention to a banknote [18]. In italics an example is provided for giving attention to a banknote in *authenticity mode.*

iii. Heuristic quality and rule-based quality
Kahneman not only introduced the two brain modes, automatic and controlled mode, he also emphasised on the importance of heuristics and biases [34]. Heuristic refers to discover, knowledge gained by incidence. Synonyms for heuristics include rules of thumb, presuppositions, cognitive illusions and intuitive flaws. Applied to a product like a banknote, the *heuristic quality* is the quality people *expect* that the product will show, based on people's general experience-derived knowledge on low and high qualities. The opposite term of heuristic quality is *rule-based quality* and refers to *knowledge* on the individual features. However, such an understanding was known before Kahneman opted for heuristics, as illustrated by the various terms relating either to the complete banknote or to single features (figure 3).

	 **Overall banknote**	 **Individual features**
Perceived quality	Heuristic	Rule-based
Perceived by public in	Automatic mode (fast) Configural mode Inattentive Holistic manner	Controlled mode (slow) Feature mode Attentive Focussed manner
Long-term memory	Implicit	Explicit

Figure 3.
Overview of terminology concerning the overall banknote and its features.

However, the heuristic quality of a banknote is a clarifying term to understand people's behaviour with banknotes, as will be illustrated with some examples. First, when comparing an original and a counterfeited banknote, people expect that the original is the one showing a more saturated colour or a more sharper design. Such assumptions may turn out to be wrong, as an original banknote may have less brighter colours than an imitated banknote or the original may look blurred compared to an enhanced reproduction. A second example is that a more glossy foil is expected to be the original. The heuristic quality also explains people's first reaction when they say that an upgraded banknote looks phoney, which is a third example. A heavily damaged banknote, repaired with cello tape, is one more example. Repaired banknotes trigger awareness, just as limp banknotes deliver a conspicuous feel. Although genuine, people expect that something is wrong, as the genuine banknote does not match the heuristic quality.
The focus of modern banknote designers is on feature mode, rather than on configural mode, an incomplete approach, as "the note itself does not explain which security feature should be inspected by whom" [7].

2. PUBLIC ATTITUDE TOWARDS AN AUTHENTICITY SELF-CHECK

To be successful, a banknote feature should receive attention as elaborated in section 1. Independent of its design, it seems that people are less-and-less inclined to give attention to the authenticity of a banknote and they are right. In daily payments people may trust their banknotes, which starts with a banknote withdrawal from an ATM. Banknotes coming out of an ATM do *not* have to be verified, at least not in the Eurozone. All euro banknotes which are used to fill ATMs are checked on genuineness and fitness before they are re-issued. This situation is the result of the decision of the European Central Bank (ECB) on recirculation of euro banknotes [24]. The majority of these genuine ATM-notes are brought to shops, where people receive their change back in lower denominations and coins. People witness retailers passing banknotes more-and-more through devices, a further encouragement of their confidence in the authenticity of banknotes. These two developments in the cash cycle, genuine notes from ATMs and retailers checking banknotes, changed the attitude of the Dutch towards an authenticity self-check of banknotes. A change which can be explained by the Coaster-model as a shift from checking authenticity (UIF 3) to increased trust (UXF 3). The change observed, from UIF 3 to UXF 3, is supported by measurements showing that people are less-and-less inclined to check banknotes on its authenticity (subsection 2.1). As a result of the two identified developments in the cash cycle, people have a high trust in their banknotes as indicated by measurements carried out in Canada and the Netherlands (subsection 2.2). Finally, it will be demonstrated that the design of public authenticity features fails, as their design does not correspond to the general user requirements. The result is that current banknote designs do not encourage people to do an authenticity self-check and therefore, once more as a consequence, people rely on their faith in banknotes being authentic (subsection 2.3).

2.1 Declined interest in a self-check on authenticity (UIF 3)

The general public only incidentally reports a counterfeited banknote, so is the experience of De Nederlandsche Bank (DNB). About 10 % of the counterfeits are detected by retailers and the large majority, about 90 %, by commercial sorting systems operated by CIT-companies (Cash In Transit). These experimental data are in line with the outcome of two studies within DNB's biannual researches to people's attitude towards the need of an authenticity self-check, respectively in 2013 [53] and 2015 [44]. People may trust the banknotes withdrawn from an ATM and they will also rely more-and-more on the retailer, as they see retailers checking banknotes more often, like is the case in the Netherlands (table 1). Dutch retailers using a device increased from 55 % in 2007 to 80 % in 2015. Checks under UV-light are more-and-more replaced by checks with an automatic device, in 2015 about 1/3 of the retailers check with UV-lamps and about 2/3 checks with an automatic device [19].
These two developments, genuine notes received from an ATM and retailers obviously checking banknotes, make people more confident on the genuineness of their banknotes, resulting in a large majority of the Dutch residents telling not to have checked the authenticity of a banknote in the last five years as indicated by table 2 (65 % in 2013; 62 % in 2015). Even more illustrative is that they do not expect that their behaviour will change in the future (53 % in 2013). The Dutch respondents who did carry out an authenticity check said, as reported in table 3, that they did so because of the appearance of the received banknote (46 %). People in other countries may have a more active attitude towards an authenticity self-check, like for example in Mexico. Unlike the Dutch, the majority of the Mexicans (60 % in 2014) tell that they do check their banknotes [3]. These quarterly Mexican measurements started in 2008 and are a fine example of longitudinal data on the behaviour of banknote users.

The aging of the population in modern societies is a specific concern, as older people verify banknotes received less often than others [53]. A German study reported a similar finding for the attitude of elderly German citizens towards an authenticity self-check [40]. Elderly Germans have a high trust in the euro banknotes they receive and do not see a need for a check on their genuineness.
People may trust ATM-notes and may observe retailers verifying banknotes, but this perception does not cover low denominations, which may remain unchecked. However, low values are usually not mimicked or appear in smaller quantities as reproductions of high ATM-denominations. The risk of damage caused by these lower values is therefore smaller. It seems that an authenticity self-check is only needed in specific situations like on markets, large entertainment events or purchasing a product via internet platforms from private persons [e.g. 50].

	Eurozone Average (%)	**Netherlands (%)**			
	2009	2007	2009	2011	2015
Ultraviolet lamp	19	35	33	31	24
Infrared viewer	8	4	3	3	-
Automatic device	8	16	22	30	56
Do not use any tools	54	45	40	36	20

Table 1.
Use of authenticity devices by retailers in the Eurozone [49] and the Netherlands [29]. As of 2012 figures are no longer available, as the branch organisation providing these figures has terminated these studies. The 2015-figures are reported by De Nederlandsche Bank [19].

Attitude towards an authenticity self-check of banknotes	**Netherlands**	
Year	**2013**	**2015**
Number of respondents	1,020	1,010
I did not consider a self-check	52 %	54 %
I did consider a self-check, but did not do it	13 %	8 %
I checked once or more in past 5 years	35 %	38 %
I do not expect my behaviour will change	53 %	-

Table 2.
Public attitude towards an authenticity self-check in the Netherlands [53, 44].

Why did you do an authenticity self-check?	**Netherlands**
Year	**2013**
Number of respondents	1,020
1. Appearance of the banknote	46 %
- Dirty, pale, wrinkled, damaged	*22 %*
- Paper felt different, too nice, too new	*19 %*
- High-value banknote	*3 %*
- Colour seemed different	*2 %*
2. Out of curiosity or habit	22 %
3. Part of my job	13 %
4. Heard about falsifications and/or security features	6 %

Table 3.
Response on the question “Why did you do an authenticity check in the past five years?” [53].

Vicious circle
The changing attitude of the public brings central banks in a vicious circle as shown in figure 4 [15]. The circle starts with the public not giving attention to authenticity of the banknote, because of their high trust. As a result of reduced interest of the public in authenticity, counterfeiters settle for a lower quality of mimicked notes, as indicated by the *Simple Method* [15]. This lower quality makes it easier to distinguish between a real and a counterfeit note. This segment of the circle provides central banks the argument that it is easy to see the difference between real and imitation. The vicious circle of figure 4 may be broken when the number of counterfeits is increasing, a situation expected to make people more alert.

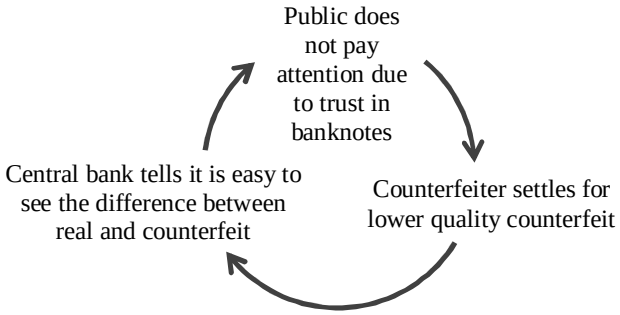


Figure 4.
Vicious circle of public attention to authenticity check.

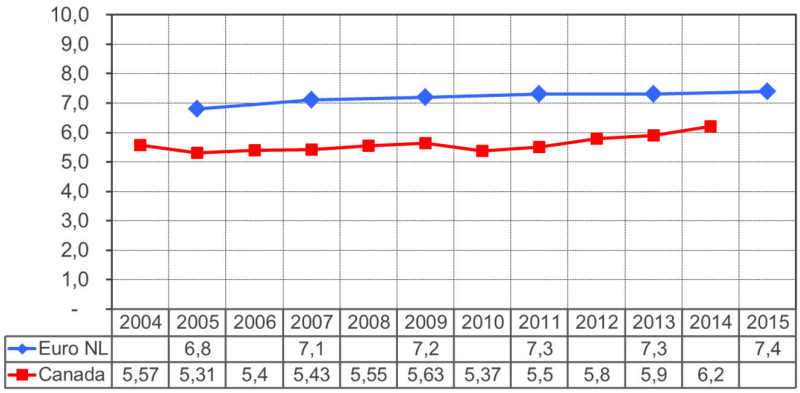
2.2 Increased confidence in banknotes (UXF 3)

Confidence in banknotes (UXF 3) is a key user experience function and can be monitored (item *i*). User functions include several *user sub functions*. In case of 'keeping confidence' (UXF 3) user sub functions are the time spent on an authenticity check (item *ii*) and an aversion of the public to obtrusive authenticity checks (item *iii*).

i. Increased trust in banknotes being authentic
Confidence in the authenticity of banknotes is periodically measured in Canada and in the Netherlands, respectively since 2004 and 2005 [15]. Although the scores can be compared on a scale from 1 to 10, the measurement method applied is not similar. Figure 5a provides the latest results, demonstrating that over the last decade confidence in banknotes is high and stable. This is a remarkable finding, as the number of counterfeits in both countries were not stable. In Canada the level of counterfeits reached its top in 2004 counting 470 c/mnic (counterfeits per million notes in circulation) and came down in the following years below 50 c/mnic. Also in the Netherlands the number of counterfeits fluctuates, as shown in figure 5b, peaking at 65 c/mnic in 2009 and increased in 2015 to about 70 c/mnic. The graphs of figure 5 lead to the assumption that up to a level of 500 c/mnic the level of mimicked banknotes does not seem to be of influence on people's trust in banknotes. The graph in figure 5a shows a slight upward trend for the trust of the Dutch in their euro banknotes. This upward trend is mainly caused by the increase of respondents providing a score of 8 or higher, as provided by figure 6.

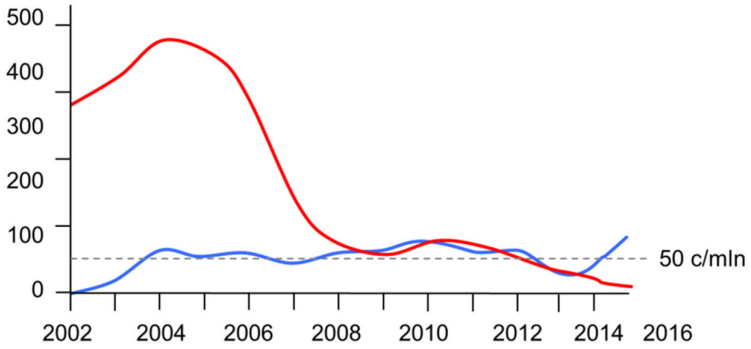
ii. Time spent on an authenticity check
The time needed to verify a feature is probably the most relevant user requirement for an authentication self-check. Studies have been carried out on the *inspection time of single features* and on the *inspection time of a complete banknote*. Two studies report on the inspection time of single features and reported in table 4, respectively a study on Russian rouble banknotes [39] and a study on Canadian dollar banknotes [2]. First conclusion is that checking a single feature may take 3 s up to 18.4 s. Second, the two studies report quite different figures for the authentication of a similar feature, like a watermark and a security thread. These different values are explainable, because the instruction given to the respondents was different. In case of the Russian Rouble banknotes respondents were asked to be as accurate as possible, not worrying about the time, while the Canadian respondents were asked to be as fast as possible while optimising accuracy. Another difference with the Russian method, using common banknotes, is that features in the Canadian experiment were masked out, while the rest of the banknote was covered. However, both studies indicate that the time threshold of an authenticity check of one single authenticity feature is at least 3 s. Another study reported on the inspection time of a complete banknote. Respondents spend 5.3 s on verifying a euro 50 banknote; the front was kept up for 3.5 s and 1.8 s was spent on the reverse [38].

a)



CONFIDENCE

b)



COUNTERFEITS

Figure 5.
Relation between confidence in banknotes and the number of counterfeits.
a) Confidence levels are stable in the Netherlands and Canada .
b) Number of counterfeits vary in the Netherlands and Canada.

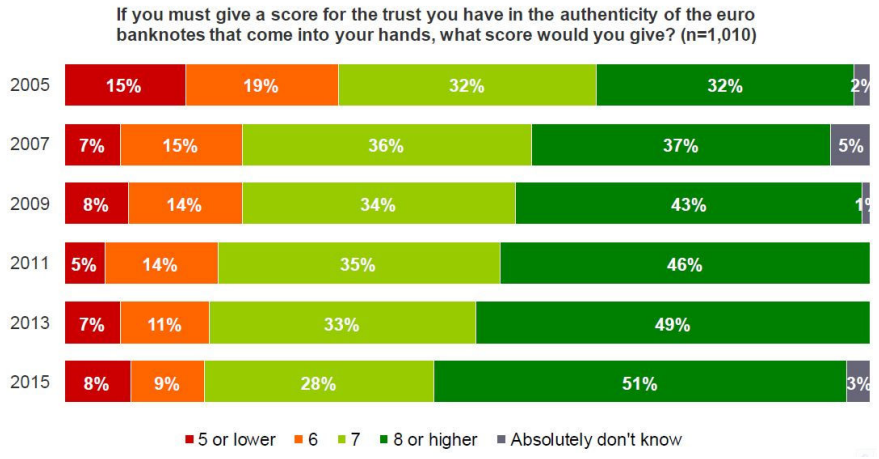


Figure 6.
Increased confidence in the authenticity of euro banknotes in the Netherlands over the years 2005-2015.

Most likely, people will be prepared to spent more time on high value banknotes like a 100 dollar banknote, than on low denominations like a 5 dollar note, although no supporting studies seem to be available. Information on how much time people may spend on the authentication of a complete banknote may also be derived from studies done on the detection of counterfeits. Subjects may receive different time slots to judge whether a banknote is genuine or not, varying from 2 s [31, 48] up to 7 s [35]. A recent large scale study focussing on the influence of soil on the detection of genuine and counterfeited banknotes within a pile of banknotes reported an average authentication time of 6.3 s [51]. Experienced people like retailers needed less time (5.0 s). Furthermore it was reported that spending more than 10 s on a banknote did not lead to higher scores for judging correctly whether a banknote is a counterfeit or not.
Electronic means of payments may also set a bench mark for the time spend on an authenticity check. A *contact less payment* by a debit card takes only 7 s, while a cash payment takes 14 s and a standard debit card payment using a PIN-code 17 s [47]. Furthermore, it is the intention of the National Forum on the Payment System in the Netherlands that in 2019 electronic payments will be credited to the payee's account within 5 seconds [20].
All this leads to the following tentative conclusion. Verification of a single public authenticity feature takes at least 3 s. When three features have to be checked will take at least 9 s, above Lingnau's finding of 5.3 s and the other studies introduced which indicated a maximum of 6 to 7 s. Retracing, if three features should be verified within 6 s, each feature may take about 2 s. The preliminary conclusion is that an authenticity check of a single public feature may take between 2 s and 3 s; a threshold to take into account when designing new optical authenticity features.

Public security feature	**Reported checking time**	
	Central bank of Russia (2002)	Bank of Canada (2010)
	As accurate as possible, not worry about the time	As fast as possible, while optimizing accuracy
1. Watermark	8	4
2. Security thread	10.1	3.5
3. Holographic stripe	-	3
4. See-through register	-	5.5
5. Optically Variable Ink (OVI)	3.1	-
6. Latent image	18.4	-

Table 4.
Reported time to check a public security feature based on two different instructions. In case of the RUB- banknotes people were asked to be as accurate as possible, not worrying about the time. In case of the CAD-banknotes respondents were asked to be as fast as possible while optimizing accuracy.

iii. Obtrusive authenticity checks
Collective use of banknotes implies that people have to trust each other on the genuineness of banknotes. An obvious check can be perceived as if a person does not trust their fellow citizens and people may feel offended. Therefore such checks can be experienced as impolite or even as offending. The *Feel, Look, Tilt* method is promoted by the ECB to authenticate banknotes [e.g. 26]. The first check, feel, can be done discreetly, but the action of look brings the first hesitations. Look refers to two situations, looking in reflection and looking in transmission or respectively *look-at* and *look-through*. For look-through people have to hold the banknote up to the light, an obvious action, which may hold people away from an authenticity check. The Bank of England advocate that such action should not be seen as offending or mistrust and should be seen as normal behaviour (figure 7a). A watermark is an old feature, dating back to the time that banknotes were only used by merchants and a look-through action was probably accepted. However, new developed features do not seem to take into account the public's reluctance to obtrusive authenticity checks. Almost all new optical authenticity features ask for human actions which cannot be done secretly, like in case of the "hidden numbers" in the polymer banknotes of the Bank of Canada (figure 7b) or in case of the window-feature in the new euro 20, issued in 2015 and part of the "Europa series" (figure 7c). Instead of developing look-through and tilt features, feel and look-at features should be developed, as they match better to the user experience requirement of a delicate authenticity check [15].

Bank of England, 2006 | Bank of Canada, 2011 | European Central Bank, 2015

a) b) c)

Figure 7.
Central banks promoting obtrusive methods for an authenticity self-check by the public.
a) Checking a watermark. Bank of England (2006) [6].
b) Checking 'hidden numbers' in a polymer banknote, using focussed light, e.g. a halogen lamp. Bank of Canada (2011) [4].
c) Checking a 'window' with the portrait of Europa in the redesigned euro 20 (2015). Public domain.

2.3 User-unfriendly public authenticity features (UIF 3)

The foregoing can be summarized as follows. People do not see any need to check banknotes coming out of an ATM, neither do they see a reason to verify the change received from a retailer (subsection 2.1). As a result, people have a high, stable and slightly increasing confidence in their banknotes (subsection 2.2). There is a third cause why people may not carry out an authenticity self-check on authenticity features, their design does not meet the public's user requirements, the subject of this section.
Central banks investigate only marginal in researching user preferences. As banknote design is an activity that comes along once in a decade, many central banks do not have a design manager and rely on their printer or copy what other central banks are doing. Central banks may also show a 'father knows best attitude', a rather paternalistic approach when it comes to banknote design. However, although not many, some studies have contributed on insights on public preferences for public authenticity features. First the public's knowledge of authenticity features is presented (item *i*), followed by a study on general preferences for public authenticity features by the use of conjoint research (item *ii*). Public's preferences for authenticity features throughout a series have also been subject of study, like similar or different features for low and high denominations (item *iii*). More detailed studies have been carried out on public preferences for shiny foils and glossy inks, which will be introduced in respectively section 4.1, 4.2 and 4.4.

i. Knowledge of authenticity features
Public preferences for authenticity features is apparent from the spontaneous knowledge of authenticity features. Started in 1983, knowledge of authenticity features is part of the biannual polls initiated by De Nederlandsche Bank [e.g. 12]. During the decades the average public's knowledge of correctly mentioned authenticity features has more than doubled, increased from 1 in 1983 to 2.3 in 2002, the year of the introduction of the euro. Since then this figure is quite stable, although there is a tendency to decline, as is the case in 2013 and 2015 (table 5). This decrease is reflected in the average knowledge of correct authenticity features, which fall from 2.1 in 2013 to 1.9 in 2015.
In 2013 and 2014 the first two euro banknotes were introduced of the Europa series, respectively 5 and 10 euro. Their introduction was accompanied by a large-scale information campaign. However, this did not lead to an increased public knowledge of the authenticity features. On the contrary, the recollection of the promoted features of the second series of euro banknotes scored lower; the knowledge of the watermark declined from 79 % (2013) to 71 % (2015) and the knowledge of the foil from 57 % (2013) to 37 % (2015). The new introduced rolling bar or emerald number, sold by the manufacturer under the name "Spark", remains unnoticed, scoring just 1 % (2015). Also the theme of the Europa series did not come across as will be elaborated on in section 3.

Public knowledge of authenticity features	**Netherlands**	
Year	**2013**	**2015**
Number of respondents	1,020	1,010
1. Watermark	79 %	71 %
2. Hologram/silver foil	57 %	37 %
3. Security thread	13 %	14 %
4. Raised ink	14 %	12 %
5. Glossy gold stripe	3 %	5 %
6. Colour changing ink (ES1)	3 %	3 %
7. Rolling bar (ES2)*	-	1 %
Cannot recall any authenticity feature	6 %	13 %
Average number of correct authenticity features	2.1	1.9

Table 5.
Overview of the public knowledge of authenticity features in the Netherlands in 2013 and 2015 [53, 44].

ii. Public preference for general design concepts of public features
Conjoint research is a statistical technique offering properties or attributes to respondents in different sets [27]. This technique of market research determines how people value different features that make up an individual product or service and is applicable to banknotes, as exercised in 2008 in the Netherlands [15]. Research subject was the euro 50 banknote and a total of six different attributes of the public authenticity features were distinguished as listed in table 6. The outcome is that the location of the features is judged as the most important characteristic and the appearance of public authenticity features is seen as the least important. This study also reported that when public authenticity features would be verifiable at one glance, this would give the strongest boost to a new euro 50 banknote design (deviating + 17 % of the attribute level; the existing euro 50 is used as reference).

Attributes of public authenticity features of euro banknotes	**Score in %**
1. Location of authenticity feature	30
2. Number of authenticity features	23
3. Pictorial element (type of image)	18
4. Degree of complexity	13
5. Degree of conspicuousness	9
6. Appearance of authenticity features	6

Table 6.
Relative importance of the characteristics of the public authenticity features on euro banknotes as seen by the Dutch.

iii. Public preference for similar or different features within a series
To save costs, central banks may opt to divide a series in sections, like low and high denominations. Lower cost features are applied in the lower denominations and more costly features in the higher denominations. Dividing a series of banknotes in two or more parts complicates public information tools and is not in the interest of the banknote users either, as may be concluded from studies done on euro banknotes [10, 15]. The first series of euro banknotes, “Ages and Styles of Europe”, is split in low euro denominations (euro 5, 10 and 20) and high denominations (50, 100, 200 and 500). Low and high denominations show two public authenticity features which are different, respectively a foil stripe and a gold shiny band on the low denominations and a foil patch and a colour changing feature on the high denominations. As early as in the preparatory phase of the “Euro 2002 Information Campaign” in 2001, this distinction was found difficult to communicate [22, 23]. For each description - as well as for the illustrations

- separate instructions had to be developed for the foil - stripe and patch - and the special inks, the gold shining band (iridescent stripe) and the colour changing feature (Optically Variable Ink or OVI). Despite this effort, most cash handlers (close to 70 %) did not know that there are two groups of banknotes having different authenticity features [10]. Also, at least 9 % of the subjects believe there is a foil stripe on the 50 euro banknote, although the euro 50 has a patch. Asked for their preferences, one fourth of the respondents (25 %) would like to have similar authenticity features on all banknotes and the majority (75 %) of the participants does not have a preference, which is seen as a result of the earlier reported finding that the public shows a laissez fair attitude towards an authenticity self-check (subsection 2.1).
All active public features of the banknotes of the Europa series are positioned on the front, in line with the results of the conjoint research and facilitating communication tools. However, opposite to the findings reported, this series will be split in three parts: low denominations (5 and 10 euro), medium denominations (20, 50 and 100 euro) and high denominations (200 and 500 euro).

2.4 General preferences for public authenticity features

People are less-and-less inclined to do an authenticity self-check because of two relevant changes in the cash cycle; banknotes withdrawn from an ATM are genuine and retailers are checking banknotes with automatic devices (section 2.1). As a consequence people have a high and slightly increasing trust in their banknotes (section 2.2). A third cause has nothing to do with these changes in the cash cycle, but is caused by the design of authenticity features. In general such features are usage-unfriendly, not inviting people to operate an authenticity self-check (section 2.3). In general, people do not know what to check for. They also do not know the name of the feature, neither do they know where the feature can be found and, once located, they find it hard to judge whether the feature is genuine or fake. Instead of making UIF 3 more complex, banknote designers should shift their focus from UIF 3 to UXF 3, as illustrated by figure 8.
Based on the analysis done, figure 9 presents an updated list of the general user requirements of public authenticity features [16].

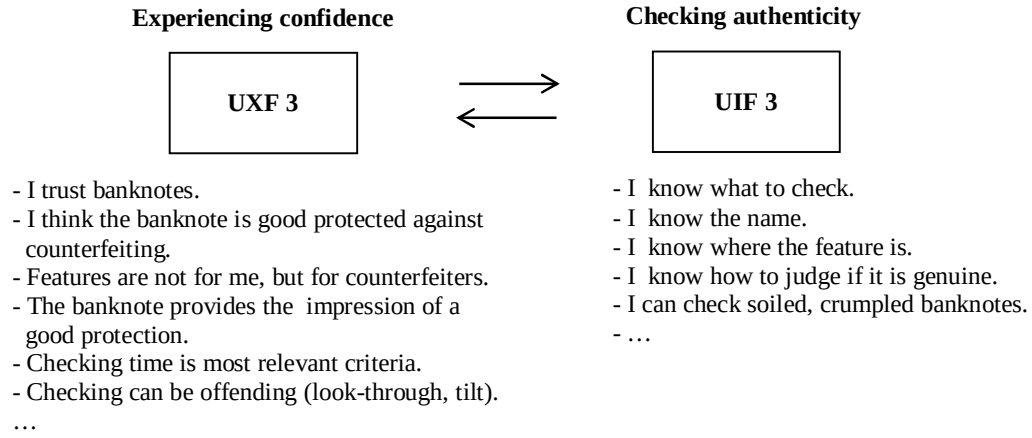


Figure 8.
User needs UXF 3 versus user needs UIF 3.

General user requirements Public authenticity features		
User need		Description
UXF	1. Time	A public authenticity feature should be operated in 2 to 3 s.
	2. Delicate	People do not want to offend others when they examine a just received banknote. Feel and look-at are preferred. Look-through and tilt actions can hardly be done discretely.
	3. Striking	The desired authenticity feature should be striking and provide pleasure during checking (the playing man: homo ludens). Realistic images should be used as part of a story.
	4. No nesting	The banknote itself is considered as one security product (nest level 0). Individual public features start at nest level 1 and should not include a second nest level. To force the counterfeiter to layer their work, higher nest levels may be considered to be included, but not for public use.
	5. No repetition	Avoid repetition of design elements like numerals or currency symbols. People will be discouraged; should they all be checked? Should they all be the same? Should I start at the top or just pick one?
UIF	1. Check at one glance	With three features advised to be verified, a complete authentication at one glance should be done within 6 s. All features on the front.
	2. Similar in all denominations	Authenticity features should be similar through a series.
	3. Feature name	Without a name, people do not know what to look for (linguistic determinism).
	4. Easy to find	Keeping the banknote at a reading distance (0.3 m to 0.4 m), human eyes would typically focus on object sizes of about 30 mm x 15 mm.
	5. Understandable	Is it clear if the features should be: felt, tilted, looked-through or should be looked-at? Is it clear how this effect should be for real banknotes and also for counterfeited banknotes?
	6. Univocal	A clear yes-or-no decision, unequivocal discrimination between a real and a counterfeit banknote.
	7. Equal perception	Perception of public features should be equivalent. When one feature attracts too much attention, people will tend to check just this feature; maximising one feature at the expense of others should be avoided.
	8. Durable	The feature should work under different light conditions and temperatures, by the young and the elderly. An authenticity feature which loses its characteristics by wear and tear will complicate an authenticity check. Authenticity features should be hard-wearing.
	9. Single user group	A feature should serve just one user group, in case the general public (to prevent sub-optimization for one or more other user groups).

Figure 9.
General user requirements of public authenticity features, divided in UXF and UIF [15 and the references therein].

3. OPTICAL FEATURES IN EUROPA SERIES

The knowledge presented in section 1 and 2 is the basis for an analysis of the latest design of optical authenticity features in euro banknotes. In 2013 the European Central Bank issued the first banknote of the Europa series (ES 2), a redesign of the first series (ES 1). The focus is on upgraded optical authenticity features, as shown in figure 10, being a silver foil stripe - in register with the print - including a holographic portrait (1), a colour changing feature with a movement effect (2) and a traditional watermark (3). Their introduction has been accompanied by intensive information campaigns and at the time of the research the upgraded euro 5 and euro 10 were respectively about two and one year in circulation. In February 2015 the new euro designs were for the first time part of DNB's biannual public opinion poll on banknotes [44]. What did the Dutch public pick up from these features introduced?

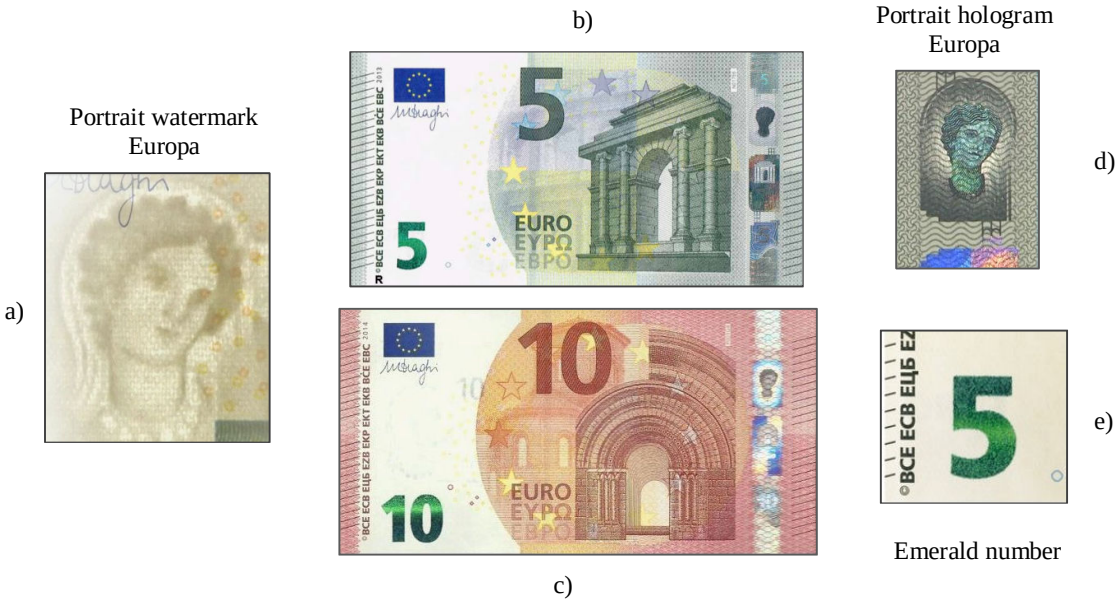


Figure 10.
Optical authenticity features the euro 5 (issued in 2013) and euro 10 (issued in 2014) of the Europa series.
a) Watermark shows a portrait of Europa.
b) Euro 5/Classic, issued on 2 May 2013.
c) Euro 10/Roman, issued on 23 September 2014.
d) Hologram in euro 5 shows a portrait of Europa, overprinted with a grey line pattern and a varnish.
e) Rolling bar: a colour changing ink, from blue to green, showing a movement effect.

New theme and features remain unknown
The Dutch received a positive impression of the introduction of the Europa series. The first two banknotes of this second series or euro banknotes, the 5 and 10 euro, are more appreciated than the old series, both in design and safety [44]. The differences observed between the new and the old series are presented in table 7. The most striking difference noticed is the banknote's change of colour (53 %); the saturated red of the old note is replaced by an unsaturated, brownish red. Changes in the watermark and the foil remain unnoticed, respectively shown in figure 10a and 10d. The promoted name "Europa", a figure known from Greek mythology, is mentioned only incidentally; from the few that mentioned a woman in the foil, a minority mentioned "Europa" (together 1 %).
The increased safety of the new series is mostly based on gut feelings, as respondents have as many difficulties describing the features of the new series as they have for the old series. When it comes to knowledge of the public authenticity features, the scores of the new series show a lower response than before, as already reported in table 5 (subsection 2.3).

Differences between the new and old euro banknote series	Netherlands
Year	**2015**
Number of respondents	1,010
1. The colours have changed	53 %
2. Looks more modern	9 %
3. The numerals are more clear	4 %
4. Woman in watermark, portrait of Europa	1 %
5. A green numeral	1 %
6. More round shapes	1 %
7. The foil at the right side has changed	1 %
8. (Parallel) lines along the sides	1 %
9. Woman in the foil, portrait of Europa	0 %
10. Other, namely	46 %

Table 7.
Overview of the differences between the Europa series (new) and the series of Ages and Styles of Europe (old) as experienced by the Dutch in 2015 [44].

The conclusion is that the introduction of the first two euro banknotes of the Europa series had no positive effect on the public's knowledge of authenticity features (UIF 3). However, introducing new public authenticity features makes people more confident on the authenticity of euro banknotes (UXF 3).
The third denomination of the Europa series is the euro 20, issued on 25 November 2015 (figure 11a). This is the first paper based banknote showing a transparent area, a 'window' (figure 11b). To check this feature, four positions should be verified, front and reverse, both in reflection and in transmission. Future studies will have to report whether this portrait window feature will be used for a public authenticity self-check.

Figure 11.
Optical authenticity features the euro 5 (issued in 2013) and euro 10 (issued in 2014) of the Europa series.
a) Euro 20/Gothic, issued on 25 November 2015.
b) Four positions of the portrait feature.

4. USER REQUIREMENTS FOR OPTICAL AUTHENTICITY FEATURES

General user requirements for authenticity features were provided in figure 9 (subsection 2.4) and the previous showed that the design of public authenticity features in the Europa series did not come across to the Dutch (section 3). The designers of the euro focussed on the techniques of authenticity features, an example of a *technology-driven design policy*. Better scores may have been received when a *use-centered design policy* would have been followed. Key to such an approach is the identification of user requirements for each user function of the Coaster-model. In case of authenticity features for public use, a balance should be created between keeping confidence (UXF 3) and checking authenticity (UIF 3).
This section continues with a search for the user requirements for respectively a foil feature and a colour feature. The need for optical authenticity features was born in the 1980s and is introduced first (section 4.1). Subsequently, public preferences for either a foil or a colour feature are presented (section 4.2). User requirements for foil features are listed, based on the identified user preferences (section 4.3) and are followed by examples of design concepts for public friendly foil features (section 4.4). In a similar approach user requirements are provided for authenticity features based on colour (section 4.5), followed by examples of design concepts for colour features (section 4.6).

4.1 Introduction of optical authenticity features in banknotes

Optical authenticity features in banknotes received a boost in the 1980s. The "Digital Revolution", the successor of the Industrial Revolution, reached the domain of banknote designs (item *i*), leading to the introduction of foil features (item *ii*) and colour features in banknotes (item *iii*). The perception of these features is often hindered by complex designs and especially by change blindness (item *iiii*). In the case of colour features their effectiveness is also hindered by the perception of colour deviations (item *iiiii*). When instead of a design aiming for perception in feature mode, the design of foil and colour features would aim for perception in configural mode, innovative banknote designs may be delivered, as was the case in the Netherlands in the 1990s (item *iiiii i*).

i. Digital Revolution influenced banknote design
In the early 1980s the first digital applications arrived in the graphic reproduction industry. These innovations became available for the home user in 1984, like the first inkjet printer "ThinkJet" by Hewlett-Packard [45]. A synchronous development was the Personal Computer (PC) and PC operating systems and software. The first version of "Windows" was presented by Microsoft in 1983. The consequences of these digital developments on the reproduction of banknotes were foreseen in the USA by the National Research Council (1985), when they gave an early warning for this impending danger for US dollar banknotes [41]. The NRC was right and the digital revolution became a real threat to banknotes in 1987. At that time the Japanese company Canon introduced the Color Laser Copier (CLC 1), the first digital colour copier using standard paper (figure 12a). Anyone could reproduce a banknote on ordinary paper within one minute by one push of a button. The resolution of the print was limited, below 300 dpi, but did deliver some relief to the copies, quite similar to real banknotes. Central banks had to react and in the United States the NRC delivered an updated report [42]. Several central banks, but not all, decided to add *anti-copy features*, like a high reflective foil, a glossy windowed security thread or a glossy ink [15]. Such *add-on features* could be incorporated without changing the existing design, leading to a boost of upgraded banknotes. In the years that followed, the Digital Revolution continued with the diffusion of home printers (1990), home scanners (1993) and image software (1995). Since the mid-1990s people received access to the internet, including the rise of electronic mail and the World Wide Web with its discussion forums and online shopping sites.
The third generation of Canon's colour copy machines appeared in 1994 (CLC 800) and used smaller pigments leading to higher print resolutions. The embossing disappeared, to the relief of the central banks. Since the year 2000 the graphic reproduction industry developed further, mainly focussing on higher resolutions and improving the colour gamut. Clear serious threats like in the 1980s and 1990s cannot be interpreted, making it difficult for central banks to target new (optical) authenticity features. Still central banks feel the need to issue every seven years new banknote designs, although no new technical threats have been witnessed. What is threatening is the availability of foil imitations and all types of colour pigments on the internet.

Color Laser Copier (1987)

a)

Visa Card (1984)

b)

Figure 12.
a) In 1987 the first colour copier appeared using digital techniques and standard paper, the Color Laser Copier (CLC 1) by Canon.
b) First holographic foil application on Visa Card (1984). When moving the card, the dove flies away.

ii. Review of foil features in banknotes

In the 1980s foils were already applied in the car, cards and packaging industry. Still foils were found a good protection to inkjet printers and colour copy machines as these reproduction devices could not reproduce glossy, silver or gold coloured foils. Efforts were undertaken to make these commercially available foils unique, most of them aimed for adding a hologram. Holograms date back to 1908 when Gabriel Lippmann (1845-1921) created the first 3D-image using an array of lenses. Dennis Gabor (1900-1979) recorded in 1947 the first 3D-image on a 2D-surface. In the years that followed a 'rainbow hologram' was developed in 1969 by Stephen Benton (1941-2003), followed in 1972 by a cylindrical 'holographic stereogram' invented by Lloyd Cross (1934-2015). This last invention showed, as the viewing angle shifted, fragments of a moving object in 3D and this invention became the basis for printed holograms. The credit card of Visa was in 1984 the first product of security printers applying a hologram, featuring a flapping wing pigeon (figure 12b). This first generation of holograms is characterised by fringes, by relief control. Many technical developments and applications followed since then, like the invention of a-symmetric fringes. The technical principles behind these optical authenticity features were reviewed in the first publication on "Optical Document Security" (1992) and a third edition was published in 2005 [52].
In the same year that a hologram was printed on Visa credit cards, 1984, the first innovative foil feature appeared on a banknote in the United Kingdom. Rectangular elements of the "Stardust thread" - in shiny silver - came to the surface of the GBP 20. The width of the Stardust thread was small, just 1 mm. Another glossy element showing colour switching effects, was a thin film layer and not a foil, appearing in 1986 on the higher denominations of the "Birds of Canada" series. The next optical authenticity feature was most innovative and appeared in 1988 in Australia (figure 13a). This banknote with a polymer substrate incorporated a transparent window with a foil patch. The patch, viewable form both sides, displayed a computer generated dot-based greyscale image, which turned, when tilted, from a positive image into a negative image, called a "Catpix grating" or "Pixelgram" [37]. One year later, in 1989, the first hologram was printed on the paper based Austrian banknote, shown in figure 13b. This computer generated hologram is based on line structures, providing 2D-images a 3D-effect appeared in a shiny gold coloured foil and was called a "Kinegram". A plain silver coloured foil design was part of the FFR 10, issued in France in 1992 and was called "Strap". Instead of a plain foil stripe, plain foil patches were applied on NLG-banknotes in the Netherlands, also since 1992. Since these early years many banknotes have been equipped with glossy foil patches and foil stripes, most of them included variants of holographic effects. A new type of optical features are floating images, of which category the "Motion" thread was the first and was first applied in 2006 in a 4 mm wide thread on the Swedish SEK 1,000 (figure 13.c). A similar, but wider thread (5 mm) is prominently present in the USD 100, issued in 2013. Another development was the introduction of transparent areas in paper based banknotes, of which category "Optics" was the first and was first applied on banknotes of Fiji in 2007 (figure 13 d). Polymer banknotes with a very wide foil stripe and large transparent areas are first issued in Canada in 2011 (foil width 16 mm, transparent areas up to 25 mm). A wide foil stripe, 15 mm, including a transparent window is first applied in the new euro 20 banknote, part of the Europa Series and issued in 2015 (figure 11). In 2013, the Bank of England was the first to abandon the foil stripe in 2013; it was replaced by Motion-thread.

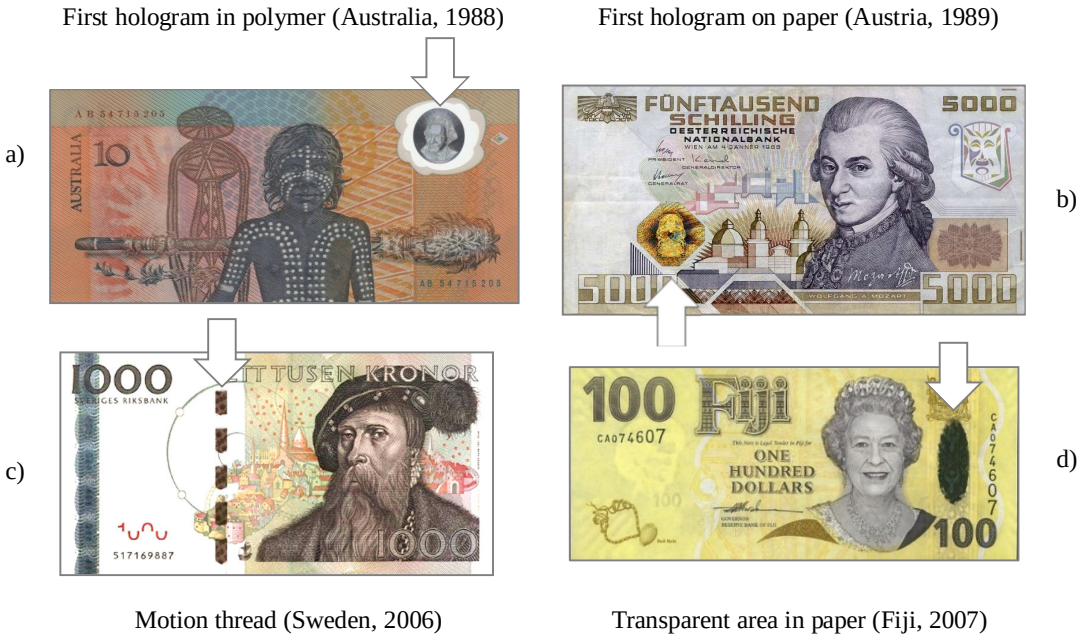


Figure 13.
The first examples of foil/thread based public features.
a) Australian 10 dollar polymer banknote (1988). Including an innovative security feature, being a transparent window and a new type of hologram, viewable from both sides. The hologram is known as “Pixelgram”.
b) First hologram on a paper based banknote in Austria. ATS 5,000, issued in 1989. The hologram is known as “Kinegram”.
c) First banknote with floating images ("Motion"), SEK 1,000, issued in Sweden in 2006. Width: 4 mm.
d) First banknote with an 18 mm wide security band and a transparent area ("Optics"), FJD 100, issued in Fiji in 2007.

An advantage of foil patches over foil stripes is that a patch can be printed in register with other printing techniques applied. The first foil stripes in register with other print appeared on Turkish banknotes in 2009. Also the Europa series displays registered foil stripes.
The new generation of holograms is characterised by nanotechnology, holes in the order of the wavelength of light. These *Nano hole arrays* create novel optical effects [e.g. 21, 28]. For example, a monochrome colour can be created by nanostructures, referred to as *structured colour*, avoiding (disturbing) rainbow effects as known from the earlier generations of holograms.

iii. Review of features based on colour
Pearl lustre inks or *iridescent inks* are based on interference and were selected to provide banknotes a glossy look, just as foil. A pearl lustre ink was first applied on a Dutch banknote in 1992, the NLG 100/Little Owl (figure 14a). The designers of this banknote covered a large area with a pearl lustre ink, about 80 % of the surface. Much smaller surfaces were applied on low euro denominations (euro 5, 10, 20), which display an iridescent band up to a width of 9 mm (figure 14b). The band is applied before the paper roles are cut into sheets by an ink roller (rotogravure). As with foils, a drawback of these iridescent inks is that they were commercially available. By adding a specific colour change such inks became unique and became known as Optical Variable Inks (OVI). The first banknote with an OVI was issued in 1989 in Belgium, the BEF 10,000 (figure 14c). OVI’s were further developed by creating a magnetic centre covered with several thin layers, which became known under the name “Spark”. In 2008 the first banknote with Spark appeared in China, the CNY 10, an occasional banknote celebrating the Olympic Games (figure 14d). Improved on health and safety issues, “Spark Life” became available in 2011 showing similar effects as Spark. A disadvantage of OVIs, including Spark-versions is the limited availability of colours.

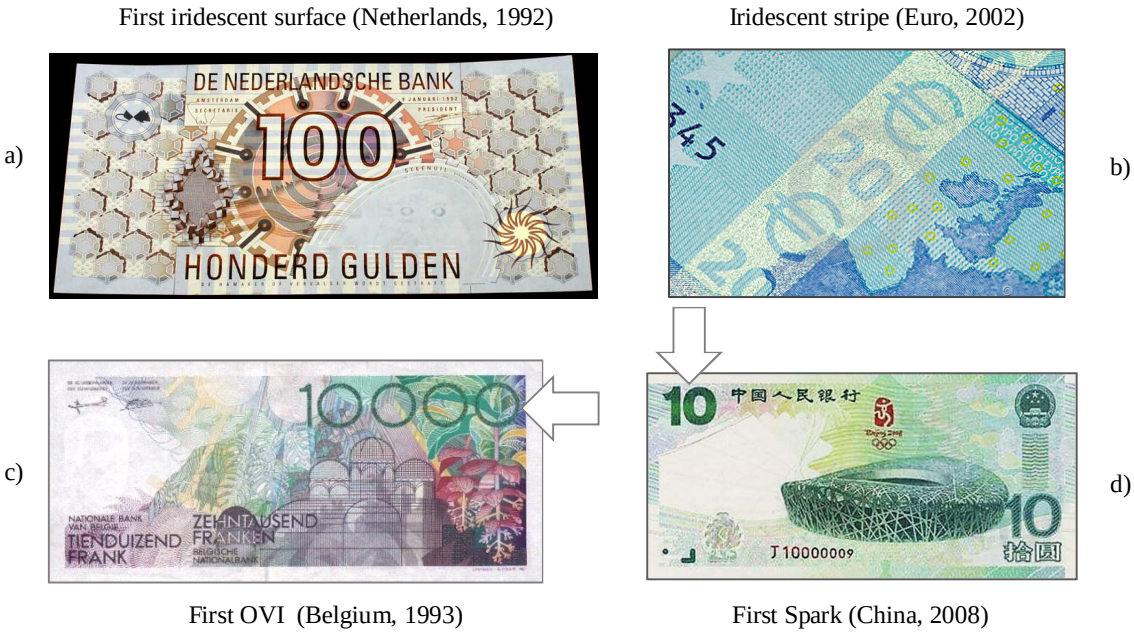


Figure 14.
Some examples of the development of colour changing features.
a) Large iridescent area. Silkscreen. Netherlands, 1992. NLG 100/Little Owl.
b) (Part of an) Iridescent band. Silkscreen or rotogravure. Eurozone, 2002. EUR 20.
c) Optical Variable Ink (OVI). Silkscreen. Belgium, 1993. BEF 10,000.
d) Colour change from green to blue including a movement effect of a rolling bar. China, 2008. CNY 10, issued on the occasion of the Olympic Games in Beijing in 2008.

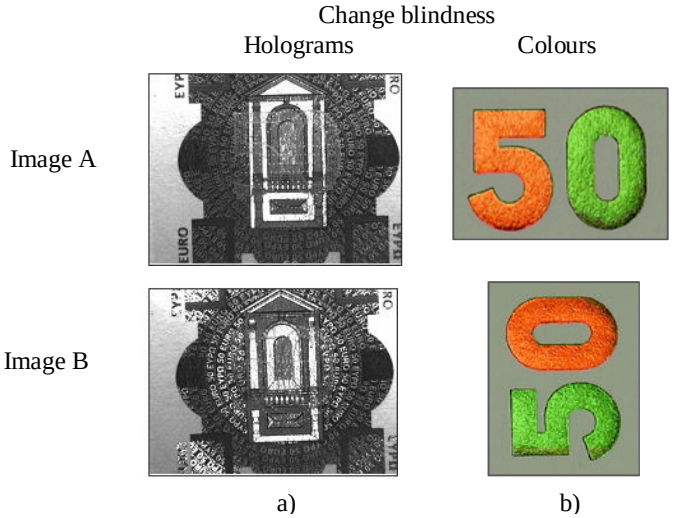


Figure 15.
Two examples of change blindness with optical authenticity features.
a) A switch from dark to light within the Renaissance window is seen when the hologram on the euro 50 banknote is tilted in east-west directions. People seem not to be able to remember what was light first and became dark and vice-versa [15].
b) Unique colours permutation is revealed when a 90°rotation is applied. Hologram Industries, around 2004.

iiii. Change blindness
Changes in a picture or video may be unknowingly offered to an observer. Their ability to identify such changes is limited, known as *change blindness*, a variant of perceptual blindness. This phenomenon of change blindness complicates the design of tilt-features in banknotes, like holograms or other kinetic features. When an image is changing from image A to image B, people may not recall image A by the time this image has changed into image B (figure 15a). One more example of change blindness is shown in figure 15b. The figure 50 shows a green 5 and a red 0 and when rotating 90°, people do not remember what they have seen, was it a red 5 and green 0 or a green 5 and a red 0? One may argue that the properties of kinetic features are explained to the public, thus they are prepared that a change is happening. However, as elaborated on in section 2, the Dutch seem to be less-and-less interested in public authenticity features and did not pick-up much from the education campaigns on the Europa Series.

iiiii. Perceiving colour deviations
There are different versions of public authenticity features based on colour effects, like iridescent features and colour changing features (item *iii*). The perception of colour is problematic for two reasons, which may explain their unpopularity (table 5). First, the perception of colour effects is hindered by change blindness (figure 15b). Second, perceiving colour deviations is problematic. The difference between two colours A and B is expressed by Δe, the result of a formula based on spectral values within the "L*a*b*-chromaticity diagram" [33]. Perceptible colour differences between two different colours in terms of Δe are provided in figure 16 [30]. Colour deviations are clear for an average human observer when $\Delta e > 6$ and will be barely perceptible for $\Delta e < 1$. An acceptable match in commercial reproductions is achieved when Δe is between 3 and 6. Usually colour-flops in banknotes do not seem to reach $\Delta e > 6$, although measurements are not carried out and/or are not published. Human perception is more sensitive to colour differences when two colours would actually touch each other, but this principle is not used in banknote design (for an example based on 'colours outside the euroscale' [15]).

Colour difference Δ e	**Visual effect**
$\Delta e < 3$	Hardly perceptible
$3 < \Delta e < 6$	Perceptible
$\Delta e > 6$	Good perceptible

Figure 16.
Perceptible colour differences in printed matter in terms of Δ e.

iiiii i. Integral approach; configural mode
The previous introduced several examples of foil and colour features as applied in banknotes. All designs were grounded on perception in feature mode, except the design of the NLG 100/Little owl (figure 14a), which is an example of a design in configural mode. Banknote designs incorporating authenticity features in configural mode is not new, in the past many designs followed this principle. Examples are alternating lines in two or three colours (instead of dots), guilloches, screen traps and special paper tints, all aiming for a reproduced banknotes with a different general impression at one glance, still the public's first preference (subsection 2.3). In such an approach optical authenticity features should work together, so that there will be a synergy of foil and colour applications. The designers of the NLG 100/Little Owl provided the complete banknote a glossy look, making optimal use of materials with high specular reflection properties like glossy foil, pearl lustre pigments, metal pigments and iridescent planchettes. People would notice a colour copy of this banknote, as under an angle different specular reflection effects were produced, fooling the scanner of a colour copier. Next to features supporting gloss, this innovative banknote carried four public authenticity features to be verified in feature mode: watermark, tactile patterns, see-through register and micro text.

Concluding, banknote designers should shift their work from a focus on individual authenticity features (perception in feature mode) to a design strategy providing the complete banknote a confident and authentic look (perception in configural mode).

4.2 Foil features preferred over colour features

The introduction of optical authenticity features in banknotes showed that there is roughly a choice between foil features and colour features (section 4.1). Which of the two is preferred by the public?

During the years, the Dutch recall foil features much better than colour changing features [e.g. 12]. Over one third of the Dutch residents (37 %) recalled in 2015 a foil feature (table 5), while a small minority mentioned a glossy stripe (5 %) or a colour changing ink (3 %). These findings are in line with an earlier study carried out in Canada, where focus groups judged different features on foreign notes, including foil and colour shifting inks [46] . Most appealing to Canadians is a holographic stripe and colour switching features are reported to have a low public appeal. The colour shifting effect is judged as too difficult to see and is always ranked towards the bottom of the list. As a result the Bank of Canada introduced in 2011 a very wide foil stripe in their polymer notes, as far as known the first example of the introduction of new public features grounded on public input. A report on US-dollar notes came to a similar conclusion, colour-shifting features are rarely used by the general public [43]. The public preference for foil features over colour shifting features was confirmed for the first banknote of the Europa series, the 5 euro [25]. This study reported that a large majority (71 %) could correctly locate the "portrait hologram" (figure 10d), the image of Europa in the foil stripe, while a minority (27 %) could locate the colour shifting feature on the euro series, the emerald numeral 5 on the front (figure 10e).

4.3 User requirements for foil features

The background of the application of foil and colour features in banknotes has been introduced (section 4.1), followed by the public preferences for foil over colour features (section 4.2). This section continues with an exploration of user requirements for foil features. Insights on user preferences for foil features are introduced (item *i*), before a list of user requirements is presented (item *ii*).

i. Review of user preferences for foil features

A large scale study to public preferences of foil features on banknotes was carried out in 2003 (study reported in [15]). The study offered 16 different banknotes with foil applications, including the euro 10 and euro 50 banknotes, to respondents in six countries of the Eurosystem (Austria, France, Germany, Italy, the Netherlands and Spain). One of the interesting outcomes was that no major cultural differences were found between the six nations. Mainly in France and Italy respondents prefer a patch over a foil stripe, as to them a patch has higher aesthetic qualities. However, in general, to the Europeans a foil was reported to be a low involvement issue. Where some people might know the name 'foil', or as they call it 'silver stripe', 'glittering thing', others barely notice it. A major finding was that the public considers itself unable to check a foil on complex parts and is unwilling to check a foil on details. The public argues that the foil serves to deter counterfeiters, as they assume that its reproduction is difficult, if not impossible (provided that it is e.g. well-integrated in the banknote, and is visually complex). The very presence of the foil in itself is deemed a sufficient guarantee of authenticity, an example of perception in UXF 3.

Foil features on euro banknotes appear in two designs, a stripe on the low denominations and a patch on the high denominations (section 2.3). A stripe is found quicker on a banknote than a patch, therefore people opt for a stripe as it is larger. Furthermore, participant judged a patch looking as if it is just stuck on, which may fool people easier with fakes. Transparent parts are associated with tape or stickers and are perceived as easy for the counterfeiter. Once people have attention for the foil, they want to touch it, as if they want to re-assure themselves whether the foil is really smooth, is really made of another material. It is also re-assuring for the public to find the numerals in the foil as they should match to the value of the banknote. The study also reported that realistic images are welcomed when they are easy to recognise, while abstract images were rejected. In a subsequent stage of this study the investigated user preferences were turned into a set of design requirements and were subsequently provided to six foil manufacturers. Based on the requirements, 13 prototypes were submitted and a clear winner was selected by the public, the design prepared by De La Rue Holographics (figure 18a).

Another study confirmed the public preference for a stripe over a patch [10]. When asked which of the foil features - stripe or patch - is preferred, Dutch respondents opt for a foil stripe (45 %) over a patch (23 %), in line with measurements reporting a higher prompted awareness of a stripe (90 % in 2005) as a patch (59 % in 2005).

ii. User requirements foil features

The studies reported are concluded in a list of user requirements for foil features as presented in figure 17. This list should be seen as a draft. Clearly, more research is needed to explore relevant user requirements further and in more detail. The approach advised is to develop different design concepts grounded on (preliminary) user requirements. Subsequently, these concepts may be offered to the public for feedback, in a similar approach as reported above [15].

User requirements Foil feature		
User requirement		**Possible design solution**
1. Foil feature should be on the front.		
1.1	A foil contributes to confidence, to the first impression of real or fake.	Not too close to the edge. Not covered by fingers. No preference for left or right.
1.2	Foil should be registered.	Registered foil stripe or a patch.
2. The foil feature is checked in look-at.		
2.1	Do not want to be obtrusive.	Plain, multi-coloured foil. Lenticular hologram. Structured colour.
3. There should be one type of foil features throughout the series.		
3.1	One type of foil feature (for learning and recognition).	One type of foil application.
3.2	Foil should be large.	Foil should be a stripe, foil width: at least 15 mm.
4. The design of foil features should be different on each denomination, but should be part of a family.		
4.1	One type of foil design.	Recognisable outline, details are different.
4.2	Different foils on different denominations (using the same foil on each denomination will facilitate fraud).	There is a strong preference for the use of only one type of foil (learning, recognition).
5. For counterfeiters the foil should be difficult to reproduce.		
5.1	A foil design should be split in an area for public usage and a 'counterfeit area'.	Multi-coloured foil. Foil stripe in colour of banknote, and a silver coloured are for public.
5.2	It should be possible to check if a foil matches with the denomination.	Denomination numerals. Colour. Realistic images, matching with theme. No abstract images.
5.3	The counterfeit area should be complex.	Too complex for the public to be checked
6. Foil should have other tactile properties than surrounding area.		
6.1	The foil feels different from the rest.	Smooth.
7. In case of holographic image: tilt direction should be north-south.		
7.1	The banknote should be tilted in landscape position and in north-south direction.	The ultimate positions of a banknote are at + 60 ° (north) and - 30 ° (south).
8. In case of holographic image: maximum 3 separate images.		
8.1	There should be two separate images.	To prevent change blindness: one image at + 60 °, no image at 0° (or one image) and one image at - 30 °.
8.2	Create a surprise, a little smile.	One image matches to main image on banknote, one image is a related surprise.
8.3	Good contrast of the hologram.	Hologram in silver coloured foil.
9. Rather not: look-through or tilt.		
9.1	Do not want to be obtrusive.	Look-at features. Holographic images like 3D-effects (lenticular holograms). Floating images. Colour effects (e.g. structured colour).

Figure 17.
Public user requirements of a foil feature in banknotes. Based on user research in 2008 by TNS NIPO [reported in 15].

4.4 Design concepts for public friendly foil features

The previous section presented user requirements for a public foil feature (section 4.3). This section continues with several examples of promising design concepts for a public friendly foil, which may be used by banknote designers to build their designs on. Starting with a description of the public's favourite concept, several other design concepts follow, concepts based on user requirements.

The result of the large scale project on a public friendly foil (section 4.3) delivered a public's favourite concept, a foil with *switching images*, images which are clearly different (figure 18a). The silver violin holds a holographic part, showing three images, switching from a portrait (tilt + 60°), via a music clef (tilt 0°) to a grand piano (tilt - 30°). The holographic portrait is similar to a printed portrait, people may compare the two images. The third image is a grand piano, not part of the printed design and is experienced as a (little) surprise. The winning concept offers two more design solutions. The registered foil is split in a public part and a 'counterfeiter part'. The public part is the silver coloured violin and the rest of the foil is kept transparent, displaying complex security elements 'especially for the counterfeiter'. Second, the numeral 50 in the foil may be compared with the printed numeral. Doing so, people reassure themselves that the foil matches with the denomination.

The foil design based on the music theme included transparent areas were rejected by the public (section 4.3). Instead of a transparent area, this area could also be produced in a colour, for example in the main colour of the banknote. This principle is laid down in a patent application describing the principles of "multi coloured foil" [13] and has been applied in the concept shown in figure 18b.

Switching images within a hologram could be constructed with different techniques, like for example one image by the (traditional) laser technology and one image by electron beam curing, which was also part of the patent application made. However, this part was judged by the European Patent Agency to be a separate invention, apart from the claim of multi coloured foil. One of the examples introduced in the patent is shown in figure 19a, a public friendly hologram with three images.

Tilt actions are experienced as obtrusive and people would probably appreciate *look-at holograms* over *tilt holograms*. Look-at holograms are possible like the example provided in figure 19b. Such 3D-effects, as if the image is on the surface, is possible by applying lenticular structures.

Transparent foil with switching images

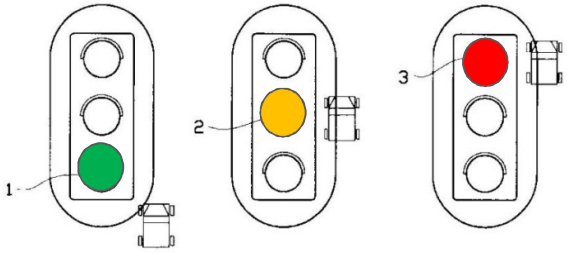
a)

Coloured foil with switching images

b)

Figure 18.
Two examples of banknote concepts with a public friendly foil based on switching images.
a) A test banknote displaying a foil with three images based on a music theme, prepared by De La Rue Holographics (2003).
b) A promotional banknote displaying a foil with two images and colour, prepared by Papierfabrik Louisenthal (2010). The foil shows two colours, silver and yellow. The hologram shows two images, which are also shown in print, a portrait and a flower.

Understandable hologram with three images



a)

Look-at hologram

b)

Figure 19.
Two examples of holographic design concepts.
a) Design concept for a foil application 'traffic light' based on a holographic element moving car and colour changing green-orange-red [13].
b) Look-at hologram: a 3D impression of the numeral 50. Sample prepared by Kurz (2003).

Exploring design concepts for a public friendly foil
Several layout schemes for a public friendly foil are explored, as shown in figure 20. Traditional public authenticity features like a thread, a foil stripe or an iridescent band are usually simply overprinted, without any design adaptations. Since 2009 foil features can be applied in register with the print, making it possible to enhance specific foil elements, inviting the public to focus (figure 20a). In general, registered print will increase the heuristic quality of a banknote and on its turn the confidence experience (UXF 3). A further development of this design concept inviting people to focus is shown in figure 20b. A silver coloured holographic area is the public part and the rest of the foil is produced in the main colour of the banknote, 'the area for the counterfeiter'. Two requirements enforce each other; holographic designs are best perceived in a silver coloured surface and the glossy silver will attract the eye. The search task for the features in this design concept is unambiguous: go in a rather straight line from left to right, an example of a configural design approach, which includes a feature design approach. Adding a similar colour to all features will ease the search task further: 'Look for the blue', and in another, red banknote: 'Look for the red'. Foil stripes in a horizontal oriented banknote are between 8 mm and 15 mm wide, relatively small to incorporate a viewable image. A banknote design in a vertical orientation will provided more design freedom (figure 20c). Next to a holographic element, a foil stripe could show a transparent area, a window (figure 20d).

Concluding, there are plenty of possibilities to arrive at a public friendly design of a foil feature.

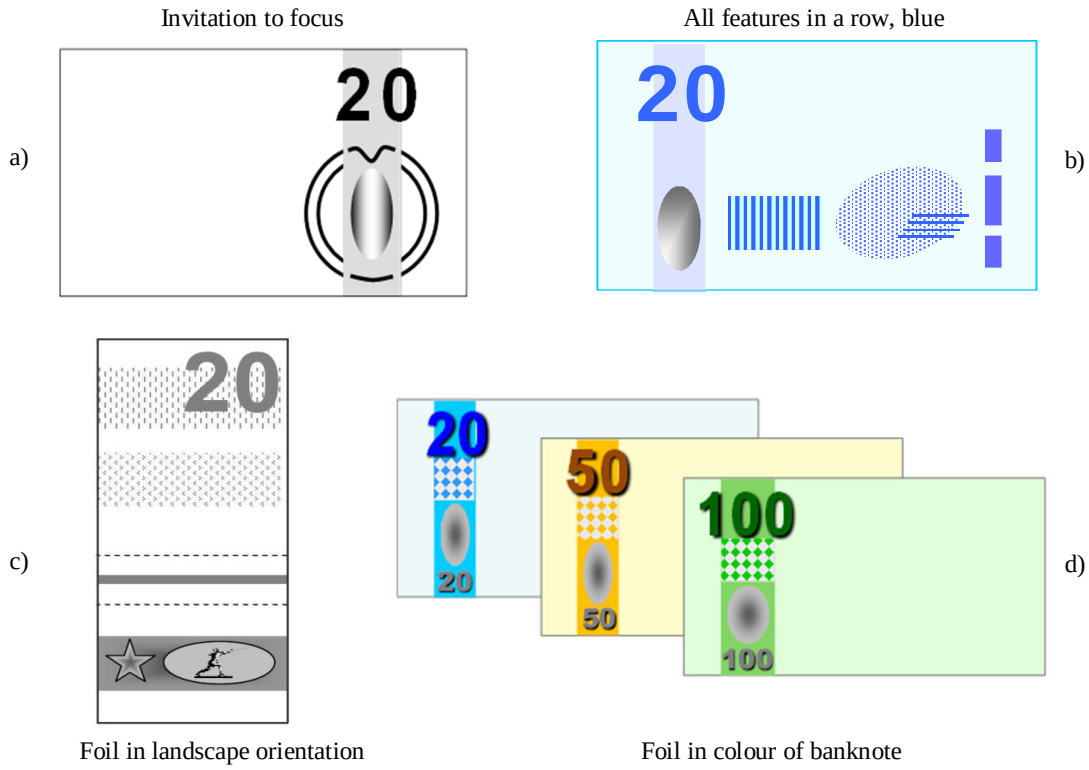


Figure 20.
Alternative design concepts for a foil stripe.
a) Invitation to focus. A specific area of a foil is enhanced by one of the banknote's printing techniques. The human eye is invited to focus on this specific area [11].
b) All public features are set in a row, from left to right. All features are designed in the colour of the note, respectively: foil stripe (including the silver hologram), watermark (coloured paper partly overprinted in colour of the note), feel/scratch pattern and windowed security thread [11, 15].
c) Foil in horizontal orientation in a vertical oriented banknote. A horizontal orientation of the foil creates more possibilities for a holographic design [10].
d) Design concept for a series of banknotes displaying foil stripes matching to the main colour of the banknote and includes a transparent area (window). The large numeral of the banknote may be compared to the numeral of the foil [11, 15].

4.5 User requirements for features based on a colour effect

Designs of colour changing features such as OVI and Spark are judged to be user-unfriendly (section 4.1). Therefore it is no surprise that foil features are preferred over colour features (section 4.2). These findings raise the question why public features based on colour effects should still be included in new banknote designs? The answer is that colour is a good starting point for a public authenticity feature, but up to date their designs fail, as will be elaborated on first (item *i*). Subsequently this section presents a review of studies carried out to gain insights in user preferences for features based on a colour effect (item *ii*) and concludes with a list of user requirements for such features (item *iii*).

i. Colour is most important design element
When asked for the difference between the new and the old euro banknotes, the change of colour was by far the most frequently given response (table 7). This answer did not come as a surprise, as - at least to the Dutch - the colours of a banknote are found to be the most important design element. Since 1983 colour is constantly reported within DNB's

biannual studies as the best recalled design feature of both guilder banknotes (1983-2002) and euro banknotes (2002-2015) [8, 9, 14, 15, 44, 53]. Dutch gulden banknotes showed bright colours and the colours of the euro banknotes are also bright, although less bright as the gulden banknotes. The Dutch public did notice this decrease of brightness [9, 12]. In other cases, an increase of brightness may be noticed, as is the case when the first design of a new series of Canadian banknotes were rolled out in 2001, named "Canadian Journey". The most frequently mentioned change, by 34 % of the respondents, was the introduction of brighter colours [46]. The Reserve Bank of New Zealand introduced the slogan "Brighter Money" to reflect the bold colours and designs of their upgraded series, which was issued in October 2015 (figure 21). The designs were prepared by using several forms of public input [36]. These new designs also show a large, silver coloured foil area within a transparent area. Another relevant conclusion concerning colour is that people associate the main colour of a banknote to its value, to the main user interface function (UIF 1). Therefore, when the design of a colour feature would be linked to the main colour of the banknote, a (first) stepping stone is offered to recall an (optical) authenticity feature.

New Zealand, 1999 Brighter colours, 2015

a) b)

Figure 21.
Redesign of New Zealand dollar, accompanied by slogan 'Brighter Money'.
a) Polymer banknote NZD 100, 1999.
b) Upgrade of NZD 100, 2015. Large silver coloured foil area within a transparent area.

ii. Review of user preferences related features based on colour effects
On the reverse of the first series of euro banknotes there is a gold shining band printed on the low denominations and a colour changing numeral on the high denominations (section 4.1, item *iii*). Invited in 2005 to provide their preference, Dutch respondents favoured the gold shining band (36 %) over the colour changing numerals (26 %) [10]. Features based on colour effects, like iridescent and colour changing inks receive much lower scores when it comes to public knowledge of authenticity features (table 5). An explanation for their low ranking is that colour variations are difficult to perceive in the designs produced. First, the colour change on offer is not large enough (subsection 4.1, item *iiiii*). Second, change blindness hinders the precise recollection of a colour switch (subsection 4.1, item *iiii*). People may recall that a colour is red, but they cannot remember the colour shade; was it merlot, scarlet, mahogany or cherry blossom red? Furthermore, when tilting an original banknote, colour A will gradually change into colour B. In an imitated banknote the colour change will travel from A' to B', most likely different from the original colours A and B and certainly difficult to perceive. The perception of colour changing features will also depend on light conditions and crumples may disturb their perception even more.

iii. User requirements for features based on colour effects
The studies done result in a list of user requirements for features based on colour effects as presented in figure 22. This list should be seen as a first draft; more research is needed to explore these user requirements further and in more detail.

User requirements Colour feature		
User requirement		**Possible design solution**
1. Colour feature should be on the front.		
1.1	A colour feature contributes to confidence, to the first impression whether a banknote is real or fake.	Not too close to the edge. Not covered by fingers. No preference for left or right.
1.2	Colour feature should be registered.	No continuous bands.
2. The colour feature is checked in look-at.		
2.1	Do not want to be obtrusive.	Look-at colour features, like structured colour.
2.2	Feature should have gloss.	Iridescent and metallic inks (silkscreen, offset).
3. There should be one type of colour changing features through the series.		
3.1	The colour changing feature should be large.	Area at least 30 mm x 15 mm (or 450 mm^2).
3.2	Should be one element.	Not 50 (5 and 0).
4. The design of colour features should be different on each denomination, but should be part of a family.		
4.1	One type of colour effect design.	Designs should relate to the banknote, e.g. to its colour, denomination or main image.
4.2	Colours can note be remembered.	Colour change should relate to the banknote, e.g. to its colour, denomination or main image.
4.3	Create a surprise, a little smile.	An enhancing, realistic image, part of the banknote design theme. For example, the colour feature is the centre of a flower or eye of an animal.
5. In case of a colour change: the colour change should be obvious.		
5.1	Colour A and B should be visible separately, without merging into one another.	Colour A should be clear at + 60 °, no colour at 0° and colour B should be visible at - 30 °.
5.2	The colour difference between A and B should be $\Delta e > 6$.	Select an appropriate technology, e.g. structured colour (instead of ink pigments).
5.3	Change blindness should be prevented.	One colour matches to main colour of the banknote and one colour is standard through the series.
6. In case of colour change: tilt direction should be north-south.		
6.1	The banknote should be tilted in landscape position and in north-south direction.	The ultimate positions of a banknote are at + 60 ° (north) and - 30 ° (south).
7. Rather not: look-through or tilt.		
7.1	Do not want to be obtrusive.	Look-at colour effect features, like structured colour.

Figure 22.
User requirements to a colour changing feature in banknotes.
Based on user research in 2008 by TNS NIPO [reported in 15].

4.6 Design concepts for public friendly features based on a colour effect

The previous section presented user requirements for a feature based on a colour effect for public usage (section 4.5). An example of a banknote design to be perceived in configural mode, providing the banknote a heuristic quality - the genuine note is the glossy one - is the NLG 100/Little Owl shown in figure 14a. A more recent example of optical authenticity features based on an heuristic approach is provided in figure 23. These designs are based on what people intuitively may experience as genuine, an alternative to the common rule-based design of such features. The designs of the features shown in figure 23 refer to reflections in water or to fire, phenomena known by the public. Studies on the concept of intuitiveness should take care of 'perception pitfalls', like when the perception of a genuine and mimicked feature do not discriminate anymore.
Another concept for a colour feature is provided in figure 24. As people may forget the first colour (colour A), when a colour flop is made, the first colour is in the main colour of the banknote. Furthermore, when the banknote is tilted, the second colour (colour B) is for all denominations the same. The concept shown proposes a gold colour, as gold is associated with valuable and will create a little smile.
By tradition features based on colour effects are created by specific inks. However, since 2005 such features can also be created by foil applications. These new technologies lead to new concepts, like a foil stripe including a hologram and a colour effect feature as shown in figure 25. Such a colour effect feature can be based on a structured colour, a colour related to the banknote denomination, or any other new innovation addressing a user friendly colour effect in a foil.

Concluding, there are plenty of possibilities to arrive at a public friendly design of a colour effect feature.

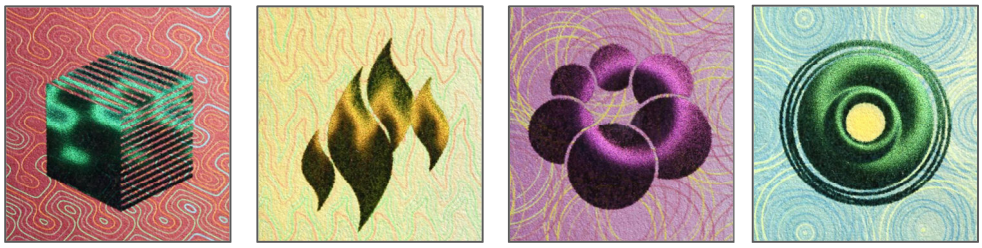


Figure 23.
Examples of colour features based on a heuristic design approach (instead of rule-based design of features). People will have a ‘correct perception’ by intuition. Designs by Gestaltung Manuela Pfrunder GmbH, 2014.

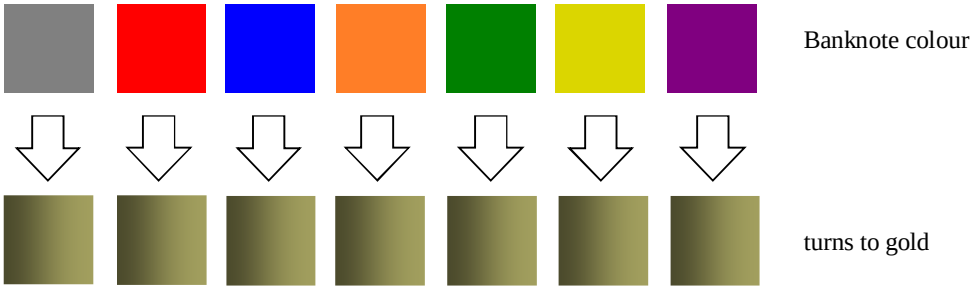


Figure 24.
Colour concept for a banknotes series. Easy to communicate: all colours turn to gold [15].

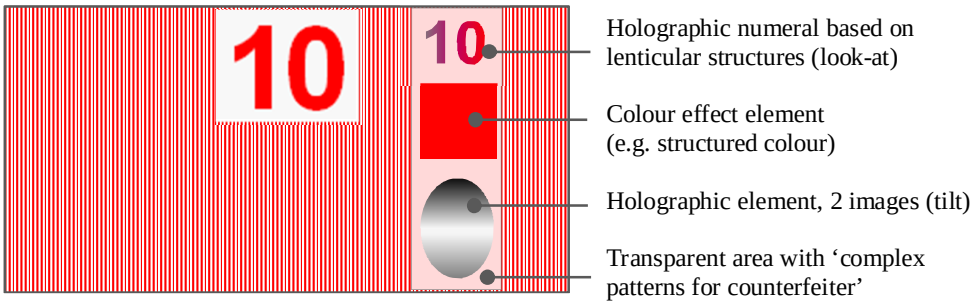


Figure 25.
Design concept of a registered foil stripe application, including both a colour effect and a holographic effect. The colour effect is a look-at effect, a bright monochromatic colour matching to the main colour of the banknote. The hologram is a numeral at the top (look-at), based on lenticular structures, and a holographic element at the bottom showing two images. One image can be compared with a (printed) image within the banknote and one image has to be discovered when tilted and will provide a little smile.

6. CONCLUDING

The present design of optical authenticity features does not come across to the general public. Future optical authenticity features should first of all be based on user requirements. Therefore central banks should research such user requirements. Second, instead of feature oriented banknote design, designers should deliver banknote designs based on a configural approach. Instead of making public features more complex by adding more technology (UIF 3) the focus should also be on keeping confidence (UXF 3).
Based on the user requirements and a use-centered design policy, a central bank should develop preparatory design studies. The results of these studies should be offered for feedback to respondents of the general public.

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